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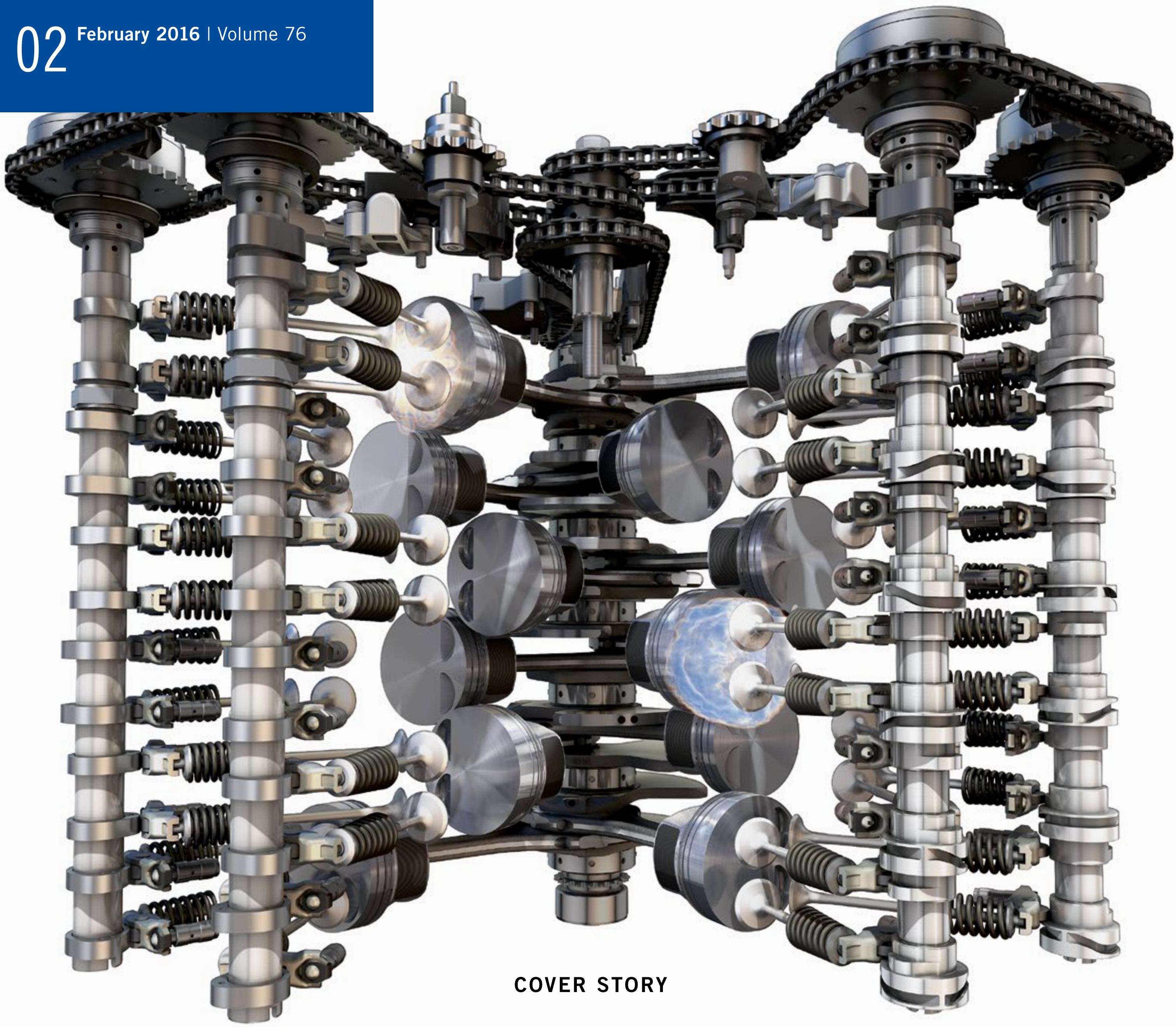


COVER STORY

Efficient Engines

CLUTCH-BY-WIRE
Enables New Functions with Manual Gearboxes

PISTON SHAFT COATINGS
with Innovative Formulations to Further Reduce Friction

BIODIESEL
Evaporates Better from Engine Oil through a Lowered Boiling Curve

/// GUEST COMMENTARY Markus Schwaderlapp [Deutz] **/// INTERVIEW** Michael Fleiss [Volvo]

Magazine 4.0

Dear Reader,

Everybody is talking about Industry 4.0. It is not just OEMs, suppliers and development service providers who currently have to change and completely redefine their roles. The same also applies to publishing houses. We, too, are undergoing fundamental change; one that we at SpringerNature wish to actively shape. That is why our English language subscribers have been receiving the complete MTZ and its sister publications as a modern digital magazine from the start of this year. And also our German language readers will receive a digital edition from February on.

The digital magazine world opens up new perspectives. It allows us editors greater freedom with regard to layout and gives you as reader a different magazine experience – more pictures, technical animations and films as well as in-depth links to knowledge and company pages provide even more information and supplement the articles.

Look no further than the powerful cover story of the current MTZ issue, for example, where the new W12 from Volkswagen sets the ball rolling as an extraordinary engine that belies its size to give a refined and elegant impression: an ideal starting point for the topic of efficient engines. Read a fascinating interview about current developments and trends at Volvo, a carmaker that has rarely featured in MTZ. We round off the cover story with an article on the Ecotec family of engines for the new Astra K. MTZ has once again become a “hefty issue” – with which we are delighted to catalyse this phase of digital expansion and now repackage our already excellent content to offer still more extra features.

I hope you enjoy reading your new digital MTZ.

Dr. Alexander Heintzel
Editor in Chief

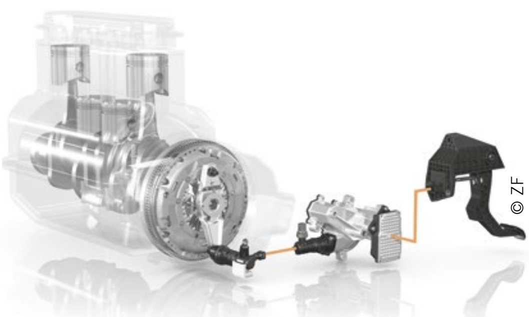
COVER STORY

Efficient Engines

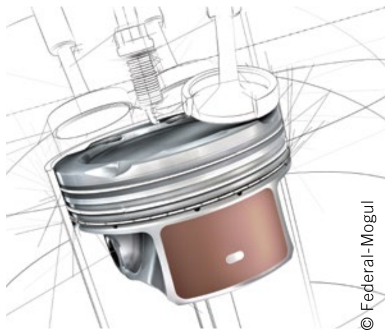
To further reduce fleet fuel consumption, efficient engines are the top priority in all vehicle classes and for all manufacturers. Although increasing electrification is currently the key lever for achieving lower fuel consumption, the efficiency of combustion engines is constantly being improved. The task is becoming increasingly challenging. Costs and benefits must be carefully weighed up for every gramme of CO_2 that can be saved with a particular measure.

© Volvo | Lars Ardarve

DEVELOPMENT


© ZF

Clutch-by-Wire from ZF means important functions previously reserved for automatic transmission and automated gearboxes are now possible with manual gearboxes for the first time.


© Federal-Mogul

Federal-Mogul has expanded its range of piston shaft coatings for gasoline and diesel engines with two new formulations, further reducing friction in the combustion chamber.

RESEARCH


© Thünen Institute of Agricultural Tech.

The Coburg University of Applied Sciences, in collaboration with the Thünen Institute of Agricultural Technology, has modified the boiling properties of biodiesel to facilitate its evaporation from engine oil.

IN THE SPOTLIGHT

NEWS

RUBRICS I SERVICE

COVER FIGURE © Volkswagen


© Deutz

Technical University of Darmstadt | **Demo Centre for E-mobility**

© TU Darmstadt

The new e-mobility and hybrid centre allows research in the field of hybrid powertrains

The Institute for Internal Combustion Engines and Powertrain Systems (VKM) of the Technical University (TU) of Darmstadt has opened a demo centre for e-mobility and hybrid technology on the Lichtwiese campus. The new e-mobility and hybrid centre, with around 160 m² of floor space, was planned by the construction department of the TU Darmstadt and built in just four months. The vehicle hall was constructed with a steel structure and packed in a thermally insulated shell; including several access doors and an inspection pit for assembly work. According to the TU Darmstadt, construction costs totalled EUR 470,000. One of the main reasons for the new building was the increased space required to install hybrid drive systems into vehicles.

Schaeffler | **New Plant for Thermomanagement Modules in the Czech Republic**

The Schaeffler Group is building a new production plant in the Czech Republic, with the automotive supplier laying the foundation for a new plant in Svitavy. Production is set to centre on manufacturing thermomanagement modules (TMM) for the thermal control of running engines. According to Schaeffler, demand from existing customers has recently been soaring in this area. With more than EUR 92.5 million of investment, the Schaeffler Group wishes to strengthen its growth in Eastern Europe with the new production plant in Svitavy in Eastern Bohemia. The construction of the new production facility within the Svitavy industrial area began recently with the laying of the foundation stone. The first production line is due to go into service in autumn 2016, with Schaeffler expecting to reach full capacity by 2019.

Jan Goláň, David Šimek, Martin Netolický, Miloš Zeman, Oliver Jung, Jaroslav Patka (from left to right)

© Schaeffler

Renault | DUH | **Measures Increased NO_x Emissions**

© DUH

Testing the NO_x emissions of a Renault Espace 1.6 dCi

The testing centre of the Bern University of Applied Sciences in Switzerland has tested the nitrogen oxide (NO_x) emissions of a Renault Espace 1.6 dCi (front-wheel drive, 12,300 km mileage, Euro 6b) on behalf of the German Environmental Aid organisation (Deutsche Umwelthilfe – DUH). As announced by the agency on 24 November, 2015, the test conducted with a warm engine and in accordance with the New European Driving Cycle (NEDC) in particular revealed very high NO_x emissions. The values exceeded the valid threshold for Euro 6 vehicles by a factor of between 13 and 25. The report compiled by the testing centre of the Bern University of Applied Sciences found that "the NO_x values recorded in six NEDC measurements exceeded the threshold of 80 mg/km". Two tests showed values of below 80 mg/km.

Weber Hydraulik | **Reinhard Pfendtner is New COO**

The former Plant Manager in Güglingen, Reinhard Pfendtner, took over as Chief Operating Officer at the specialist for hydraulic components and systems solutions as of 1 November, 2015. He succeeds Josef Nöbauer, who will be retiring at the end of the year after a structured handover. Reinhard Pfendtner, who holds a PhD in Electrical Engineering, joined Weber-Hydraulik GmbH back in January 2015 as Plant Manager in Güglingen. Pfendtner had previously worked for the Indian subsidiary of the Chassis Systems division at Robert Bosch GmbH.

© Weber Hydraulik

Reinhard Pfendtner

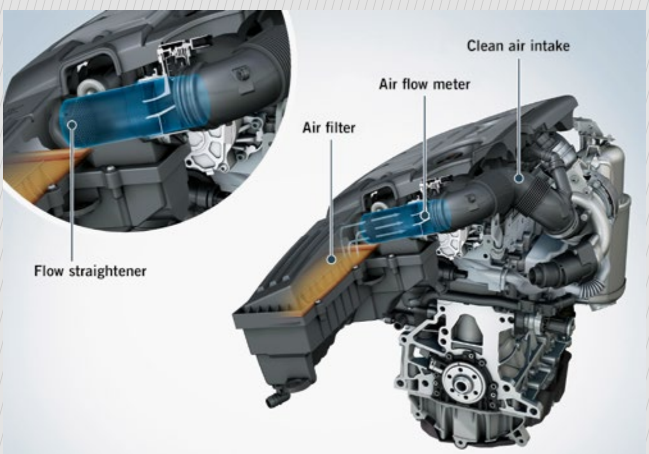
MAN | **Lipinsky Responsible for New Digitisation Strategy**

© MAN

Markus Lipinsky

Commercial vehicle manufacturer MAN Truck & Bus is developing the subject area of digitisation and telematics services into a strategic cornerstone of its business activities. To this end, the company has created the new Telematics and Digital Solutions unit, which will in future be led by Markus Lipinsky, the company has announced. In this post, he will report directly to the CEO of MAN Truck & Bus, Joachim Drees. Lipinsky was previously CEO of the software company and cloud specialist Actano. The company sells portfolio and project management solutions, primarily for the automotive and aerospace industries. Following a number of positions at Daimler, Lipinsky was CEO of Daimler FleetBoard between 2009 and 2012, where he was responsible for developing and selling telematics solutions for commercial vehicle fleets.

Volkswagen | **Plan for Emissions Scandal Presented**



© Volkswagen

A flow transformer is intended to help clean up the EA 189 diesel engines affected by the emissions scandal

Progress is being made on resolving the diesel scandal. The Volkswagen Group has submitted concrete technical measures for the 1.6- and 2.0-l EA 189 diesel engines affected by the emissions scandal to the Federal Motor Transport Authority (KBA), the company announced in a statement on 25 November 2015. The final technical solution for the 1.2-l diesel engine is due to be presented to the KBA soon and is likely to involve a software update. For the 1.6-l EA 189 engine, there are plans to fit a so-called flow transformer immediately before the airflow meter. This is a grid that calms the swirling flow of air in front of the airflow meter, thereby significantly increasing its accuracy.

IMPULSES

Wolfgang Siebenpfeiffer
Editor in Charge
ATZ | MTZ | ATZelektronik

Fast-moving Era

Scientists speak of a new era every ten years, which sounds a bit over the top. However, what they are trying to tell us matches our everyday experience. What was modern yesterday is already obsolete today, and what today seems scarcely imaginable, may be second nature tomorrow. Even when building engines, the pace of change is ever-greater. We need to process and implement these changes and new circumstances. In an era like ours it would seem that the ability to remain mentally agile and flexible is our key opportunity in life.

I think that being comfortable with and open to innovation in no way equates to chasing after every passing fad. It's all about making our lives valuable and meaningful. Being flexible is certainly a must to cope with the challenges of everyday life and respond appropriately to the unexpected. But mental flexibility takes practice. The older we get, the more effort we should put into our "intellectual workouts". There are many options open, depending on our age, job and lifestyle. Examples include: confronting our own experiences and those of others; critically questioning requirements and trends; breaking cherished habits and trying something new, like risking a new work approach or a new personal relationship; taking on a new task as well as declining an offer once in a while.

These situations teach us something important – everyday life is multifaceted and challenges me to handle whatever my own life throws up creatively and flexibly. This is how we seize our opportunities in life.

Natural Gas A Chance to be Grabbed

Driven by increasingly stringent legislation, carmakers are resorting to ever more elaborate technical solutions to lower the consumption and pollutant emissions of combustion engines. Cars powered by natural gas constitute an alternative of which many are still unaware, even though the fuel will continue to be available for decades to come – and which, in contrast to the more successful liquefied petroleum gas, is not linked to the production of gasoline or diesel. Monovalent CNG engines are key to achieving a breakthrough.

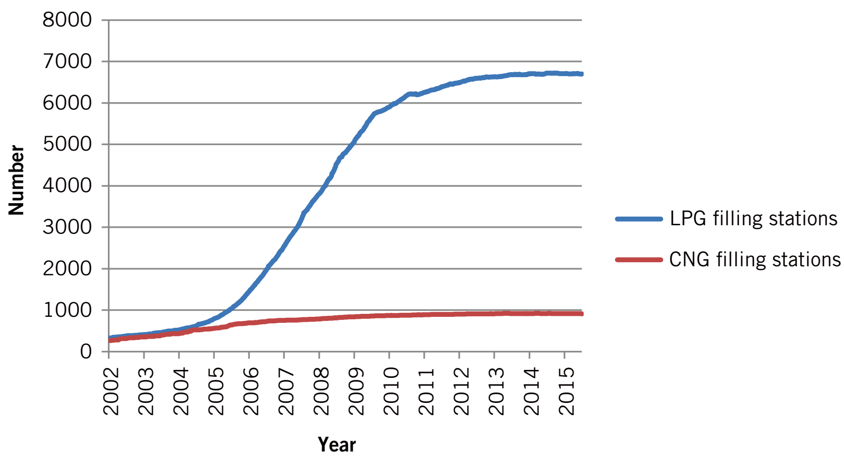
CO_2 AND POLLUTANT EMISSIONS MUST BECOME LOWER

The two big political challenges that the car industry has to face are well known: CO_2 and pollutant emissions. The statutory thresholds for these are becoming increasingly restrictive. The next emissions standard due to come into effect in 2017, Euro 6c, will limit the particulate emissions of gasoline engines. Moreover, the Member States of the European Union have agreed to reduce the CO_2 fleet threshold for all passenger cars registered from 2020 onwards to 95 g/km. This equates to consumption of 4.1 l of gasoline or 3.6 l of diesel per 100 km. Moreover, compared with the 130 g/km specified for 2015, it is a technically complex and ultimately expensive undertaking.

FAR HIGHER PENETRATION OF LPG FILLING STATIONS

While electricity in particular is progressing, natural gas could also become part of the solution. At the very least, it shows obvious benefits when used as a fuel in gasoline engines. The favourable ratio of hydrogen to carbon in methane – four atoms of hydrogen are bound to just a single carbon atom (4:1) – means up to 30 % lower CO_2 emissions compared to gasoline (2.25:1). Furthermore, the emission benefits for CO, NO_x and higher hydrocarbons are up to 80 % below those for liquid fuels [1]. Many countries, including Germany, offer tax relief on both compressed natural gas (CNG) and liquefied petroleum gas (LPG), resulting in relatively low operating costs. Even so, according to figures published by the Federal Motor Transport Authority, just 8194 passenger cars powered by CNG were registered in 2014. At 6234, the number of LPG car registrations for the same period was even lower.

Nevertheless, a clear phenomenon is emerging that can only be ascribed to the aftermarket and retrofitting of passenger cars with LPG units. According to the figures of the independent filling station directory gas-tankstellen.info, the number of LPG filling stations has multiplied tenfold over the last decade, while the total number of CNG filling stations has only increased by a factor



Compared to CNG filling stations, the number of LPG filling stations in Germany has soared since 2005 (© MTZ | gas-tankstellen.info)

of 1.75. While the proportion of LPG filling stations to CNG filling stations stood at 661 to 525 in January 2005, a comparison in January 2015 revealed 6,718 LPG to 921 CNG filling stations. By way of comparison, there were a total of 14,209 filling stations in Germany at the same time [2].

NATURAL GAS PRODUCTION IS INDEPENDENT

The drawback to this development is the fact that carmakers cannot count retrofitted gas units and the LPG propane-butane mixture cannot actually replace gasoline or diesel, despite having a CO_2 advantage of up to 15 %. This is because the three main sources are oil-refining processes, petroleum production itself and, last but not least, natural gas sources [3], meaning that when gasoline and diesel production declines, there is automatically less LPG available. In contrast, figures from the Federal Institute for Geosciences and Natural Resources (BGR) suggest that the statistical lifetime of natural gas reserves is around 58 years and a further 294 years for known resources – measured in terms of current consumption [4]. In addition, a number of processes can be used to produce methane by renewable methods – making it a bridging technology for carbon-neutral mobility.

BIVALENT DRIVE SYSTEMS ARE A COMPROMISE

Until the infrastructure for CNG has been extended, carmakers are currently making a compromise – between CNG and gasoline mode. “Dedicated gas engine development for passenger car already exists under the term of monovalent gas drive systems. However, bivalent drive systems, where compromises in consumption have to be made, still predominate given the continued lack of natural gas filling stations. If there is no easily accessible natural gas filling station nearby, a bivalent engine will automatically switch to run on gasoline,” explains Richard van Basshuysen, editor of the book „Natural Gas and Renewable Methane for Powertrains“ [5].

Compromises not only apply in terms of consumption but also performance. By way of comparison, the 2.0-l CNG engine of the Audi A4 g-tron, presented at the IAA 2015, was designed as a bivalent engine and delivers a maximum of 125 kW in gasoline and natural gas modes, producing 280 Nm of torque. In contrast, the engine on which it is based,

Dr. Gerhard Holtmeier
Chairman Natural & Bio Gas Vehicle Association (NGVA) Europe

2 QUESTIONS FOR ...

MTZ _ Monovalent natural gas engines could enhance the appeal of CNG passenger cars in terms of performance and consumption. However, more CNG filling stations are needed. In your view, who should act first – the carmakers or the energy industry?

HOLTMEIER _ Neither. The key now is to establish a clear political framework with a certain “half-life”. For Germany this applies particularly with regard to further extending tax breaks until 2026, as called for in the coalition agreement. The filling station infrastructure is currently more than sufficient in Germany, as are the number of natural gas vehicles on offer. Incidentally, Italy has demonstrated for some time now the potential to expand natural gas mobility provided the appropriate political decisions are taken.

There‘s a difference in calorific value between L gas and H gas that results in increased consumption. Wouldn‘t it be fairer to customers to offer H gas nationwide?

H gas is already on sale throughout Germany – with the exception of some areas in the north-west. Switching these L gas areas to H gas over the next few years will ensure H gas is available everywhere.

known internally as EA888 Gen.3B, has a straight gasoline-powered unit with direct injection delivering up to 288 kW and a maximum torque of up to 400 Nm [6]. As a general principle, methane with 130 octane is more knock-resistant than commercial gasoline with a maximum of 100 octane. However, the compression ratio must be increased to exploit this advantage, which inevitably means monovalent CNG engines.

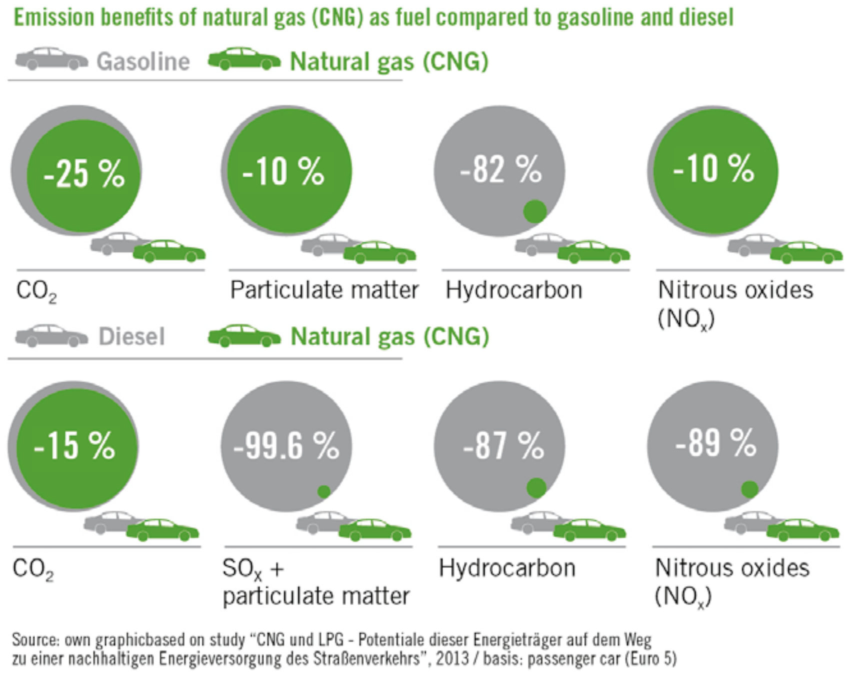
MONOVALENT RACING ENGINE FOR THE NÜRBURGRING

The potential of a gasoline engine designed as a monovalent CNG engine in terms of performance and torque is demonstrated by the development of the VW Scirocco GT24 CNG. Volkswagen Motorsport used several models of this racing car in the 24-hour race on the Nürburgring North Loop between 2009 and 2011. The EA113, a 2.0-l TFSI gasoline series engine – which was installed in a straight gasoline version in an identical Scirocco GT24 – served as the basis. “The rules limited the air intake in both engine variants to the same degree using a 38 mm air restrictor,” recalls Dr. Donatus Wichelhaus.

With this restriction, the Head of Engine Development at Volkswagen Motorsport and his team achieved virtually equivalent performance and torque values, “Our CNG engine achieved 365 hp at 6500 rpm and the gasoline version 370 hp at the same engine speed. We had to limit the torque in each car to 420 Nm with the durability of the cylinder crankcase in mind,” he explains. For racing use, the team arranged for dehydrated CNG with a very high methane content of 98 % at Nürburgring to prevent the pressure control valve from freezing up.

OUTLET VALVE SEAT RINGS ARE A CRITICAL POINT

The monovalent high-performance CNG racing engines, developed in Hanover, first had to undergo a 100-hour endurance



CNG has significant emission benefits compared with gasoline and diesel (© erdgas mobil)


The 2.0-l CNG racing engine in the VW Scirocco GT24 achieved 268 kW (365 hp) and 420 Nm torque despite the air restrictor (© Volkswagen Motorsport)

test on the test bed before being approved for the 24-hour drive under full load in the Eifel hills. Wichelhaus has been responsible for a number of developments, including racing engines for Formula 3, for rally raid use with the Race Touareg and last but not least for the 1.6-l engine with which Volkswagen became Rally World Champion in 2013 at its first attempt, going on to defend the title in the following two years.

His statement that "this robust CNG engine for the 24 hours on the Nürburgring was our most demanding development challenge ever," is all the more significant. Among other things, his team developed an outlet valve shaft and guide with a new geometry, increased the compression ratio from 9.5:1 to 12.5:1 using different pistons, connecting rod and a new crankshaft, and designed a new intake manifold with gas injection to distribute the mixture optimally to the cylinders. Furthermore, a customised exhaust manifold and a turbocharger with a two-chamber wastegate were developed for the CNG version.

Since CNG has no lubricant capability, Wichelhaus had to find new material combinations for the outlet seat rings and outlet valve, which turned out to be the core challenge of the project. "With a bivalent engine, starting the engine from cold with gasoline is more than enough to adequately lubricate the outlet ring and thus avoid any increased wear on the seat rings for 500 to 600 km," explains Wichelhaus. "But since we didn‘t have this advantage, finding suitable materials was crucial. We overcame the hurdle and subsequently briefed our colleagues in the series engine development department."

DIRECT INJECTION IMPOSES HIGH DEMANDS ON INJECTORS

One technology that Wichelhaus was not yet able to use for his racing engine was direct methane injection. He would have "certainly expected a charge advantage and no problems in distributing the CNG air mixture as occur with air manifold injection." Both Delphi and Bosch are currently working on these types of injector. A monovalent CNG engine has already been constructed for the Cult demonstrator vehicle in Austria, which has direct injection using prototype injectors from Delphi [7].

Besides a "significantly improved cylinder charge", Professor Peter Hofmann from the Institute for Powertrains and Automotive Technology at the Vienna University of Technology sees a further major benefit. "It is possible to set a flushing load change – known as scavenging – for low engine speeds and high loads. Together with the charge benefit, the rated torque can already be reached at an engine speed around 500 rpm lower than with air manifold injection, allowing significantly more dynamic driving." Hofmann states that, with higher gearing, "average consumption can be reduced by 1 to 2 %".

However, the scientist still sees a number of hurdles, despite the success of the project. "The biggest challenge in putting methane direct injection into series production is designing appropriate CNG DI injectors capable of meeting the increased demands concerning leaks and wear resulting from reduced lubrication characteristics and low gas density over the life cycle and which can be produced economically," he points out.

Delphi is pushing the development of methane direct injection with this prototype injector (© Delphi)

MAHLE IS WORKING ON A DOWNSIZING ENGINE

Mahle may take the next step in the offensive. A project team at the supplier is working on a monovalent CNG version of an inhouse-developed 1.2 l demonstration engine with three cylinders. As with Volkswagen‘s racing engine, compression is 12.5:1. Components such as the crankshaft drive and valves have already been adapted. Mahle is currently investigating two alternatives to increase the "low-end torque", i.e. torque at low engine speeds. The first involves using a turbocharger with variable turbine geometry in combination with air manifold injection. The second is a wastegate exhaust turbocharger combined with direct injection. The declared aim is to achieve specific output of 110 kW/l. There are also plans to allow peak pressures of up to 185 bar. One version, installed for test purposes in a VW Touran, currently achieves 90 kW/l. The project will certainly give new impetus if successful.

Despite the scarcity of filling stations, Professor Hofmann is unconcerned over whether a carmaker may be motivated by this to take the first step towards a monovalent CNG car with direct injection. "One obvious solution is a combined gasoline air manifold injection system. In our view, the disadvantages under full load are acceptable for the foreseeable low share of use of the gasoline mode."

Donatus Wichelhaus is more worried about CNG car customers continuing to experience an assumed product disappointment – due not to the engines but, unlike in the pit lane of the Nürburgring, the varying fuel composition. "I think it is inevitable that the image of the natural gas car will continue to suffer, given the lack of consistent CNG quality at filling stations with at least 98 % methane content and while the energy of so-called L and H gases varies by more than 10 %. No-one can expect customers to understand why power is suddenly lacking or their cars become thirstier," says the racing engine developer, addressing the energy suppliers directly.

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WHAT DO WE THINK?

„Back to the Future“

Nicolaus Otto powered the first four-stroke engine in 1876, not with gasoline but with coal gas. 140 years have since elapsed, during which time the engine named after him – the Otto gasoline engine – has been continuously improved. Is the electric motor going to replace it completely in future? Absolutely not in our view, since the now highly developed engine can be run on CNG for centuries to come. At the end of the day, methane can also be produced by renewable methods. Monovalent CNG engines are a modern and promising step back towards gas that one manufacturer must be the first to take.

Dipl.-Journ. (FH) Martin Westerhoff
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COVER STORY

Efficient Engines

To further reduce fleet fuel consumption, efficient engines are the top priority in all vehicle classes and for all manufacturers. Although increasing electrification is currently the key lever for achieving lower fuel consumption, the efficiency of combustion engines is constantly being improved. The task is becoming increasingly challenging. Costs and benefits must be carefully weighed up for every gramme of CO_2 that can be saved with a particular measure. The purely engine-related parameters are, above all, friction, combustion process and thermomanagement. In the struggle to lower friction, mean effective pressure, the crankshaft drive – especially the piston-piston ring-cylinder working surface system – offers less and less remaining potential, particularly in light of oil emissions. Light oils with very low viscosity such as 0-W20 are therefore increasingly

© alswart | Fotolia

coming into consideration as "design elements". Electric and consequently flexible coolant pumps are also making their contribution. Further de-throttling and the influence of geometric and effective compression on the thermodynamic optimum almost always spawn turbocharged engines – provided that they can be designed cost-effectively for the relevant vehicle class. Gasoline and diesel engines are increasingly converging, particularly when lean burning processes for gasoline engines come into play.

Volkswagen has succeeded in significantly increasing the efficiency of its top-of-the range 6.0-l power unit W12, which consumes up to 28 % less gasoline than its predecessor. Thanks to a new combustion method using dual injection into the combustion chambers, the W12 complies with the emissions thresholds of Euro 6 Stage 2 and ULEV 125. Moreover, the left-hand cylinder bank can be completely deactivated. Opel has completely redeveloped the engines for the generation K Astra. Special attention has been paid to fuel consumption under full load for small and medium-sized three- and four-cylinder gasoline engines. For the turbocharged 1.0- and 1.4-l versions, the developers have thus chosen moderate specific power output that they describe as rightsizing. In our interview, Michael Fleiss, Vice President Powertrain at Volvo Car Group, explains the strategy the Swedish carmaker is pursuing with its range of engines and why the internal development of supercharging systems is key in the race for optimal efficiency.

Martin Westerhoff

The New W12-TSI Engine of the Volkswagen Group

The Volkswagen Group's ultra-compact, top-of-the-range W12 engine has been in service for 13 years. Within the scope of the latest developments, the two combustion processes previously used in parallel – FSI direct injection at Audi and TMPI at Bentley – have been improved with further technical innovations and combined to form the successfully established TSI process.

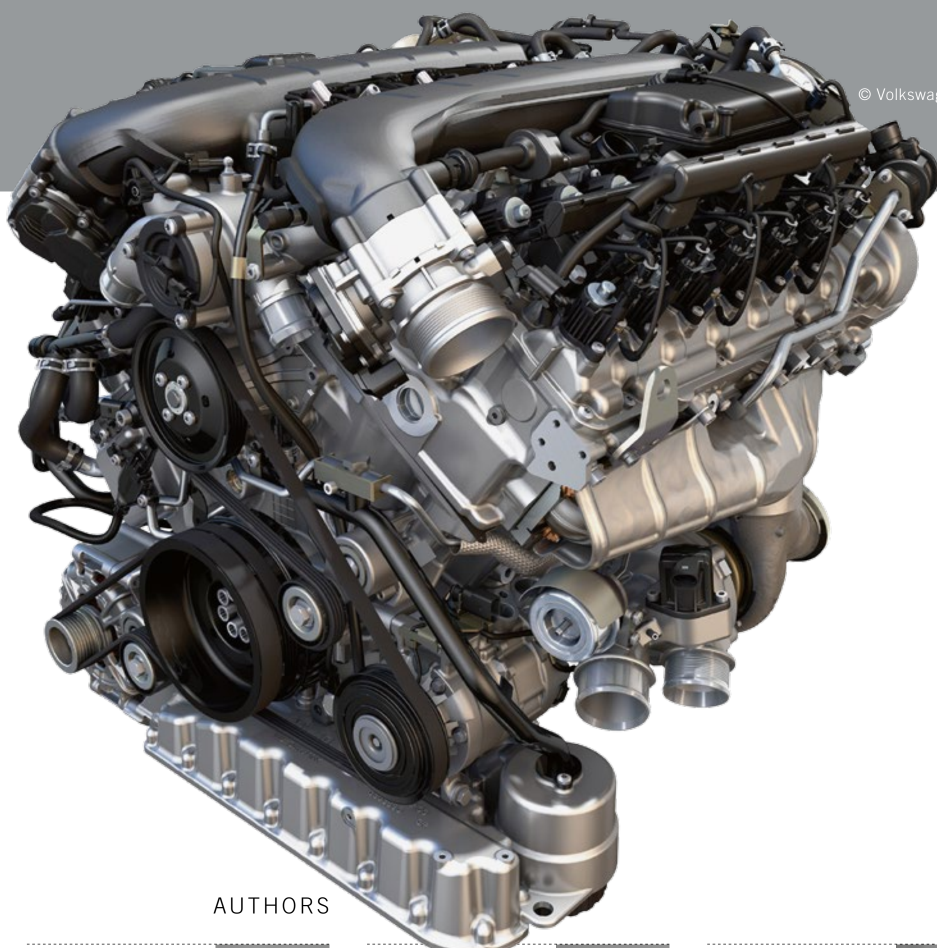

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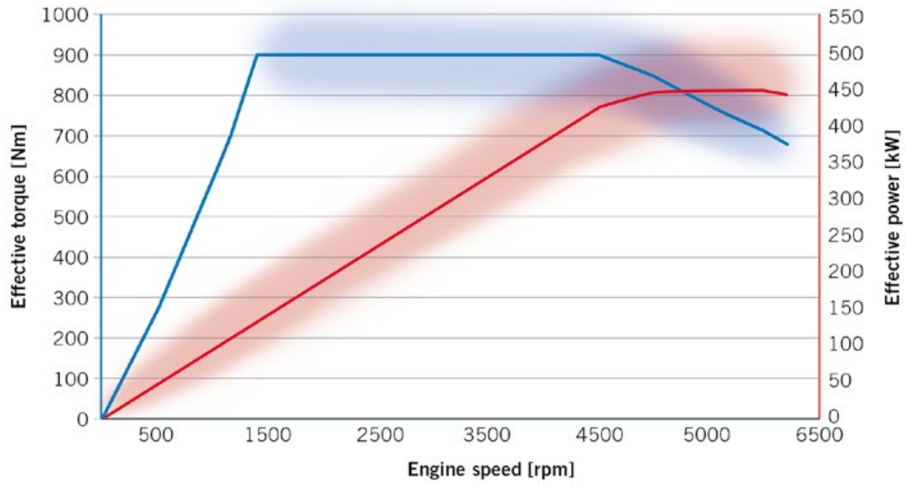
FIGURE 1 W12-TSI full load (© Volkswagen)



With the newly applied technologies, the W12-TSI now has one of the highest technology densities of any engine worldwide. The package comprises, among other things:

- a new combustion process with dual injection into the combustion chambers and intake manifold to fulfil Euro 6 phase 2 and ULEV 125 emissions limits
- cylinder deactivation of the left cylinder bank
- two twin-scroll turbochargers with excellent transient characteristics
- cylinder liners with an APS coating for increased robustness
- a crank drive suitable for start/stop operation
- an oil circuit with variable oil pump suitable for sustained use on significant inclines
- a cooling system with integrated thermal management
- powerful engine management with two control units.

STRENGTHENING OF THE BASE ENGINE FOR THE INCREASED PERFORMANCE

The base engine was adapted to the considerably higher power and torque figures, **FIGURE 1** and **TABLE 1**, in order to fulfil the high requirements for quality and durability set by the Volkswagen Group. This involved primarily the following measures:

- induction hardening of the forged crankshaft
- cracked conrod design
- redesigned bearing bushes for conrods and main bearings
- APS coating of the cylinder walls
- improved geometry of the pulsation windows in the main bearing seats.

Development work successfully lowered the temperature loading at the bearing points by 10 °K. The temperature rise under full load, even at high revs, is relatively small, **FIGURE 2**. This was achieved through the following measures:

- optimisation of bearing material with the aim of improved thermal conduction
- minimal enlargement of bearing play to enable higher oil flow
- re-engineering of conrod geometry for homogenous distribution of piston forces into the bearing bush on the rod side
- tight tolerances on the crowning of the crankshaft journals, this avoids local pressure spikes, while ensuring against edge loading in combination with the new coating on the bearing bushes.

To configure the oil supply bores and assure wear limits in all relevant operating modes, RNT analysis of the conrod bearings was correlated with oil pressure and temperature measurements.

The crankcase of the W12-TSI is made from pressure die-cast hypereutectic aluminium-silicon alloy and is designed, like the preceding engine, as a short-skirt block with bed plate. The weight-optimised bearing seats in the bed plate are cast into the structure inside the mould. The crankcase has plasma-coated cylinder barrels prepared using a laser grinding process. The steel coating is applied as a powder using atmospheric plasma spray (APS). The key benefits of this solution are reduced friction and improved corrosion resistance in the face of poor-quality fuels on world markets.

NEW COMBUSTION PROCESS WITH DUAL INJECTION

The dual injection combines high-pressure direct injection at a maximum of 200 bar with low-pressure injection into the intake manifold, where pressures reach slightly more than 6 bar. This ensures fulfilment of emissions limits set by phase 2 of Euro 6 and by the US ULEV 125 standard without the need for further measures in the exhaust system.

Both high-pressure and low-pressure injection are active across the entire engine map, **FIGURE 3**. One exception

Characteristic [unit]	Value
Engine type [-]	W
Displacement [cm³]	5,950
Power [kW]	447
at engine speed [rpm]	6000
Torque [Nm]	900
at engine speed [rpm]	1500 – 4500
Mean pressure [bar]	18.83
Specific power output [kW/l]	75.13
Bore [mm]	84
Stroke [mm]	89.47
Cylinder spacing [mm]	65
Cylinder bank angle [°]	72
V angle within one bank [°]	15
Cylinder offset [mm]	12.5
Crank pin diameter [mm]	54
Crank pin width [mm]	11.7
Split pin [°]	12
Adjustment range, intake camshaft [°]	52
Adjustment range, exhaust camshaft [°]	42
Compression ratio [-]	10.5:1
Specific consumption (at 2000 rpm, 2 bar) [g/kWh]	312
Fuel specification (for global use) [ROZ]	95
DIN weight (including turbochargers) [kg]	254
Length × width × height [mm]	585 × 747 × 696
Ignition order [-]	1 - 7 - 5 - 11 - 3 - 9 - 6 - 12 - 2 - 8 - 4 - 10

TABLE 1 W12-TSI technical data (© Volkswagen)

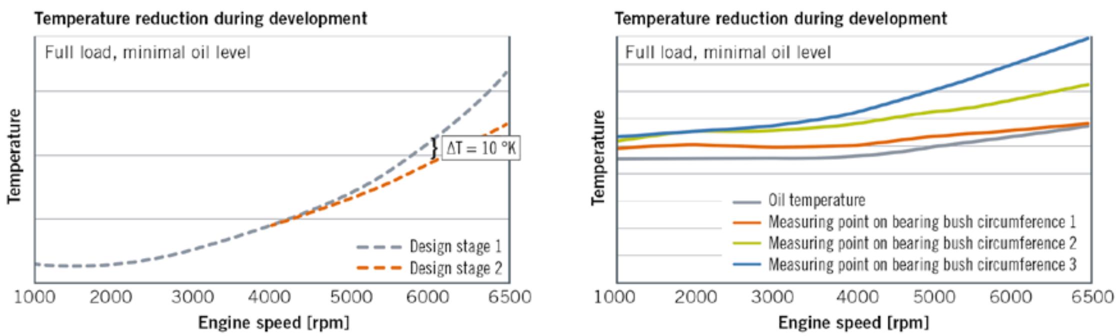


FIGURE 2 Temperature of the bearing bushes, schematical (© Volkswagen)

is cold start, when only direct injection takes place. During the warm-up phase, the engine then runs almost entirely on multi point injection (MPI), which is also active under partial load. This enables a comfort-biased combustion process with reduced pressure gradients and also has a beneficial impact on particulate emissions.

Two high-pressure pumps coupled to the intake camshafts on the drive side supply the direct injection. During the development process, the entire fuel system was configured using a simulation test bed to fine-tune the dynamic pressure distribution in the rail and throughout the lines. Even distribution of injection volume between the cylinders is assured. The high-pressure injection valves have laser-bored injection holes, with their spray pattern determined by the respective cylinder bank on account of packaging. The low-pressure injectors are located in an offset position above the high-pressure system and likewise have bank-specific spray patterns, **FIGURE 4**. Guide ribs in the intake manifolds provide precisely even distribution of the fuel/air mixture in the cylinder.

Identical combustion characteristics in all cylinders, regardless of the length of the intake port, mean the high demands set for execution, efficiency and exhaust emissions are met in full.

The intake port was optimised for flow and charge cycling using the Computer Aided Engineering (CAE) process and Automatic Motor Component Optimisation (AMO) developed within the Group. A major element of this is a parameterised CAD model of the intake port including relevant limiting factors such as water jacket, valve spring retainers etc. Each intake port is evaluated using the figures for flow and tumble from a three-dimensional CFD (Computational Fluid Dynamics) analysis. Geometry generation, meshing, calculation and evaluation are carried out automatically and controlled by an optimiser.

FIGURE 5 uses the example of the short intake port to chart the calculated αK figures against the amount of tumble for all intake ports examined. The variant selected enables a considerable increase in tumble paired with an increased flow rate coefficient.

The control units for the W12-TSI, with increased computing performance and expanded software, run on a master/slave principle. Individual adaptations and diagnostics are necessary to accommodate the combination of MPI and direct injection. A brand new software priority control system coordinates single and mixed-state operating modes. In parallel, emissions optimisation, diagnostic and monitoring requirements and protection functions are weighted and evaluated accordingly. The monitoring process also takes into account both fuel paths with their respective proportions.

The two control units control a large number of actuators and sensors and ensure communication with the vehicle's surroundings. In the W12-TSI, they have a 2×196 PIN layout to provide the control power necessary for handling the large volume of signal traffic. Important data is exchanged via an internal data bus (Inter-SG-CAN).

NEW TWIN-SCROLL TURBOCHARGING CONCEPT

Integration into the space available inside the engine compartments of the Volkswagen Group's luxury-class vehicles was achieved through innovative packaging solutions. The layout of the

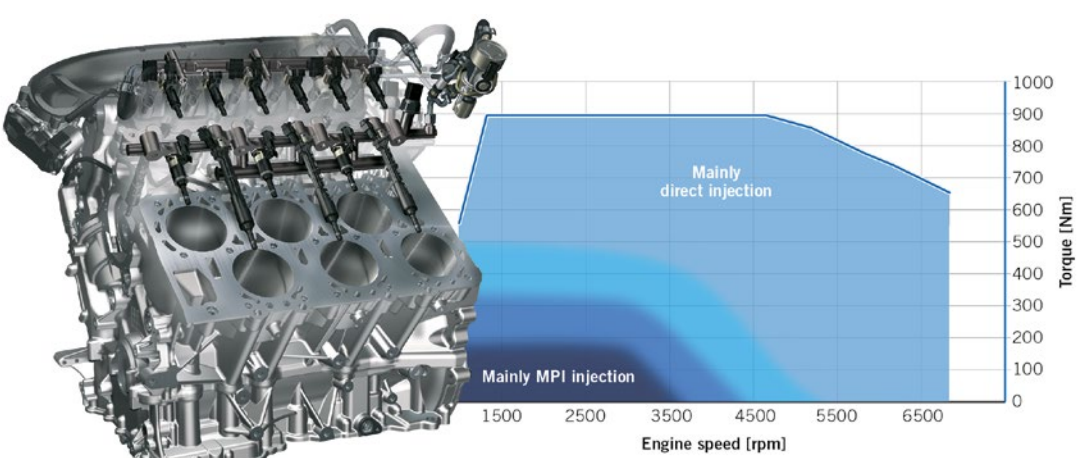


FIGURE 3 Engine mapping for direct and MPI injection when the engine is warm (© Volkswagen)

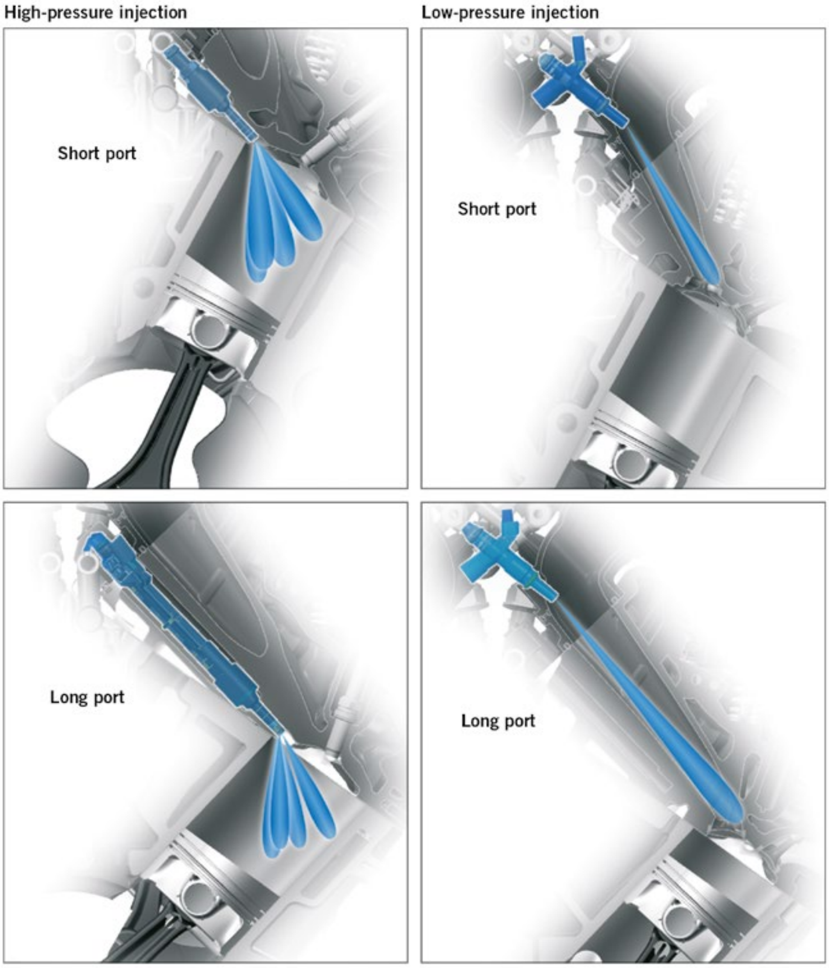


FIGURE 4 High and low-pressure injection spray in short and long port (© Volkswagen)

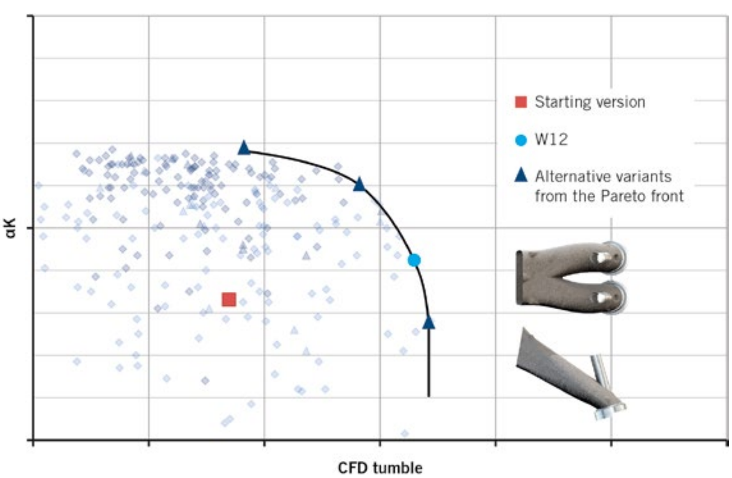


FIGURE 5 Intake ports variants, schematical (© Volkswagen)

turbocharger assembly, comprising the twin-scroll turbochargers, ancillaries and engine mounts is particularly space-saving, while ensuring favourable flow conditions. The exhaust assemblies for the three front and three rear cylinders are separate from one another, and the fully insulated turbine housings are welded to the manifolds, which feature air-gap insulation. In keeping with the flow separation, the secondary-air system also has a split configuration.

A central objective in the development of the turbochargers was to achieve spontaneous transient characteristics. At 1500 rpm, the load step from low partial load to full load occurs around two-and-a-half times faster than in the TMPI engine, **FIGURE 6**. This improvement results primarily from the very good flow characteristics of exhaust pulses at low engine speeds, too. These were determined using transient 3-D-calculations taking into account the twin-scroll effect. **FIGURE 7** shows on the left side the comparatively high flow speeds occurring in the exhaust port, in the exhaust manifold and in the twin-scroll turbine under full load at just 1500 rpm.

Measurement of the turbochargers' rotational speed with the aid of speed sensors enables full use of the compressor map, **FIGURE 7** (right), all the way to the choke line and protects the turbocharger against overspeed, for example as a consequence of dirt in the intercooler. This permits the use of a machined compressor rotor with a small diameter and correspondingly low moment of inertia. The turbine rotor has likewise been optimised for moment of inertia and efficiency, which also benefits responsiveness. The exhaust gas turbochargers (EGT) have thus been systematically configured for dynamic characteristics without any loss of rated power.

Analysis of turbocharger speed enables the control unit to compare between the desired characteristics modelled and the actual characteristics. This serves for the purpose of diagnostics, adaptation and rapid and predictive turbocharger protection.

The waste gate flaps are actuated by vacuum valves. Electrically regulated bypass valves positioned on the compressor casings prevent unwanted noise caused by turbo pulsing. Due to the ACT compact cylinder deactivation on cylinder bank 2, induction of the blow-by and tank breather gases takes place only at the turbocharger on bank 1. Electrical heating at the induction point prevents freezing at outside temperatures well below -30 °C.

INCREASED DEMANDS ON THE OIL CIRCUIT

The W12-TSI is conceived as a wet-sump engine. Depending on the vehicle model,

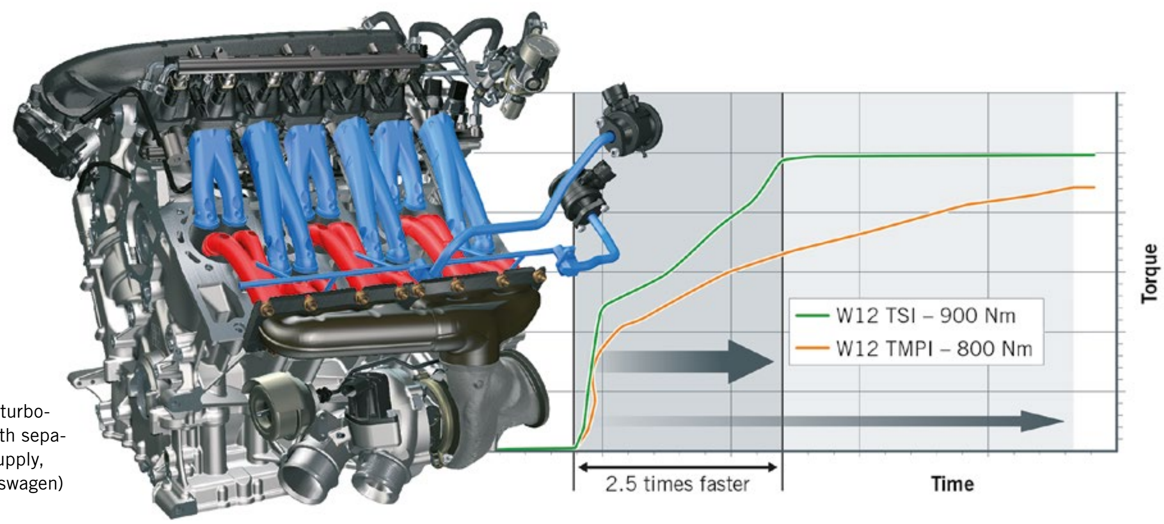


FIGURE 6 Twin-scroll turbocharger assembly with separate secondary-air supply, schematical (© Volkswagen)

its oil supply handles the demands of off-road use as well as those of a sporty on-road driving style with high centrifugal forces of more than 1 *g*. The oil pump is driven from the crankshaft via a largely encapsulated chain. The shape of the oil sump and the positioning of the oil suction ensure continuous oil supply at extreme angles of up to 45° through a full 360°. An oil-level sensor monitors the oil level.

The two turbochargers are coupled to the two-phase switchable oil pump with separate oil suction stages. To ensure no oil can escape from the EGT bearing housings into the intake and exhaust tracts, suction also occurs under operating conditions where the second cylinder bank of the W12-TSI is deactivated.

The oil system was tested on a tilting test rig and in corresponding off-road driving situations, where the focus was on assuring oil supply, oil foaming, oil suction from the turbochargers and engine venting.

COOLING SYSTEM WITH INTEGRATED THERMAL MANAGEMENT

The thermal management of the W12-TSI shortens the warm-up phase after cold start and specifically channels the heat generated by the engine to the relevant areas. The focus is on warming up the cylinder heads as fast as possible. This brings the combustion chambers to optimum operating temperature quickly in the interests of good mixture preparation. By using a switchable main coolant pump, it also facilitates independent heating of the vehicle interior. The reduction of friction inside the engine is another positive aspect.

For the purpose of needs-based heat distribution, the overall cooling circuit, **FIGURE 8**, comprises three sub-circuits:

- heating circuit (red) incorporates cylinder head, heating system heat exchanger and an electrical coolant pump
- main water circuit (blue) comprising crankcase, engine oil cooler, a thermostat designed as a 3/2-way valve, the main radiator block and a mechanically driven coolant pump that can be pneumatically deactivated
- turbocharger circuit (green) with a separate, electrically driven coolant pump
- a separate transmission heating and cooling circuit can be integrated if required.

Equipping the sub-circuits with their own coolant pumps enables them to be operated independently from one another. The fast-reacting coolant temperature sensor was moved to the cylinder head, close to the combustion chambers.

ACT COMPACT – CYLINDER DEACTIVATION IN RESTRICTED PACKAGING SPACE

In the Volkswagen Group's tried-and-tested valve control system (AVS), all switching is carried out via cams mounted on sections of tubing. When

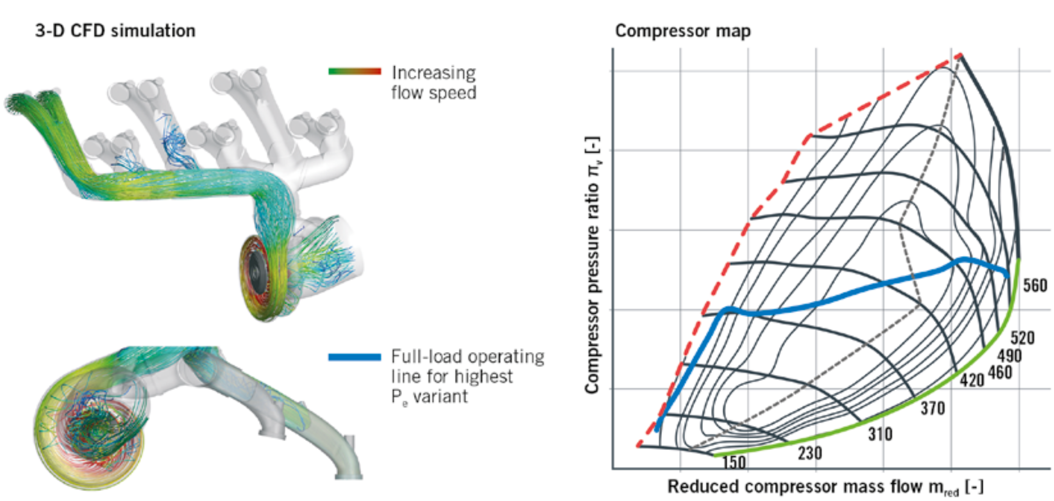


FIGURE 7 Transient 3-D CFD simulation of outlet ports, exhaust manifold and twin-scroll turbine (© Volkswagen)

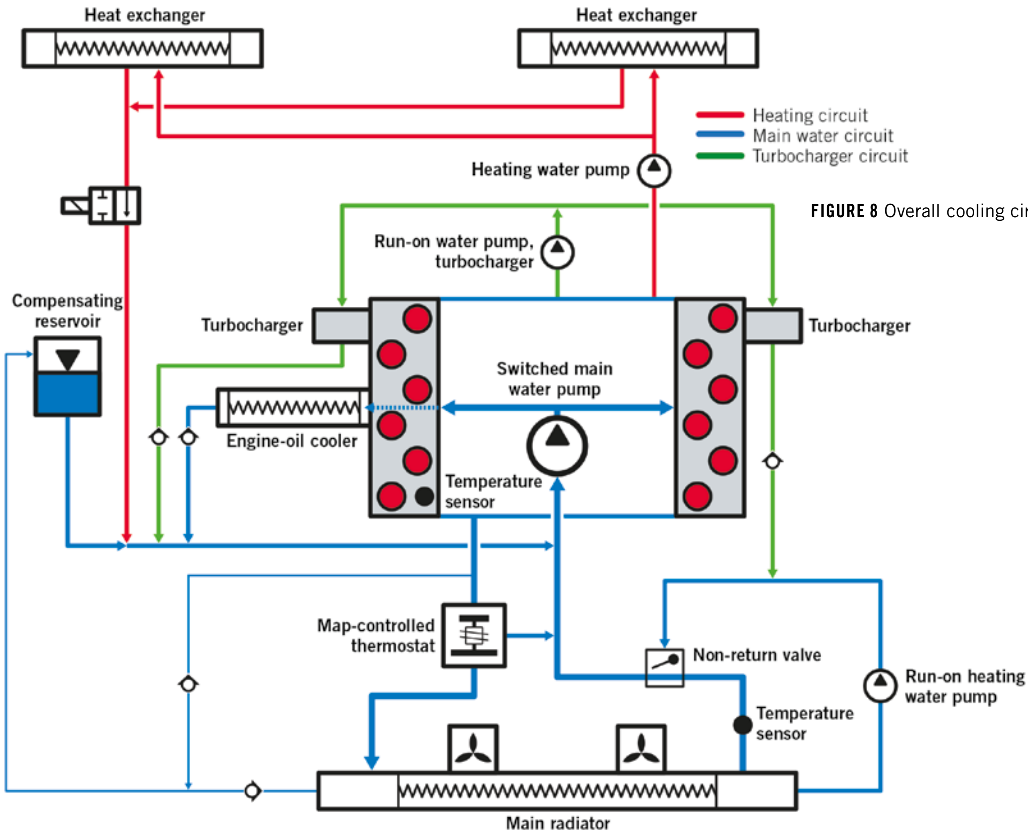


FIGURE 8 Overall cooling circuit (© Volkswagen)

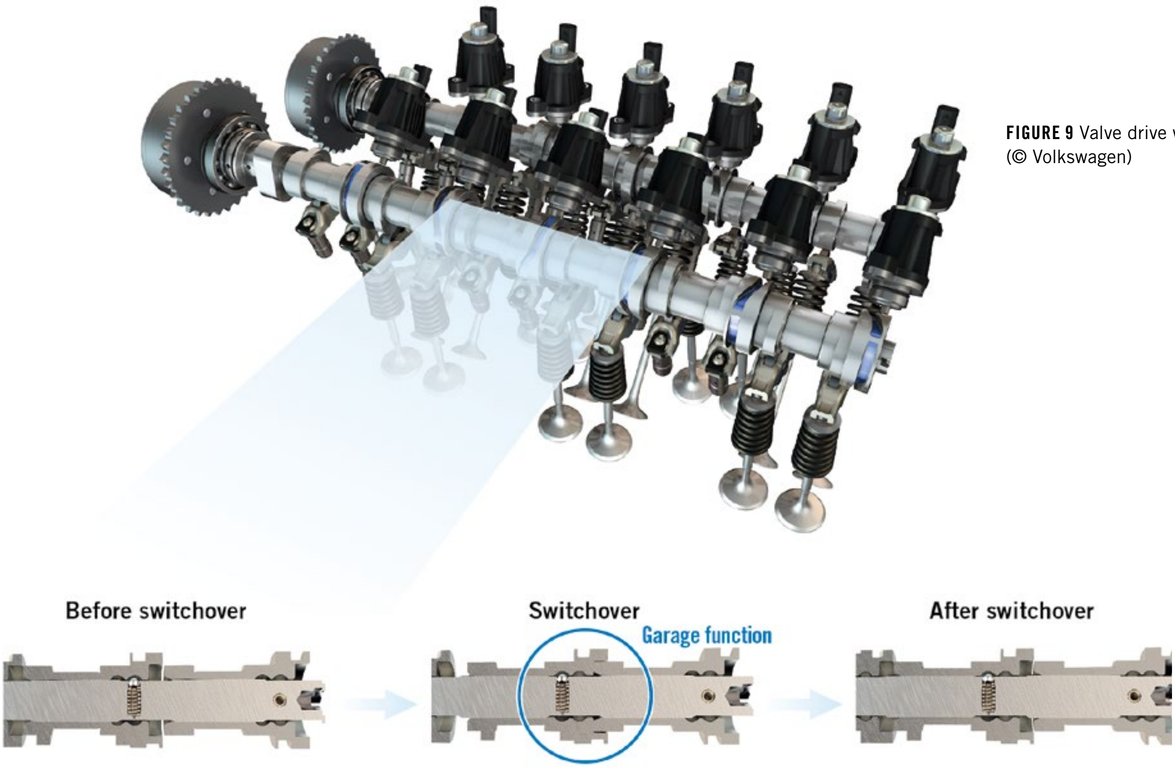


FIGURE 9 Valve drive with ACT compact (© Volkswagen)

the cylinders are deactivated, a so-called zero-lift cam with a 360° base circle rotates above the rocker arms without actuating them.

Because of their offset, the cylinder spacing in the W12-TSI is just 65.0 mm and the valve spacing 36.5 mm. The decision was taken to use one single-pin actuator and a double-s groove geometry, where the grooves for engaging and disengaging the cams are machined into a single disc at the end of the cam section. These also feature a so-called cam-garage, into which the cam under load can retract during the switching procedure, **FIGURE 9**.

Switching into ACT operation begins with the next cylinder in the firing order and occurs through activation of the magnetic actuator. The pre-magnetising time is around 3.2 ms, after which the spring-assisted flight phase of the switching pin commences, taking from 3.1 to 3.3 ms depending on the temperature, slotting into the linear groove area. All the other cylinders on that bank are deactivated via the same process. The load shift on the air path and adjustment of the ignition angle towards "late" ensure a moment-neutral process. Switching occurs so smoothly that it has virtually no impact on the excellent running characteristics of the W12-TSI and is imperceptible to the customer.

Each actuator weighs just 120 g. In the development of the system, a multi-body simulation (MBS) model was used to optimise the flanks of the switching grooves. In the course of the development process, this enabled a reduction of 45 % in the pin force and of 55 % in the striking momentum. The Hertzian stress at the contact between the switch pin and groove flank dropped by 26 %. The ACT compact system deactivates all six cylinders of the left bank (bank 2) under moderate load and engine speed by closing the intake and exhaust valves and switching off injection and ignition. Prior to closing the valves, the combustion chambers are filled once more with a fresh charge. During ACT operation, the shift in operating point leads to increased efficiency, while the W12 functions as a VR6 with an ignition sequence of 1-5-3-6-2-4. By using active cylinder deactivation (ACT compact) in the W12-TSI, CO_2 emissions are reduced by more than 5 % (NEDC).

The main operating range ends at 2600 rpm. Upwards of this, the start of forced induction in the active right cylinder bank forms a sensible boundary. Under lower loads, ACT operation is also maintained during trailing throttle. Even when revving is highly dynamic, sufficient distance from the system rev limit permits completion of the switching cycle, for example during kickdown.

During development of the engine control unit, the use of ACT compact necessitated a new control strategy, taking into consideration separate air-mass regulation. Each of the two engine control units evaluates separately whether or not ACT operation is possible. When authorisation is available, switching takes place individually. In its detail, the process is based on the role of the respective control unit within the master/slave concept. This strategy contributes to lowering the communication load on the CAN bus between the two control units.

CONCLUSION

The new W12-TSI made its debut in the Bentley Bentayga presented at the Frankfurt International Motor Show and will subsequently be used in other group vehicles. With the combination of dual injection, cylinder deactivation, twin-scroll biturbocharging and integrated thermal management, its existing strengths – powerful performance, smooth running characteristics and high efficiency – have been further enhanced and all development targets met in full. The elements of the W12-TSI and the use of innovative production methods such as the APS process also offer significant future potential for further increases in power and torque as well as fuel savings. The concept development of the W12-TSI has already taken into consideration its configuration as a mild hybrid system with a 48-V-vehicle electrical system.

The ultra-compact, new twelve-cylinder has the highest technology density of any engine worldwide and sets new benchmarks with its enormous bandwidth of features and characteristics. It thus offers an excellent basis for a fascinating portfolio of future luxury-class vehicles. The W12-TSI – engineered for excitement.

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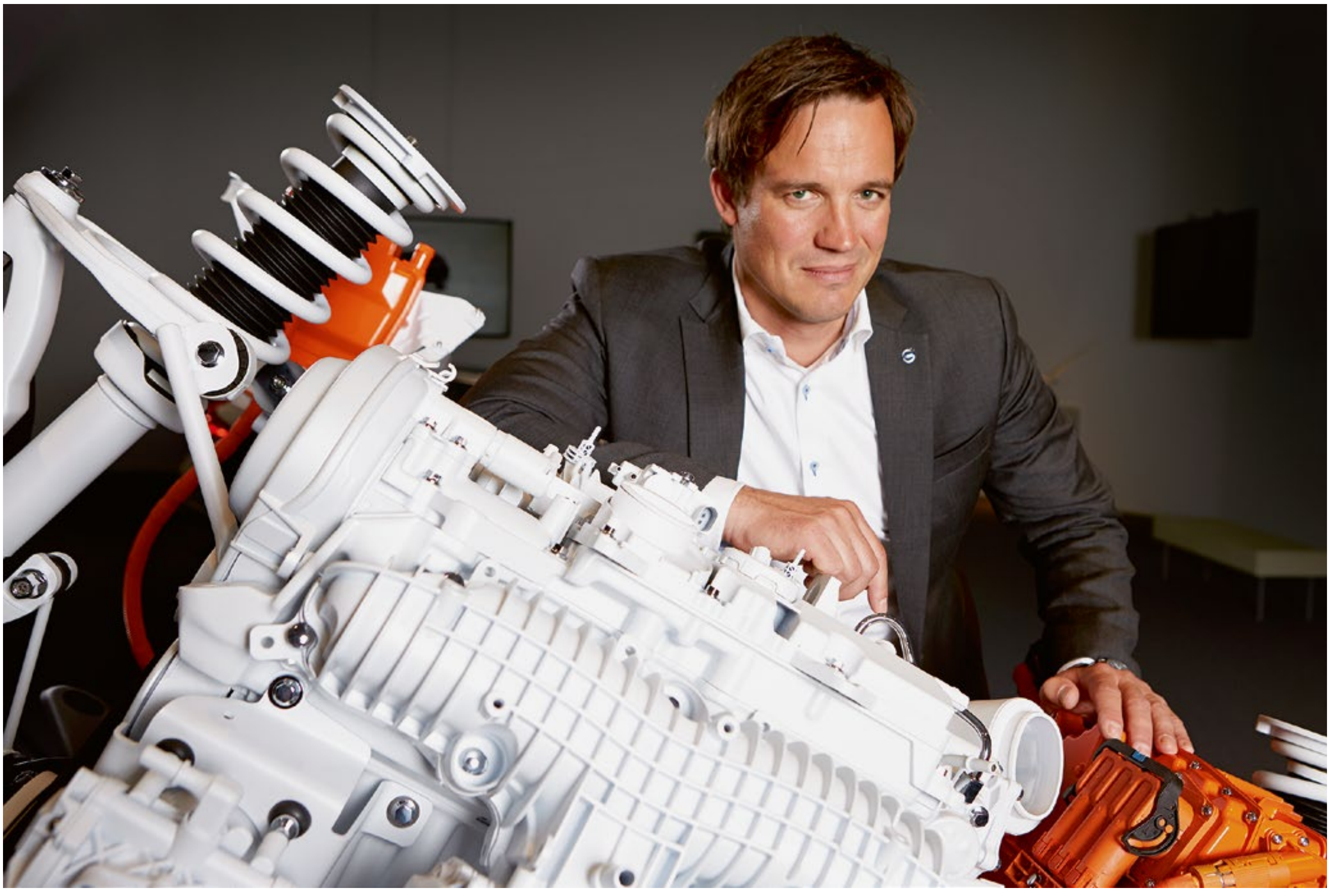

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"We exploit efficiency gains by understanding the details"

Michael Fleiss, Vice President Powertrain at Volvo, knows how measures to enhance efficiency can boost combustion engine potential still further. Friction, combustion processes and high injection pressures are all key parts of the solutions that the Swedish company has devised. In an interview with MTZ, he discusses the relevance of in-house developments and explains what led to the engine development engineers in Gothenburg becoming charging experts.

Michael Fleiss, born on 26 January 1973, in Luebeck, started his professional career as a design engineer at Volkswagen in 1997 after studying mechanical engineering at the Luebeck University of Applied Sciences. He held various roles at Volkswgen up to 2006, overseeing the intake systems of small gasoline engines and later the 1.4-l TSI engine. He also worked as a calibration engineer for the company for just under two years. Next, from 2006 to 2012, he managed engine development at Bentley in Crewe (UK). In February 2012, Fleiss moved to Volvo Car Corporation in Gothenburg (Sweden), where his first task as Director of Engine Engineering was to launch serial production of the VEA engine as part of the Drive-E engine series. Since January 2014 Fleiss has taken over from Derek Crabb as Vice President Powertrain at Volvo and also overseen e-mobility since the end of 2015.

MTZ _ Mr. Fleiss, can you confirm that Volvo has really abandoned its five-cylinder tradition?

FLEISS _ Yes, we are now phasing out the five-cylinder engine across the whole range. And it was a very deliberate decision, in fact, made by my predecessor, Derek Crabb, in 2008. At the time it was seen as an extreme – and bold – move. Nowadays, however, this decision would be much easier, given the far greater downsizing trend. In fact, the SPA (Scalable Platform Architecture) platform scope no longer includes five cylinders.

Why are you focusing on such a narrow 2-l four-cylinder diesel engine sector at Volvo?

We want to create appealing cars by reducing the rear and front overhangs. A transverse engine is the only way. Installing it in this position also frees up more space inside the car. Plus safety is top of the agenda for Volvo and so reducing the space required to install the engine also helps boost crash and pedestrian protection. Although studies have also shown that major changes would make it feasible to install a five-cylinder engine, we've discounted that option.

But in the German market, for example, wouldn't that prevent you from being able to market any product in the high-performance diesel sector?

Well, that is undeniably a challenge when you have a four-cylinder diesel engine with this capacity. The trick is to successfully generate effective spontaneity, despite the lack of capacity, and we've already mastered that one with our current engine range. And, we have more appealing innovations in the charging sector to improve the dynamics still further.

One of which you introduced recently at the Aachen Colloquium 2015 – the so-called Power Pulse System. Can you tell us more about the technology behind this name?

The Power Pulse System, which is scheduled for serial roll-out at the start of 2016, is an air compressor, similar to the one used in air suspension, with a valve and pressure cylinder. Driver input and an engine map-controlled approach control the injection of compressed air into the exhaust tract: 15 g of air in 300 ms on average. We use this to speed up the exhaust gas turbocharger, which enables us to achieve an even better start-up and dynamic response, even outperforming the six-cylinder diesel engine model with 3 l cubic capacity. For diesel engines in particular, the limit of four cylinders and 2 l cubic capacity results in original solutions from Volvo.

You developed this system in-house. As a modestly sized company, don't you automatically think twice before branching out in a new direction?

The easiest way is always taking and then applying an off-the-shelf solution from a supplier. That is why we analysed everything in fine detail beforehand: mechanical supercharging, followed by the compressor – familiar from the gasoline engine – and of course electric charging. Charging the engine already involves two stages. After we compared

"We know charging inside out."

efficiency with the costs involved, we concluded that pneumatic charging would be the best solution and then devised another Volvo "tailor-made" solution to give our customers the best possible end result.

Talking of electric charging ...

Naturally, we are also working on an electric turbocharger – assisted by suppliers – which we envisage deploying in the medium term. Right now, the power density of a 12-V e-charger just isn't enough and, despite positive steps made in the 48-V battery technology field, the cost remains prohibitive. Moreover, the performance of the 48-V e-charger, which we use in our own test vehicles, is comparable with our pneumatic charging. In fact, the pneumatic charging solution we developed even achieves slightly higher turbine speed acceleration. In other words, even if we bring out the electric turbocharger in the medium term, we are also reflecting on how to further enhance pneumatic charging for the diesel engine.

In 2014, jointly with AVL Schrick, Denso and Polestar, you presented a four-cylinder engine study in Aachen featuring spectacular triple supercharging. Was this more a project for show or a serious venture?

We know charging inside out and that was also one of the things we wanted to convey with this study. Given that we have limited displacement, exceptional charging is simply a must. With as little as 2 l capacity, our engineers managed to generate power of 331 kW (450 hp). The response to our engine design was accordingly positive. And yes, specific discussion continues on whether we should develop this into a production vehicle.

Will the charging design correspond to the one included in the study you presented in 2014?

Whatever happens, the benchmark parameters should be attained. Whether that ultimately translates into two parallel-connected turbochargers and an electrically driven compressor or some other design remains to be seen. Instead of the supercaps – used given the lack of development time – the solution will probably be a 48-V battery. We would also definitely deploy an e-charger. The question remains as to which is really best, a two-stage or parallel double-turbo version. Having a two-stage turbine and just the one compressor would also be feasible. For example, AVL showcased a twin-pipe solution at the Aachen Colloquium 2015 – featuring the 2-l gasoline engine and 200 kW output. In some cases, that is the optimal approach.

As well as improved charging technologies – what instruments will you leverage in future to boost the efficiency of Volvo combustion engines even further?

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"For diesel engines in particular, the limit of four cylinders and 2 l cubic capacity results in original solutions from Volvo", Fleiss explains

© Volvo I Lars Ardarve

“Even if we bring out the electrical turbocharger in the medium term,” says Fleiss while discussing with ATZ editor Angelina Hofacker, “we are also reflecting on how to further enhance pneumatic charging for the diesel engine”

The work of our Research and Development department centres on friction, combustion methods and high injection pressures – for both gasoline and diesel engines alike. For this purpose, cylinder deactivation for gasoline engines and diesel engines may involve valve lift switching. Here in Gothenburg we have a transparent engine to investigate the combustion method, which lets us analyse the process in great detail.

How important are alternative combustion methods at Volvo, for example Miller/Atkinson?
We are looking into that. Investigations to date have shown that cylinder deactivation is the optimal solution when it comes to a switchable valve system, and even more effective than the Miller/Atkinson method.

What do you think of rolling cylinder deactivation? We also covered that in a presentation in Aachen.
The technology is interesting, but relatively complex. It also raises the question of how much you will get out of it and how much will have to be invested. The engine is a little longer, owing to the gearbox located before it, in order to halve the camshaft speed, although that makes things a bit trickier given the limited construction space available to us. It is one possibility in a three-cylinder engine to actually achieve cylinder deactivation. That would also be more feasible with regard to the package on our side.

How well is Volvo doing in terms of reducing friction?
We achieved a new benchmark using friction scatter bands for such engines with the first-generation VEA engines during the FEV competition. In fact, minimising friction was one of the key themes when we developed the VEA engine. After all, friction is the only area that is cost-free if you want to reduce CO_2 emissions. It improves the efficiency in the complete engine map. That is also why, for example, we are looking at how we can further reduce the diameter of the main bearing – or reducing piston ring forces while also keeping particulate emissions constantly in mind. It's a balancing act for which new technologies like PVD coatings are invaluable. We also continue to focus on the crankshaft with a roller bearing.

> **“Spontaneity is challenging in a diesel engine with little capacity.”**

How do you assess the use of steel pistons in a diesel engine?
We have already tested steel pistons in our diesel engines. However, since our results showed that no exceptional efficiency boost was possible, we have yet to identify any major advantages of using them. Even so, it's an interesting area and one we will continue to monitor.

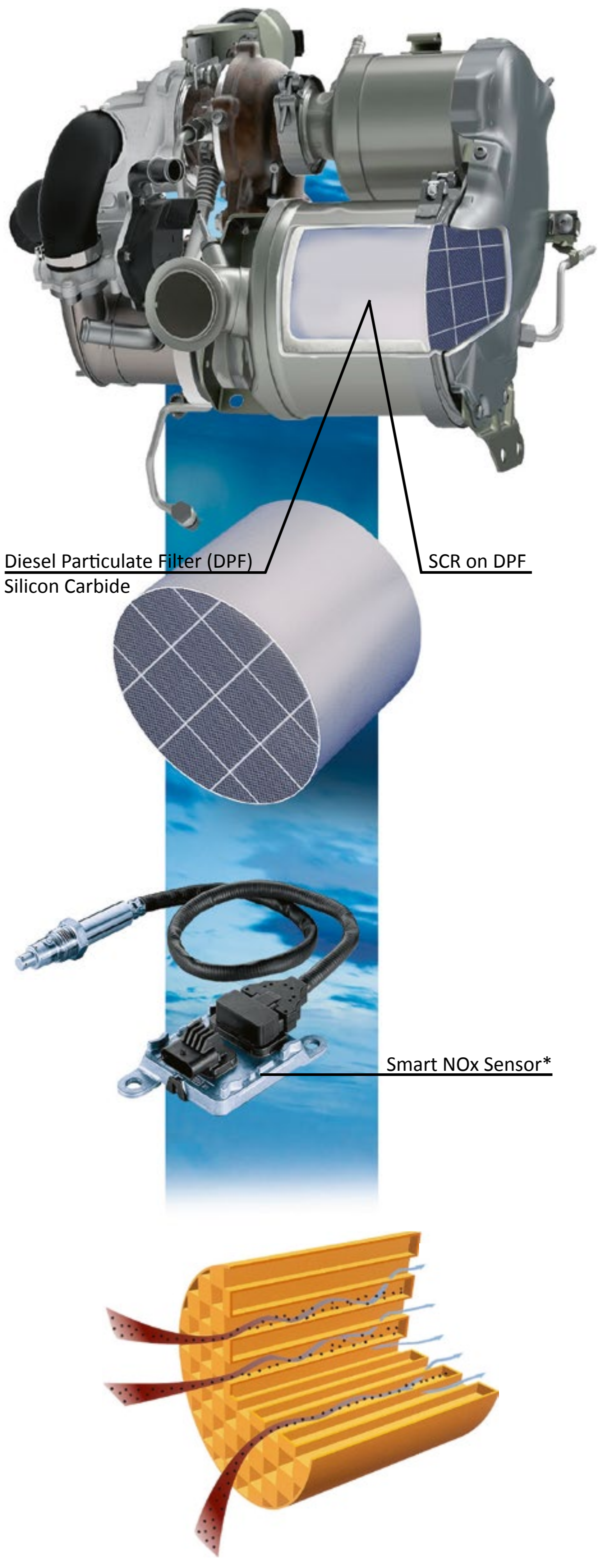
What would you consider the stand-out feature of Volvo powertrain development?
We have arranged all the departments in a way that lets them work very efficiently. For example, the same team is tasked with developing both gasoline and diesel pistons, which elicits synergies and helps keep things consistent. This applies to all areas across the board. Another unique aspect is the high number of engineers who handle software development. We wrote our own software from a very early stage. 80 % of the entire control unit content was programmed in-house. This boosts both the pace of development and our flexibility. Here, it's just the same as with the Power Pulse System: We tap into efficiency gains by understanding the details and achieve competitive advantage for ourselves as a complete vehicle manufacturer in the process.

Please give us your opinion: How much extra efficiency can you get out of the combustion engine using mechanical optimisation alone?
I have set the goal of creating a series of engines by 2020, which achieve 95 g CO_2/km without additional electrification other than the PHEV and BEV projects already decided on. For us in Sweden, the 95 g figure is 103 g, depending on how the WLTP is decided and which other factors have an impact. The simulation results for the third Drive-E powertrain generation, which we are developing right now in the design phase, have been very promising. This would make us one of the few manufacturers capable of complying with the CO_2 threshold values without any additional electrification. But that doesn't mean I am opposed to electrification – on the contrary. It's just that I would like to create a series of combustion engines that allow us, more or less, to achieve the target without it.

Mr. Fleiss, thank you very much for an interesting discussion.

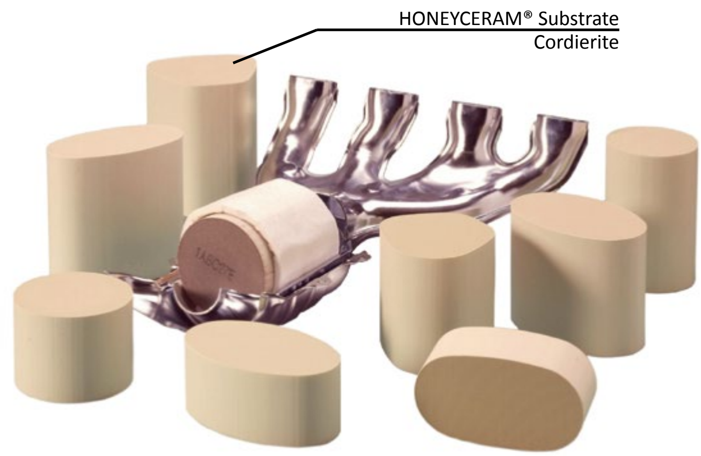
INTERVIEW: Angelina Hofacker

[Ceramic] in perfection

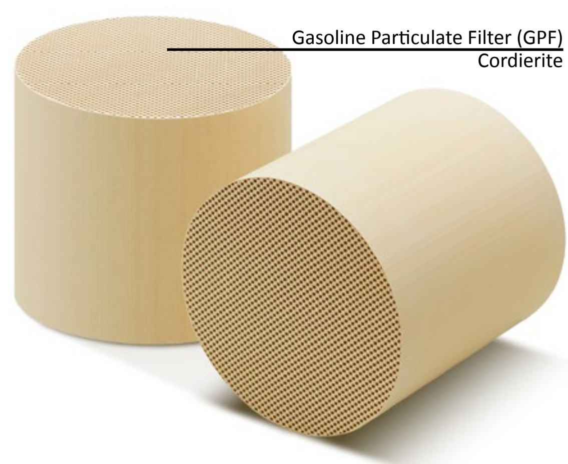


For almost 40 years NGK is developing ceramic products for effective exhaust aftertreatment in the automotive and commercial vehicle industry.

Catalytic Converter | Thin wall ceramic substrates are the basis of our HONEYCERAM® technology. They provide fast light-off, high conversion rates and low exhaust gas backpressure. Since their market introduction NGK has supplied over 1 billion substrates globally.



Particulate Filter | Ceramic particulate filters provide very high filtration efficiencies across the entire particle size distribution. Highly porous filters can be combined with an integrated catalyst such as an SCR coating for diesel engines. Since their commercialization approx. 10 years ago NGK has supplied more than 10 million diesel particulate filters. In 2014 NGK started the world's first serial application for gasoline particulate filters in Europe.



Sensor | The Smart NOx Sensor* complements lean burn combustion concepts by monitoring and regulating the catalysis and dosing logic of a DeNOx system. It detects exhaust gas components such as NOx, Lambda and NH_3 within ppm range. The Smart NOx Sensor was commercialized more than 10 years ago and has received several awards.

* The Smart NOx Sensor is a joint development by NGK INSULATORS, Ltd. (sensor probe) and Continental AG (control unit).

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The Efficient Gasoline Engines in the New Opel Astra K

Opel has re-developed the engine range for the new generation of the Astra. Compared to the predecessor model, the three- and four-cylinder engines have smaller displacements and are more compact. The engineers paid particular attention to fuel consumption at full load. For that reason, a moderate specific power output was chosen for the 1.0- and 1.4-l turbocharged engines.

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24 MILLION CARS IN THE COMPACT CLASS

Opel and the compact class – a success story that started as early as 1936 with the first Kadett and is now continuing in the eleventh generation with the new Astra. More than 24 million Kadetts and Astras have left the factory to date. The latest generation of the Astra is heralding a new era at Opel; it is taking a real quantum leap. Opel has literally developed this clean sheet design following three decisive premises: efficiency, networking and athleticism. It is based on an entirely new lightweight vehicle architecture, is only driven by the latest generation engines and enables state-of-the-art networking via Smartphone integration as well as the pioneering, personal online and service assistant, the Opel Onstar.

The new Astra is up to 200 kg lighter than its predecessor and its athletic design can be seen from the outside. Its proportions have been reduced, but the available interior space and the comfort have noticeably grown.

TARGETS AND DEVELOPMENT ASSIGNMENT

Just like the new Astra, all of the latest generation engines have been completely redeveloped, **FIGURE 1**. The same fundamental development goals applied to all engines, giving all of them the same genes:

– Maximum efficiency: Thanks to the low friction levels and excellent utilisation of fuel combined with rightsizing, our engines make a significant contribution towards the overall efficiency of the new Astra.
– Great response: High transient torque, even at low speeds, provides very good elasticity levels – and lots of driving pleasure.
– Perfect smooth running: The aim is to be top of the class in terms of comfort; over the whole range of engine displacement.

With their extensive experience in the area of small and medium-sized three- and four-cylinder gasoline engines, Opel and GM have been able to pursue very demanding goals for the family of engines in the new Opel Astra K. Completely new construction of the engine series was necessary for the relatively small engines to achieve the low fuel consumption and feel "big" while exceeding customer expectations. The engines built into the new Astra K are designed to surpass the similarly high-performance units from the predecessor model in every respect.

A specific focus was placed on the consumption of fuel at full load in order to meet the above-mentioned goals with a family of engines with a smaller engine displacement and smaller size in comparison with the predecessor model. A moderate specific torque output capacity of 170 and 175 Nm/l was therefore selected for the 1.0- and 1.4-l turbo engines, which was also referred to as rightsizing.

The prioritisation of the partially contrasting development targets does move around within the engine displacement, but great importance was attached to achieving an excellent acoustic characteristics and very good dynamics in the introductory engines.

ENGINE SMOOTHNESS

The entire knowledge of Opel's and GM's global development teams was used in the development of engines for the new Astra K, especially to deal with the traditionally challenging running characteristics of the three-cylinder engine. As a result, not only the three-cylinder engine has a "soundtrack" similar to that of a four-cylinder, but the three-cylinder and four-cylinder engines all have acoustic characteristics that actively support the Astra K's advertised "quantum leap".

Throughout the entire development process, avoiding and suppressing vibrations and unusual noises were the focus of development work with extensive simulation and tests on the individual components as well as on the full engine. Engine control and integration of the powertrain in the vehicle were also key elements in this process.

The engine architecture was acoustically designed so that noises have been minimised at the source both on the air and mechanical vibration paths, eliminating the high cost and time-consuming optimisation of the transfer paths of engine noises inside the vehicle at a later date. This such quietly designed engine not only allows greater freedom for integration in the engine compartement, but sound engineering also has fewer restrictions.

Not only the four-cylinder versions are within the best in their class as a result of this intensive focus on the acoustic characteristics, it must be particularly pointed out that the sound level of the three-cylinder engine is lower than many competitive four-cylinder units, **FIGURE 2**.

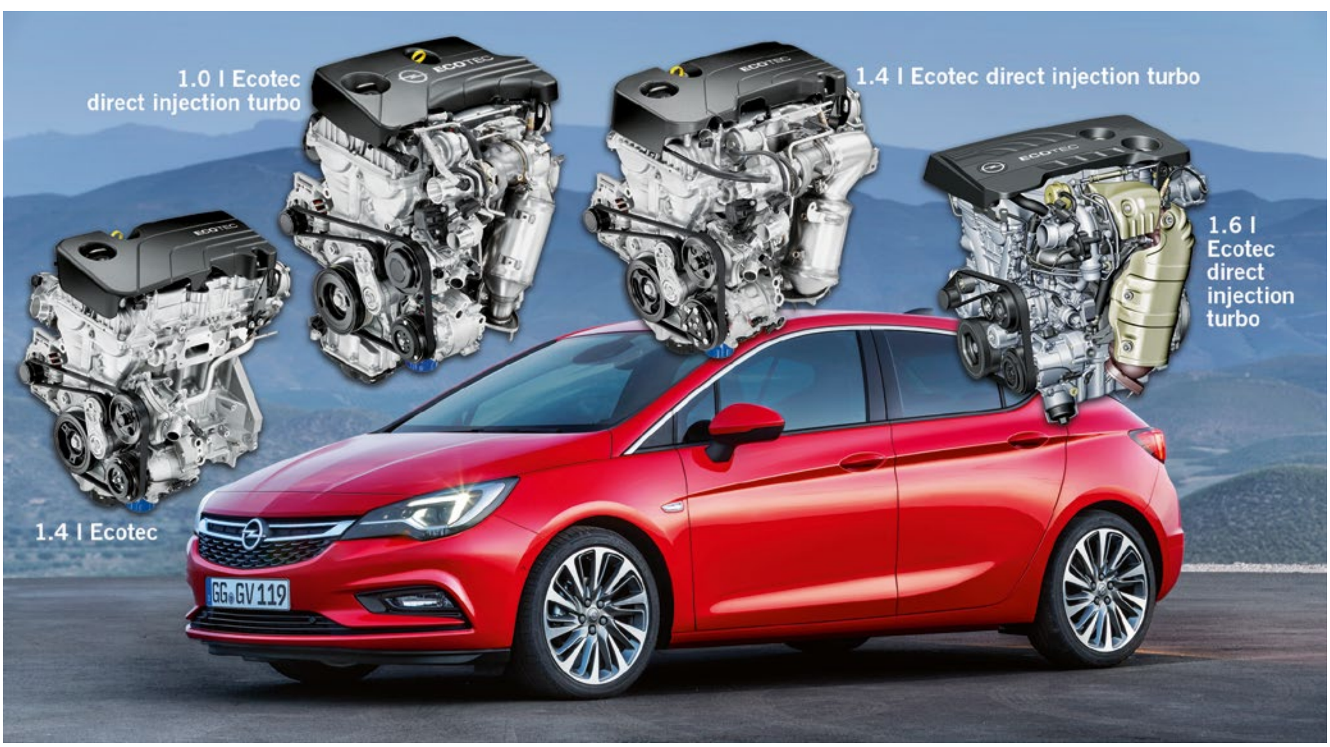

FIGURE 1 Gasoline engines in the new Opel Astra K (© Opel)

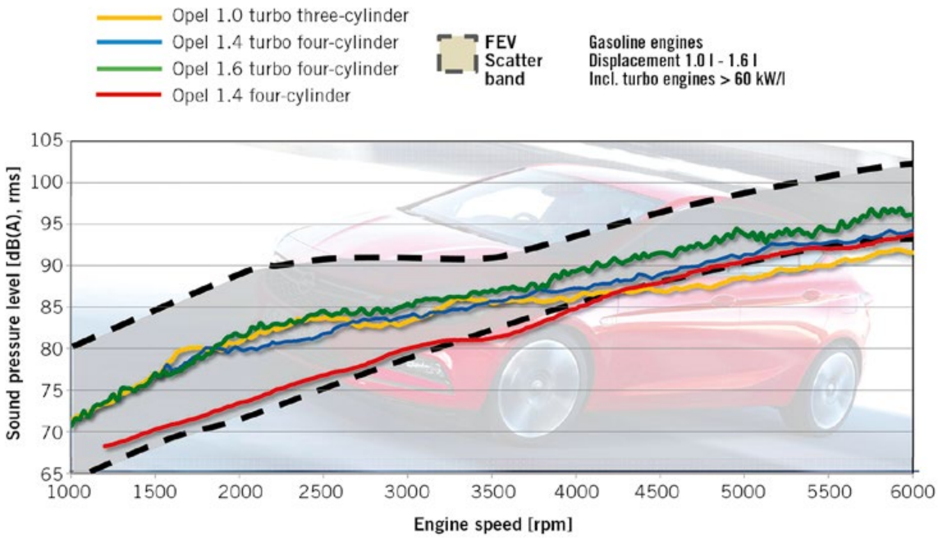

FIGURE 2 Smooth and quiet: the sound pressure level over gasoline engine speeds (© Opel)

Examples of some measures that have contributed towards these impressive acoustics characteristics in a formidable way include:

– The inverted tooth design of the timing chain is optimised for low sound radiation. The full architecture of the chain, tensioners and guides has been developed to guarantee low sound radiation and to eliminate perceivable, unusual noises while delivering low friction.
– acoustically decoupled high pressure fuel injection system
– very rigid base engine with bedplate and low sound radiation through optimisation of each component.

Excellent sound quality is achieved by major reduction of any irregular engine noises in combination with a low level of overall noises. This strategy allows technically simple and cost-effective vehicle integration.

With these engines in the new Astra K, the customer experiences a calm noise and vibration level as well as a precise sound quality, irrespective of the number of cylinders.

ENGINE DESIGN

The 1.0- and 1.4-l engines have an aluminium die-cast block, the 1.6-l engine with high specific performance has a cast iron block and all engines have an aluminium die-cast bedplate for a very rigid construction. Cylinder liners made of steel are cast into the aluminium blocks. The rough outer diameter of the liners ensures an excellent form fit between the block and liner. Warping is minimised by a corresponding heat treatment process. The liners are overmoulded on the top to ensure easy machining and function of the sealing surface to the cylinder head. In order to be able to transfer the high specific output of turbo engines, a forged crankshaft is used with six counterweights in the three-cylinder engines and eight in the four-cylinder engines to achieve endurance as well as excellent noise and vibration characteristics. The base engine components of the three- and four-cylinder engines are illustrated in **FIGURE 3**.

The combination of the forged crankshaft and low bearing clearance provides excellent acoustic characteristics over a wide range of engine operating temperatures and conditions. The new 1.4-l naturally aspirated engine with its comparatively low combustion pressures is equipped with a casted crankshaft with four counterweights. To optimise the mass even further, the crankshaft is hollow cast in the areas of the main and connection rod bearings.

The top of the piston was designed on the basis of CFD analyses as part of the combustion development. Numerous finite element analysis (FEA) simulations were carried out to guarantee durability. As a result, the piston construction has been optimised in relation to the thermal expansion of the cylinder block and to ensure the stability of the piston system.

Piston oil squirters on all engines in the Astra point their cooling jets onto the underside of the piston to ensure lubrication at high loads and to reduce noise emissions for cold start. The piston ring package is optimised with respect to friction, durability and efficiency. The top piston ring has a low friction surface

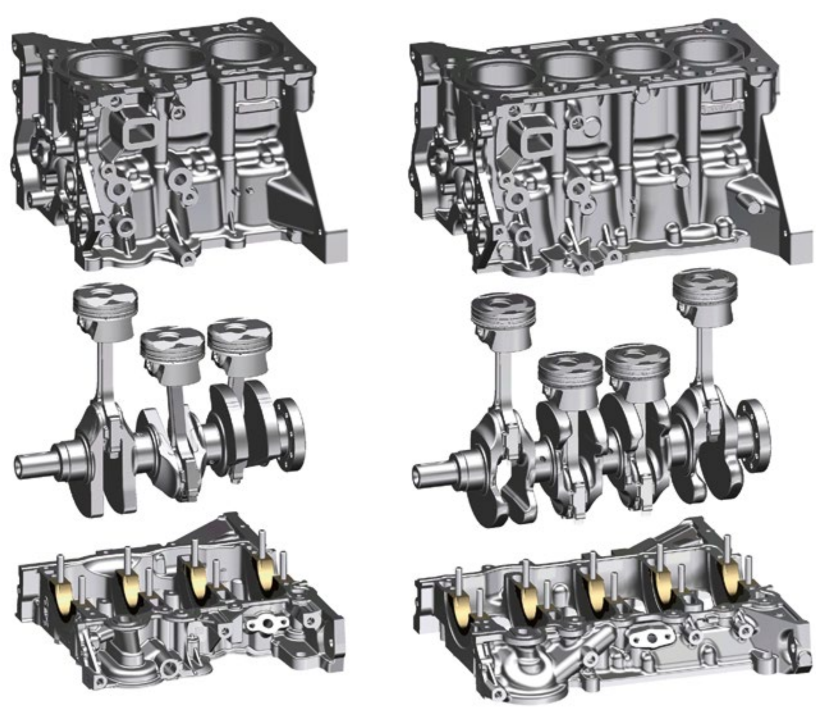

FIGURE 3 Aluminium die-cast block with bedplate (© Opel)

with excellent resistance to abrasion and therefore minimises wear on both the ring and the cylinder bore. Sintered connecting rods offer at least equivalent strength properties to standard forged parts, but reduce both the machining work and the weight variation with the much more accurate sintering method.

A water-cooled exhaust manifold as illustrated in **FIGURE 4** is used in the cylinder heads of all engines up to and including 1.4-l engine displacement. This reduces the heat-up time of the catalytic converter close to the engine and reduces the maximum temperature on the turbocharger. An external exhaust manifold is used on the 1.6-l turbo engine to give the vehicle‘s cooling system a logical size.

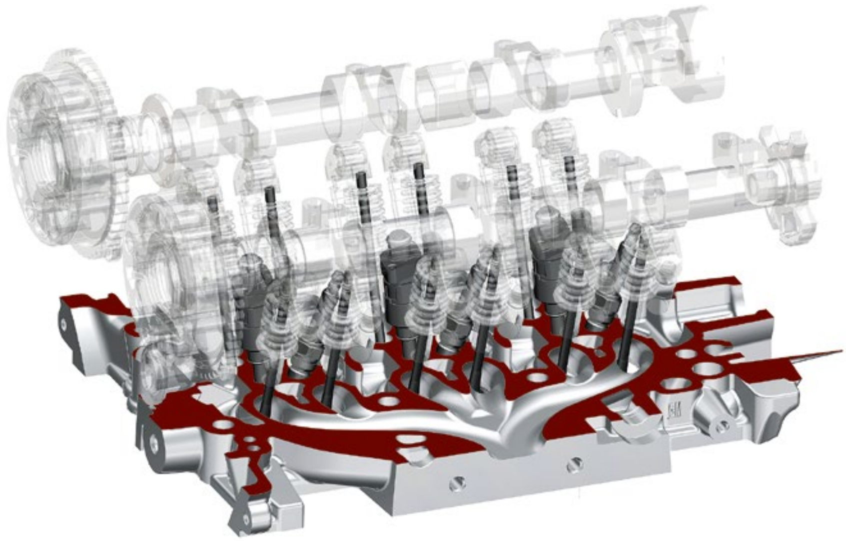

FIGURE 4 Cylinder head with roller cam follower valve train and integrated exhaust manifold (© Opel)

All turbo engines are equipped with a 200 bar direct injection system with centrally positioned injection nozzles. The high pressure fuel pump for direct injectors is attached to the cylinder head and driven by specific cams at the end of the inlet camshaft. The exhaust camshaft drives a mechanical vacuum pump.

The valve train is operated by low friction, hydraulic roller cam followers and driven by a timing chain with hydraulic tensioner. The chain is optimised for low noise development with the use of a low friction inverted tooth design. The entire architecture of the chain, tooth design, chain tension and chain guides lead to a low overall acoustic radiation and eliminate all perceivable irregular noises. Two independent camshaft adjusters provide optimum timings for all driving conditions with all engines, which achieves the best possible fuel consumption, acoustics, performance and exhaust emissions with an adjustment range of 60 to 65°.

In order to improve the fuel consumption and engine performance of all models even further, the oil is circulated through an oil pump with variable displacement using an integrated, electronically controlled valve. This valve cont-

Engine	1.4 Ecotec	1.0 Ecotec turbo	1.4 Ecotec turbo (125 hp)	1.4 Ecotec turbo (150 hp)	1.6 Ecotec turbo
Engine type	R4, naturally aspirated	R3, turbo	L4, turbo	L4, turbo	L4, turbo
Mixture formation	Port fuel injection	Central direct injection	Central direct injection	Central direct injection	Central direct injection
Displacement [cm³]	1399	999	1399	1399	1598
Bore × stroke [mm]	74 × 81.3	74 × 77.4	74 × 81.3	74 × 81.3	79 × 81.5
Cylinder distance [mm]	81	81	81	81	86
Compression ration	10,6:1	10,5:1	10,0:1	10,0:1	9,5:1
Peak power at engine speed [kW at rpm]	74 at 6200	77 at 5000	92 at 4000-5600	110 at 5000-5600	147 at 4700-5500
Peak torque at engine speed [Nm at rpm]	128 at 4400	170 at 1800-4250	245 at 2000-3500	245 at 2000-3500	300 at 1750-4700
Specific torque [Nm/l]	91	170	175	175	175
Camphasing intake/exhaust [°CA]	65/65	65/65	65/65	65/65	60/60
Valve actuation	Roller finger follower	Roller finger follower	Roller finger follower	Roller finger follower	Roller finger follower
Timing drive	Chain	Chain	Chain	Chain	Chain
Cylinder block	Aluminium	Aluminium	Aluminium	Aluminium	Cast iron
Crankshaft	Cast iron	Forged	Forged	Forged	Forged
Fuel specification	RON 91-98	RON 91-98	RON 91-98	RON 91-98	RON 91-98
Emission class	Euro 6	Euro 6	Euro 6	Euro 6	Euro 6
CO_2 in NEDC Opel Astra 5-doors [g/km]	124	99	114	114	139

TABLE 1 Technical data of gasoline engines in the new Opel Astra (© Opel)

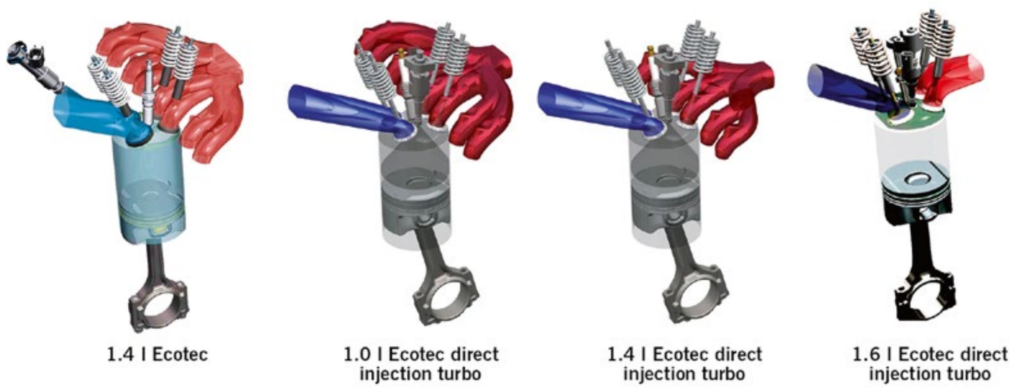

FIGURE 5 Combustion chambers, injection and channels of the individual gasoline engines (© Opel)

rols two oil pressure levels to also activate the piston cooling jets and to reduce friction at low engine speeds.

The data for the various gasoline engines in the Opel Astra K are shown in **TABLE 1**. The bore and bore spacing are only selected larger on the 1.6-l turbo engine; the 1.0- and 1.4-l models have the same bore spacing of 81 mm with a 74 mm bore. The various engine displacements are set using the various strokes of the crankshaft.

COMBUSTION PROCESS AND MIXTURE CONTROL

Optimum mixture control in the turbo engines with small bores is achieved by the central position of the high pressure fuel injector, **FIGURE 5**. The six-hole injection nozzles achieve a precise fuel jet with low space requirements. Mixture control has been developed with intensive use of computational fluid dynamics (CFD) analyses and optical engines. The maximum fuel pressure is 200 bar. The optimisation of the acoustic behaviour was an important development aspect in optimised mixture control. To achieve low sound radiation with the engine running, the construction was designed to avoid all direct contact between the cylinder head and injection system. A shock absorber system consisting of rubber elements and teflon seals filled with carbon fully decouple the unavoidable vibrations in the fuel system from the rest of the engine.

Alongside injector cabling, the wiring harness assembly includes the cable tree and the fuel pressure sensor and therefore considerably facilitates handling in the engine plant as a complete component. This single part construction allows numerous tests on the sub-system in the engine plant before assembly, for example leak tests.

TURBOCHARGING

To ensure that the Astra is fun to drive, the direct injection versions of engine families with 1.0-, 1.4- and 1.6-l engine displacement are turbocharged. This delivers excellent torque availability, power, handling and superior acoustics. These demanding performance targets are provided by a turbocharger with tested, robust and efficient technology. The focus of the design was on quick torque buildup and high efficiency. The design is a single-stage turbocharger with pressure actuated bypass valve. Moderate exhaust temperatures from the exhaust manifold integrated in the cylinder head also allow the use of cost-effective materials for the turbine wheel and housing. However, the temperature capacity of these components has been fully used to optimise the consumption of fuel under high load operating conditions. The turbochargers for the three turbo engines are illustrated in **FIGURE 6**.

With extensive simulation work, it was possible to reduce the number of hardware development loops to a minimum while still deriving a great pairing of the turbo design to the engine. For example, the selected turbochargers allow excellent response, giving 90 % of the maximum torque in just 1.5 s for the three-cylinder turbo engine. An optimised flow contour on the bypass system was developed to prevent unwanted noise phenomena during rapid throttle closing manoeuvres.

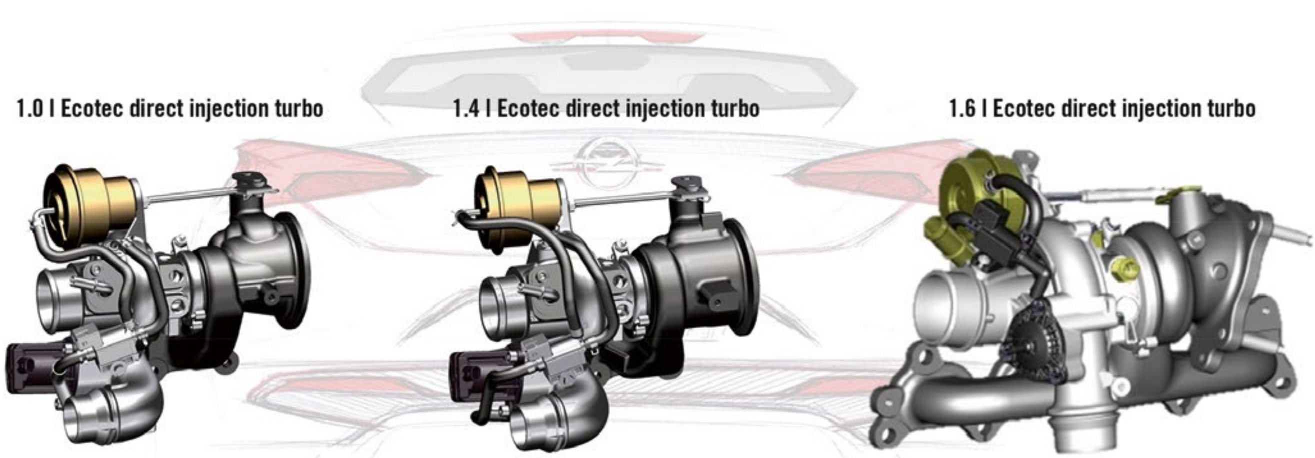

FIGURE 6 The gasoline engine turbo charger in the new Astra (© Opel)

PERFORMANCE AND FUEL CONSUMPTION

The gasoline engines in the new Opel Astra K are precisely chosen for use in this low driving resistance vehicle. With any choice, the customer receives a good price-performance ratio in procurement and excellent fuel consumption. There are also sporty engines in several grades. The 1.0-l turbo engine with manual gearbox in the Astra five-door and Sports Tourer only emits 99 g CO_2/km in European driving cycles, and even just 96 g when combined with the Easytronic 3.0. The 1.6-l turbo engine awaits with a magnificent 147 kW and excellent smooth running. Driving pleasure is, however, guaranteed with any one of these units.

The engines were developed in several repeat tests, starting with simulation. In the second step, the most promising designs were manufactured and operated as a single-cylinder engine to verify the assumptions from the simulation phase and allow conclusions to be integrated in the model. The huge advantage of single-cylinder engines in development is that only a few parameters, such as the bore, stroke, combustion chamber and cams need to be adapted. The lead times for repeat loops are shorter and the costs are lower in comparison with multiple-cylinder engines. In the last step, the final work is carried out with the three- and four-cylinder engines in the corresponding building phases of the development programs. These build stages are used to examine the reciprocal impacts of gas impulses and resonance in the different cylinders on the inlet and outlet side, evaluate the influence of the actual temperatures of pistons, liners and the combustion chamber and ultimately confirm the engine friction.

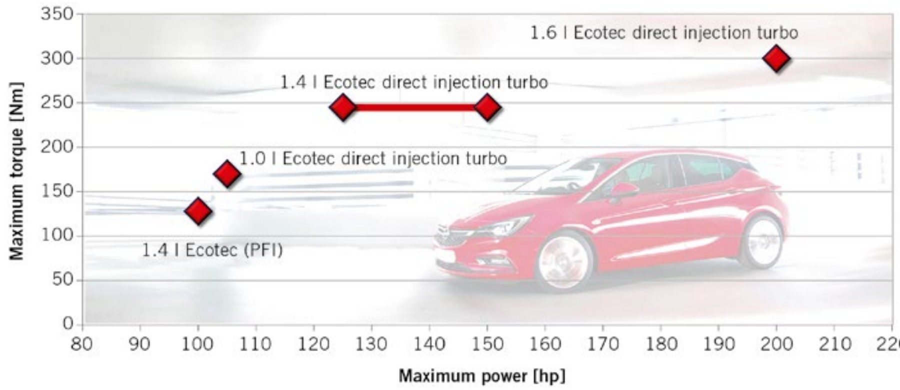

FIGURE 7 Good performance grading of gasoline engines in the new Astra (© Opel)

FIGURE 7 shows the performance and torque ratings of the different Opel Astra K engines. As previously described, this results in narrow gradings for the customer to choose from.

MAXIMUM EFFICIENCY

FIGURE 8 shows the normalised, specific fuel consumption in comparison of the FEV scatter band in the operating point at 2000 rpm and 2 bar brake mean effective pressure (BMEP). The new engines in the Opel Astra K display excellent ratings without exception.

"FLEX PLANT" ENGINE FACTORY

The entire engine family for the new Opel Astra K is produced in Szentgotthard, Hungary. This is supported by the innovative "Opel Flex Plant" concept, which allows us to build different gasoline and diesel engines on the same processing and assembly line. This strategy gives Opel the flexibility to react quickly and simply to changing market conditions. The gasoline and diesel engines are optimised in weight, efficiency and costs.

OUTLOOK

The new Opel Astra achieves excellent ratings with this new portfolio of engines. But the engineers are already working on more engine models and the next generations of engines. The speed at which Opel is developing new vehicles and drives and introducing them to the market will not slow down.

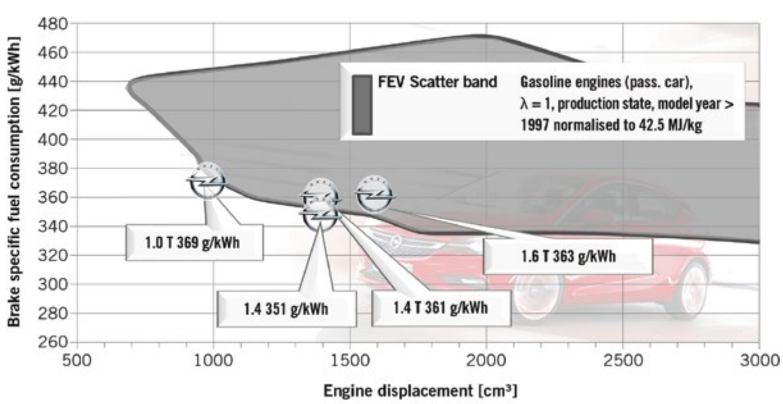

FIGURE 8 Fuel consumption of gasoline engines in the standard point 2000 rpm and 2 bar BMEP (© Opel)

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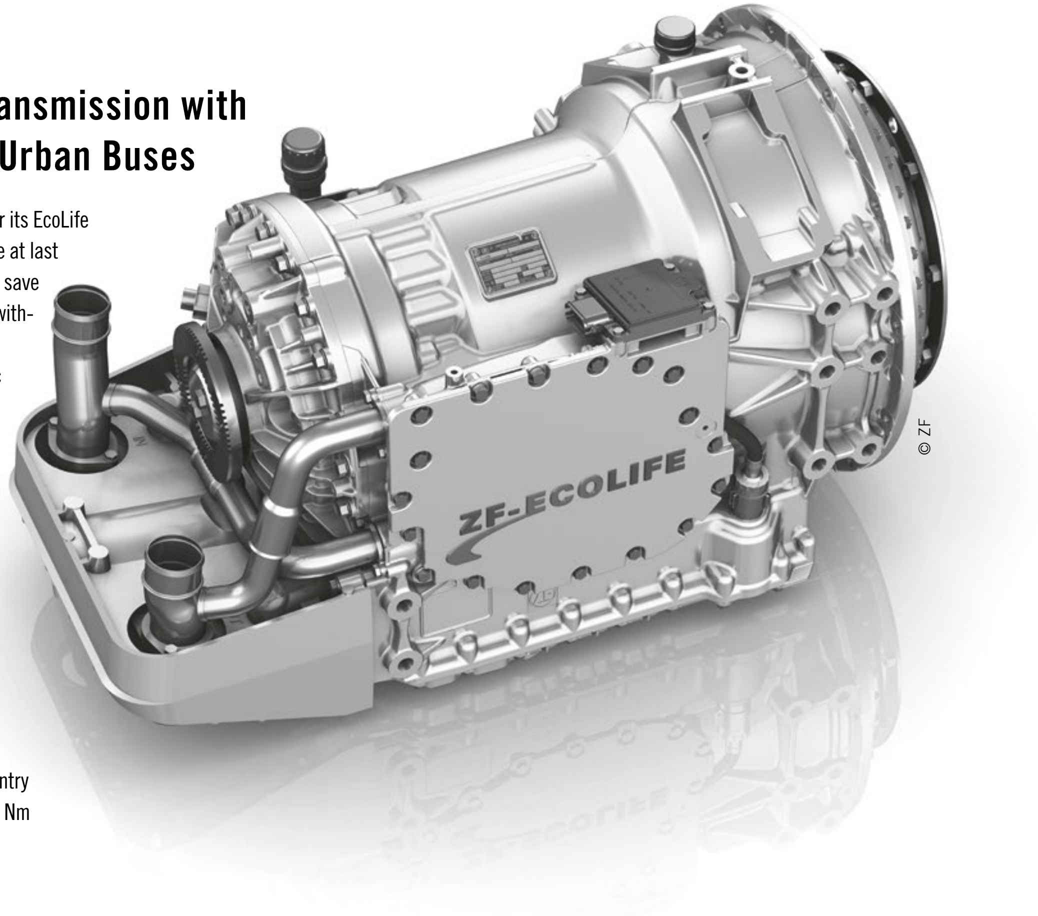
ZF | **Automatic Transmission with Start-stop Function for Urban Buses**



© ZF

ZF presented the innovative start-stop function for its EcoLife six-speed automatic transmission for the first time at last year's Busworld trade fair in Kortrijk. The aim is to save fuel in conventional diesel-powered urban buses without an additional electric motor in the powertrain. By further refining its six-speed EcoLife automatic transmission, ZF intends to meet the growing calls for efficient, low-noise and low-emission mobility in public transport. The company claims that the additional function reduces fuel consumption in urban operation by 10 %. It was possible to integrate the necessary design modifications, such as an enhanced converter and the converter clutch, into the current series transmission. Eliminating the need for an additional electrical machine helps reduce the installation effort and costs. Another new product is the transmission variant EcoLife Coach, which is now offered for cross-country buses and long-distance coaches with up to 2300 Nm input torque.

Toyota | **3.0 l/100 km Sufficient for Full-hybrid Prius**

Following its September debut at the IAA in Frankfurt 2015, Toyota is now revealing further technical details of the Prius. According to the company, the fourth generation of the full-hybrid vehicle is said to consume 3.0 l/100 km in the combined cycle (provisional figures). Accordingly, CO_2 emissions are around 70 g/km of CO_2. By way of comparison, its predecessor required 3.9 l of fuel, producing 89 g/km of CO_2. The new Prius accelerates from 0 to 100 km/h in 10.6 s and from 80 to 120 km/h in 8.3 s. It has a top speed of 180 km/h. The new hybrid system delivers a total output of 90 kW (122 hp). Toyota reports that the hybrid system of the new Prius has been extensively re-engineered to boost efficiency. In addition, a particularly aerodynamic body design has been developed. A low centre of gravity and slim lines contribute to a sharp-edged design that, together with changes to the underbody, results in a drag coefficient (C_d) of 0.24. Toyota has also improved the vehicle dynamics, handling and response characteristics.

© Toyota

University of Rostock | **Gas Engine for Tractors**

Researchers at the Faculty of Mechanical Engineering and Marine Technology at the University of Rostock have teamed up with specialists from Deutz and converted a series diesel engine to run on the principles of a gasoline engine. The modified engine has passed all test-bed testing. The University's aim in developing the gas engine for agricultural tractors is to raise emission protection for alternative drive concepts for use in agriculture to a new level. The engine is based on a water-cooled four-cylinder in-line diesel engine from the Deutz TCD 3.6 series range that generates 83 kW of power from a capacity of 3.6 l, and which has been converted in a number of ways to run on natural gas or biomethane. The detailed changes included replacing the diesel injectors with ignition plugs, lowering the compression ratio, installing a natural gas feed system and adapting various engine components and ancillary units such as the turbocharger to the changed operating conditions. Previous systems for exhaust aftertreatment such as the oxidation catalytic converter and SCR could be dispensed with and were replaced by a three-way catalytic converter. The decisive factors were analysing and mastering the combustion process in the gas engine.

© University of Rostock


© Audi

Audi | **Software Update Diesel Engine**

Audi has admitted to the US authorities EPA and CARB that it used inadequately declared software in its 3.0-l V6 TDI diesel engines. It involves three of the so-called AECDs (auxiliary emission control devices), one of which is considered to be a "defeat device" under current US legislation. Audi will update parameters in the software installed in the 3.0-l V6 TDI diesel engines, document them and resubmit them to the USA for approval, according to an announcement made by Audi on 23 November, 2015. The updated software will be installed as soon as approved by the authorities. It affects the three brands of Audi, Porsche and Volkswagen. Audi estimates this will incur costs of several tens of millions.


© KIT

KIT | **Hydrogen from Methane**

The Institute for Advanced Sustainability Studies (IASS) and the Karlsruhe Institute of Technology (KIT) have developed a reactor that generates hydrogen from methane without emitting any CO_2. Following two years of research, it has now been possible to prove the basic feasibility of the process to generate hydrogen from methane in an environmentally compatible and efficient manner. KIT claims that the reliable and continuous operation of the test reactor has demonstrated the future potential of this technology. The reactor produced hydrogen at a conversion rate of up to 78 %.


© Federal Mogul

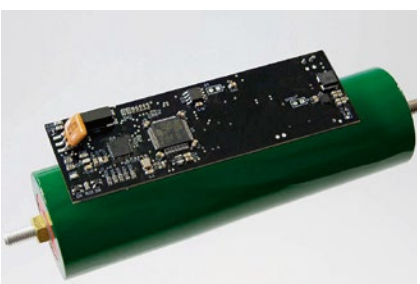
Federal-Mogul | **Improved Sealing**

Federal-Mogul Powertrain has developed a new manufacturing process to improve the sealing of turbocharger outlets. The company is focusing on adapting the design of the component and using a new welding technique to enable a permanent connection between the various sealing flange materials for the turbocharger outlet. Gaskets for turbocharger outlets generally comprise a spacing layer coated with aluminium to protect it from corrosion and to reflect heat away. In addition, so-called functional layers made from spring steel and featuring an integrated sealing bead are fitted to both sides of the spacing layer. These three layers are then welded together to merge them into a single component.

KIA | **Compact SUV Niro with Hybrid Drive**

© Kia

Kia Motors is expanding its range with a compact SUV in the form of the Niro, which the carmaker terms a hybrid utility vehicle (HUV) and which represents a new concept for the Korean brand. For the first time the Koreans have developed a platform for the Niro specially tailored to eco-vehicles. The Kia Niro will be produced in Hwasung, Korea, where the first models for international markets will roll off the assembly line in mid-2016. The powertrain of the Kia Niro includes a 1.6-l gasoline engine with direct fuel injection (GDI) from the Kappa series that delivers 77 kW of power and 147 Nm of torque, a 32 kW electric motor as well as a lithium polymer battery with a capacity of 1.56 kWh. The combined power of the system is transmitted to the wheels by a six-step direct clutch transmission system (DCT). The carmaker explains that the platform on which the compact SUV is based is specially designed for this next-generation gasoline-electric hybrid powertrain. Kia is planning to extend the range of Niro models at a later date to include a plug-in hybrid version.



© Fraunhofer IPA

Fraunhofer IPA | **Intelligent Battery Cell**

Fraunhofer researchers have developed a power storage medium that claims to outperform previous models in terms of cost-effectiveness over the entire life cycle. A microcontroller in the battery cell records physical parameters such as temperature and charge level. If a cell is empty, it is automatically deactivated. To date, electric car batteries comprised a monolithic block accommodating the individual battery cells and the necessary technology. In theory, the individual battery cells can all store the same amount of energy, but the reality is somewhat different, given variation in capacity due to the manufacturing process.

© KIT

KIT | **Steels for More Efficient Engines**

Scientists at the Karlsruhe Institute of Technology (KIT) have developed a new process for hardening steel. They enrich low-alloyed steels with carbon and nitrogen using methylamine. Steels hardened in this way are suitable for highly stressed parts in energy-efficient and low-emission engines. Engine developers increasingly have to push the boundaries of established materials technology in response to combustion engine downsizing and other methods targeting improved fuel efficiency and emissions characteristics. Ever-increasing injection pressures require qualities of steel to produce injectors resembling those of ball bearing steel to withstand the mechanical and thermal stresses that develop.

© ITI

ITI | **Modelling Software**

ITI has launched version 3.7 of its SimulationX CAE software. The new release of the modelling software comes with twelve new libraries for gearbox, chain drive and battery simulation and provides a connection to the Modelica FMI 2.0 interface standard. SimulationX was invented in 2002 and has served ever since as CAE software to simulate physical-technical systems. It has its origins in control engineering. The code runs on MS Windows computers. Early applications focused on investigating vibration of torsional irregularities in powertrains.

Lexus | **5.0-l V8 Naturally Aspirated Engine with 351 kW**

The Lexus GS F is the fourth model of the Lexus F range and features a new 5.0-l V8 naturally aspirated engine. When driven carefully, the eight cylinder engine runs on the economical Atkinson cycle; when higher performance is required, the engine returns to the normal combustion process of a gasoline engine. To minimise oscillating mass, the engine works with high-tensile forged connecting rods and lightweight titanium valves on the inlet and outlet sides. The twin cylinder rows, with a total of 32 valves, are intended to ensure the V8 has sufficient air to breathe. In addition, the low-friction valve gear design and optimised cam profile are designed to enhance performance. The extended adjustment range of the VVT-iE (variable valve timing-intelligent electric motor) and the optimised aspiration and exhaust system are intended to help the engine develop power of 351 kW at 7100 rpm and deliver maximum torque of 530 Nm at between 4800 and 5600 rpm. The Lexus D-4S direct injection system injects fuel into the combustion chambers at high pressure, enabling a compression ratio of 12.3:1.

© Lexus

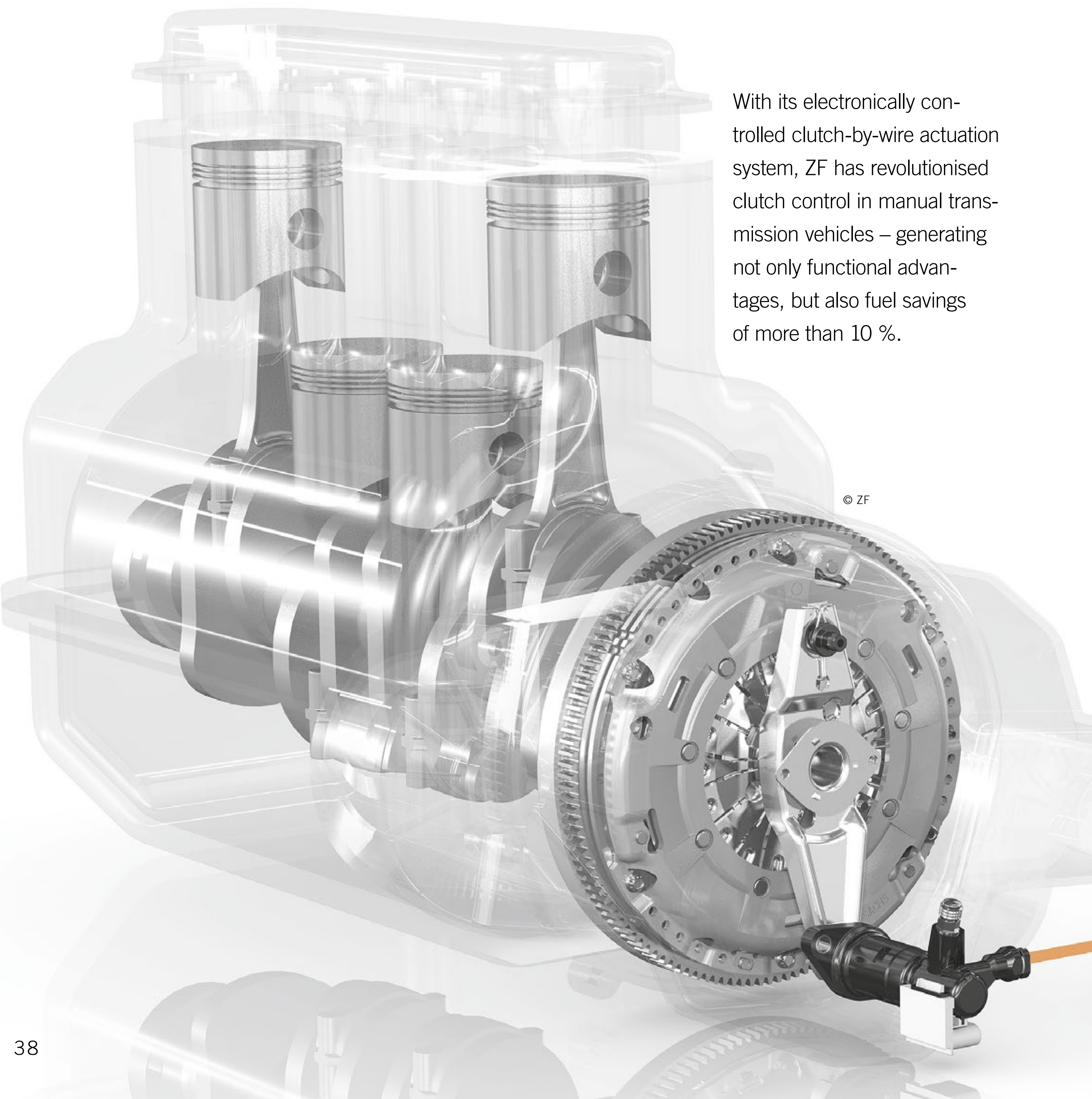
Volkswagen | **Engines for the Beetle Buggy**

Volkswagen presented the new Beetle Dune at the Los Angeles Auto Show 2015. In Germany, Volkswagen will be offering the crossover with a choice of three turbocharged gasoline engines and two turbocharged diesel engines. In terms of output, the gasoline engines will deliver 77, 110 and 162 kW and the diesel engines 81 and 110 kW respectively. The Dune, intended to evoke the legendary dune buggies of the 1960s and 70s, includes many off-road features, 18-inch wheels, a wider body and greater ground clearance. The Beetle Dune is making its debut as both a coupé and a convertible. For its launch in the USA, the car will exclusively be fitted with a turbocharged gasoline engine with 125 kW.

© Volkswagen

"By Wire" Boosts Efficiency in the Clutch System

With its electronically controlled clutch-by-wire actuation system, ZF has revolutionised clutch control in manual transmission vehicles – generating not only functional advantages, but also fuel savings of more than 10 %.



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BUSINESS AND TECHNICAL ENVIRONMENT

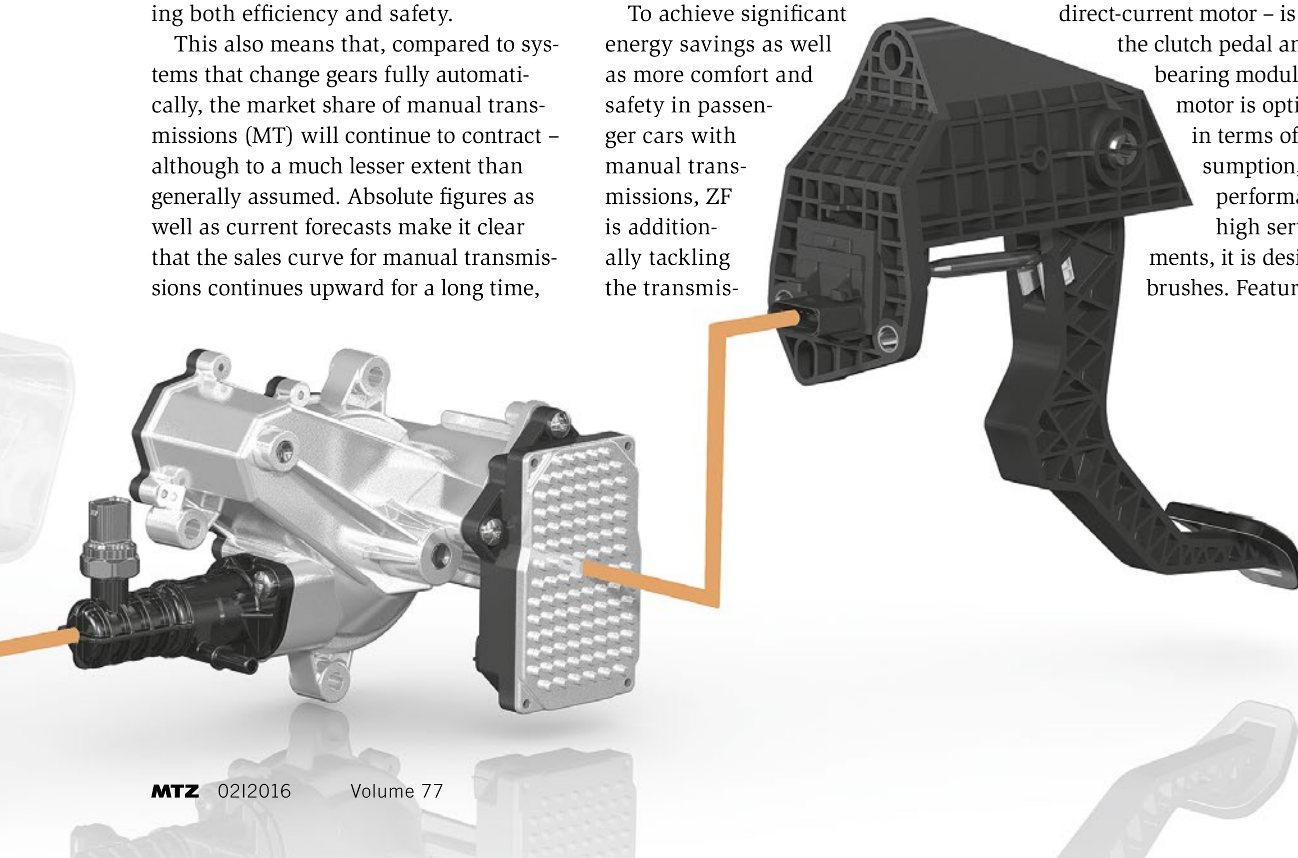
Car drivers in different market regions around the globe favour different transmission systems. Nevertheless, a general trend is identifiable: steady growth in demand for automatic variants in the form of automatic transmissions – whether as planetary gear systems (AT), dual-clutch applications (DCT), or continuously variable transmissions (CVT) – and automated manual transmissions (AMT). Vehicle manufacturers are relying increasingly on these technologies because they are essential for the ever more advanced electronic assistance functions, leading to future autonomous driving solutions, as well as for increasing both efficiency and safety.

This also means that, compared to systems that change gears fully automatically, the market share of manual transmissions (MT) will continue to contract – although to a much lesser extent than generally assumed. Absolute figures as well as current forecasts make it clear that the sales curve for manual transmissions continues upward for a long time, **FIGURE 1**. This applies particularly to the globally growing vehicle segments of mid-size and smaller cars as well as to emerging markets, where price is a decisive factor in the choice of vehicle. Against this backdrop, it is necessary not only to develop automation and electrification, but also to continue to identify new efficiency potentials in conventional combustion-engine drivelines. And corresponding technical innovations are required to exploit these potentials. This is becoming ever more relevant as emission and fuel consumption regulations for all vehicles continue to be tightened worldwide. What is more, in some places these regulations may be introduced more quickly and strictly than previously planned.

To achieve significant energy savings as well as more comfort and safety in passenger cars with manual transmissions, ZF is additionally tackling the transmission periphery, or more precisely the clutch actuation system. That has led to the current clutch-by-wire (CBW) development project. For the first time, it makes important functions that were previously reserved for AT and AMT, such as sailing with the combustion engine on or off, also possible for MT.

STRUCTURE AND FUNCTIONING OF THE CBW SYSTEM

The automated CBW clutch actuation system provides scope for more functions. Eliminated without replacement are all mechanical links from the clutch to the clutch pedal – whether realised in the past by hydraulic systems or bowden cables. Instead, a special CBW actuator – with a direct-current motor – is installed between the clutch pedal and the release bearing module, **FIGURE 2**. This motor is optimally balanced in terms of current consumption, dynamics, and performance. To meet high service-life requirements, it is designed without brushes. Featuring a power of



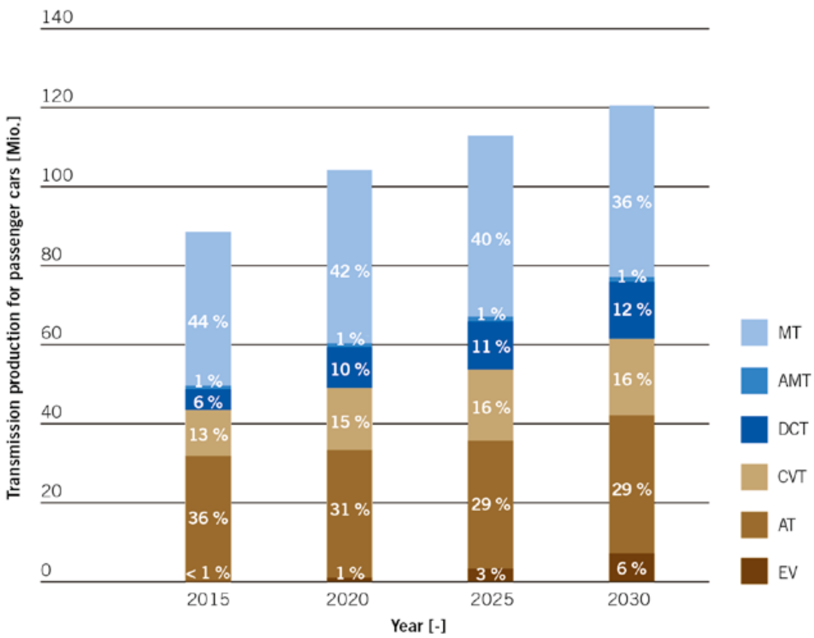


FIGURE 1 Global driveline trends (© ZF)

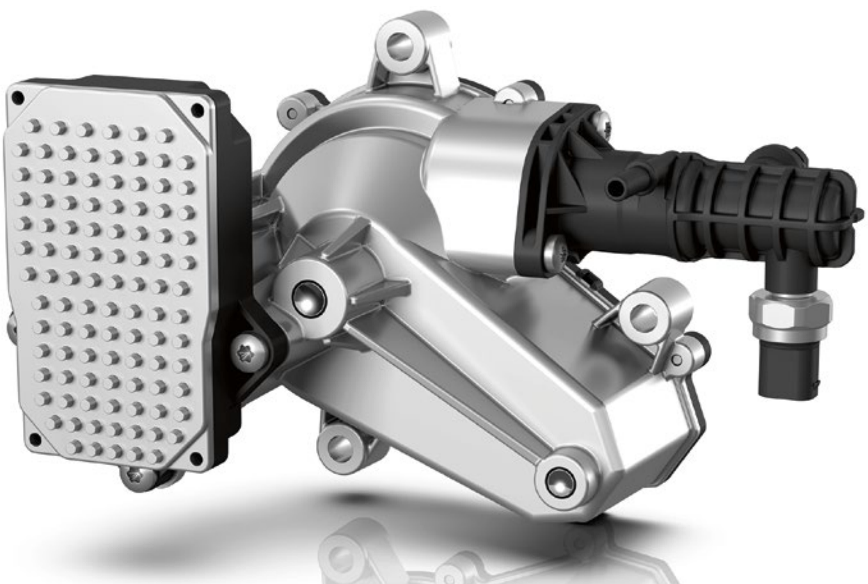


FIGURE 2 Electrohydraulic CBW actuator inclusive master cylinder for hydraulic applications, EC engine, and clutch control unit (© ZF)

some 0.1 kW, aligned mechanics, and an accumulator spring, this unit engages and disengages the clutch – if required, completely independently of the driver's left foot. Furthermore, its performance characteristics make the actuator suitable for clutches that must apply a high downforce due to more powerful combustion units, in other words clutches that require a very high releasing force. Another component is the integrated ZF CCU (clutch control unit) which controls the system depending on the clutch pedal position

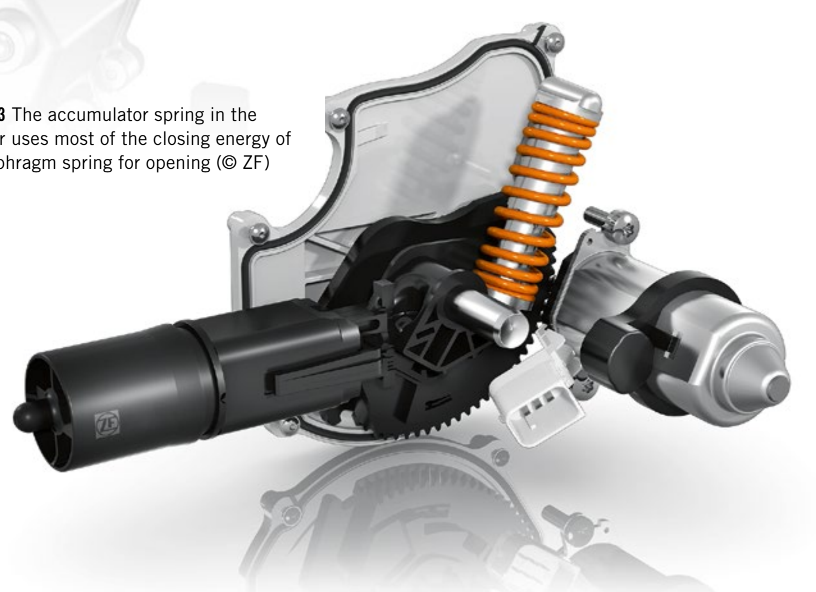


FIGURE 3 The accumulator spring in the actuator uses most of the closing energy of the diaphragm spring for opening (© ZF)

and the vehicle signals. It is linked to other ECUs such as the engine control.

The CBW team drew on AMT know-how already available at ZF for development of both the software – particularly for the clutch control – and the actuator elements. This expertise is already implemented in a whole number of volume applications in passenger cars since 1994. That is why the CBW actuator meets the daily requirements of even sporty drivers: Depending on the pedal operation, it can open the clutch in less than 100 ms – measured from the fully closed state to the touchpoint. At the same time, CBW from ZF combines high mechanical efficiency with low electricity consumption, also in absolute terms. The electric power consumption in operation is on average 4 A, depending on the clutch release force, **FIGURE 3**. This is due to the accumulator spring in the actuator which uses most of the closing energy of the diaphragm spring for opening. Furthermore, the individual system components are contained in a space-optimised unit. As a result, the CBW from ZF can be integrated into almost all common manual-control drive concepts relatively easily and cost-efficiently. This design also ensures that vehicle manufacturers can combine the CBW comparatively easily with volume-produced transmissions already in use. That is a major requirement for broad market acceptance and application of the electronic clutch system.

Overall, the CBW technology concept from ZF is designed with this aspect in mind. The starting point were vehicle manufacturer applications in which the gear shifting operation takes place exactly as before. One reason for this is

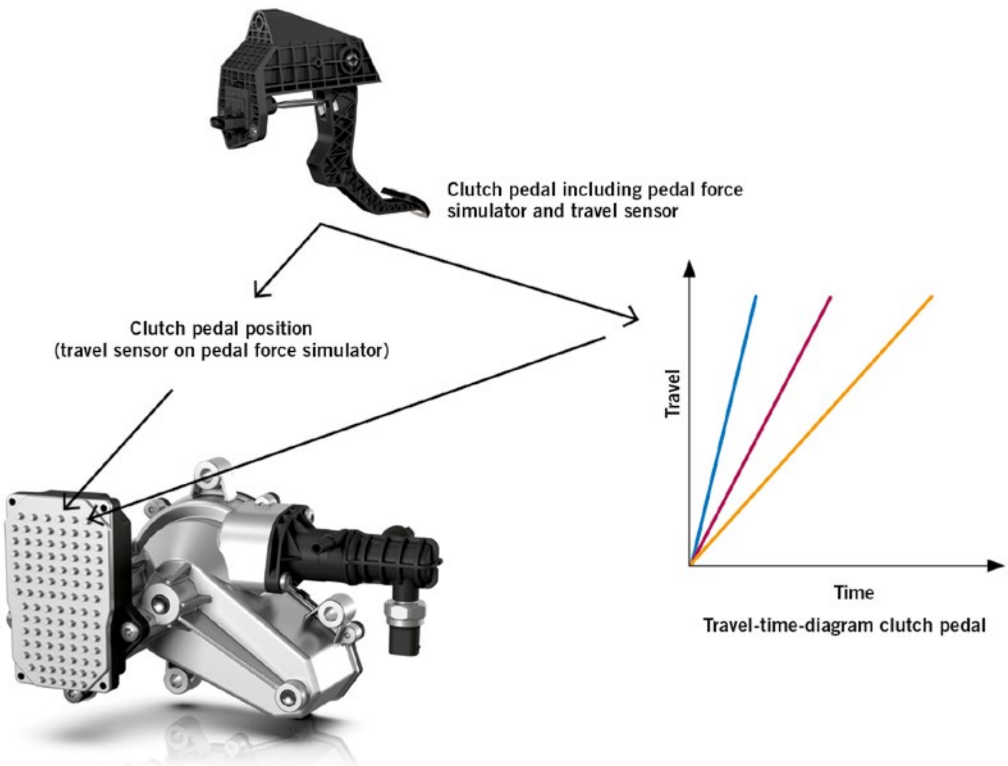


FIGURE 4 Information transferred by the clutch pedal to the CCU, schematical (© ZF)

customer acceptance, because drivers operate the shift lever and the clutch pedal in the familiar way. To achieve this, CBW requires a sensor system that measures continuous parameters such as actuation speed and position, **FIGURE 4**.

The current concept also features a newly developed mechanical pedal force simulator including a travel sensor. This simulator flexibly determines or simulates the pedal curve for each model and engine variant – irrespective of the actual clutch type and size, because there is no mechanical connection to the clutch, **FIGURE 5**. Consequently, with a CBW application, the clutch pedal can in the future be actuated more easily, for instance in sports cars. That means a comfortable force application of 80 N instead of the typical 160 N required today, depending on the release force. The basic characteristics (for example drop-off) remain unchanged without any limitations. Once it has been set, the pedal feedback does not change over the vehicle lifetime, because the force increase required due to lining wear is no longer transferred to the clutch pedal.

MORE FUNCTIONS FOR MANUAL TRANSMISSIONS

Most significant among the new efficiency, comfort, and safety advantages offered by CBW for manual transmissions is the first MT sailing function. This is because, as the CBW actuator automatically uncouples the engine from the driveline in all appropriate driving situations, fuel consumption and CO_2 emissions drop more than 10 %, **FIGURE 6**. And the driver does not even notice the clutch operation. With 11 %

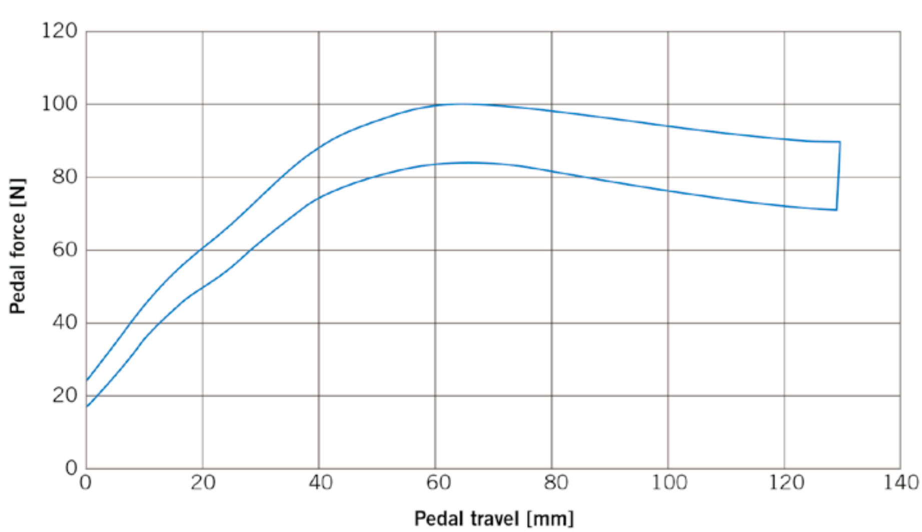


FIGURE 5 Pedal curve of a clutch-by-wire application with a pedal force simulator for a diesel application with a maximum torque of 450 Nm (© ZF)

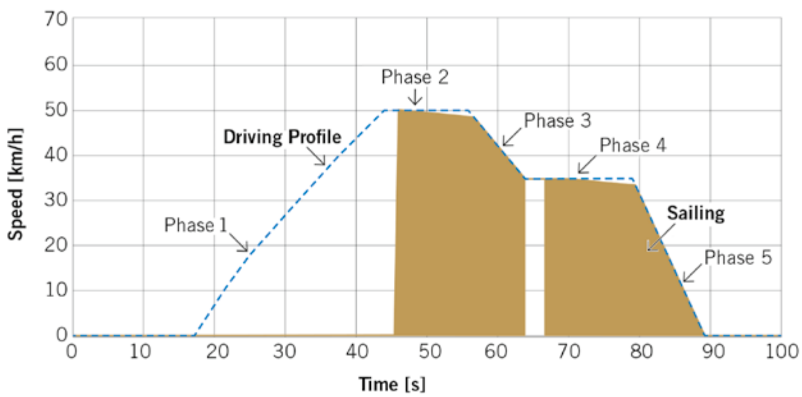


FIGURE 6 Schematic illustration of a driving profile in connection with sailing periods (© ZF)

of savings potential measured during tests with a CBW prototype, expectations were exceeded. The test involved a representative route profile (mixed profile) in which sailing was active while the engine was running.

Two main variants of this function are available. First there is a simpler option with a lower savings potential. As the vehicle sails, the engine can continue to run in idling mode, at approximately 700 to 900 rpm. The second option achieves maximum efficiency by switching off the engine completely and requires a start-stop system connected to the CBW technology in the vehicle. This option also requires an electrified steering system and an electrified brake. There is another conceivable option involving reactivation of the switched-off combustion solely by recoupling as the vehicle sails, but this is ruled out for volume-production vehicles for reasons of comfort.

The option of being able to control the clutch independently of the driver can also generate functions such as stalling prevention. If the electronic system registers a critical engine speed gradient, CBW actively prevents imminent stalling by means of partial or complete disengagement. This is helpful in many situations, for instance starting in the wrong gear or with too little acceleration, releasing the clutch too quickly, or decelerating without pressing the clutch pedal. Particularly during emergency braking, CBW significantly increases driving safety because it prevents not only stalling, but also the resulting unstable driving conditions.

The functionally similar creep option is important for comfort and driver relief. With electronically controlled slipping, CBW makes maneuvering and driving in traffic jams easier because the driver no longer has to operate the clutch pedal. In normal driving operation, CBW ensures reliably precise clutch engagement and disengagement which has a correcting and optimising effect and is both subjectively palpable and objectively measurable. This active clutch support almost completely rules out incorrect use of the clutch and increases its service life.

CONCLUSION AND PROSPECTS

The new mechatronic clutch-by-wire system has the potential to fundamentally and permanently alter the current nature of clutch activation in manual-transmission cars – similar to the way EPC systems changed throttle control. The primary objectives of this mechatronic innovation are further significant fuel and CO_2 savings. The ZF system achieves savings of more than 10 % in conjunction with a start-stop system – above all due to the sailing function which can be implemented for the first time in MT. Furthermore, the CBW actuator can be integrated into existing MT drivelines economically and with relatively little effort.

In subsequent steps, a large number of further CBW types and extensions are conceivable, although they are mostly more expensive. Included here are linking with automatic “follow-to-stop” speed control as well as a clutch pedal with an integrated electric motor instead of a mechanical pedal force simulation unit. This would make it possible to vary the pedal feedback according to the selected driving mode such as “city” or “sporty”. There is also the option of dispensing the left pedal altogether in the future. Then, for instance, contact sensors in the shift lever or motion recognition in the shift gate would register when the clutch needs to be actuated. Electronic and actuator systems would independently determine how to actuate the clutch. This is similar to the principle already known from AT and ATM.

Electrically Heated Catalyst for Optimising Emissions in Mild Hybrid Systems

© Continental

In hybrids, idling the combustion engine, for example in the so-called coasting mode, is one of the most efficient ways of reducing fuel consumption and CO_2 emissions. An electric heating disc keeps the catalyst up to temperature without the need for the hot exhaust flow. It makes heating via the combustion engine unnecessary, even when coasting for long periods. Continental has developed an electrically heated catalyst for use in the 48-V mild hybrid system.

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EMBRACING THE GROWING IMPORTANCE OF CATALYST HEATING

In addition to the ever-decreasing permissible fleet consumption (95 g CO_2/km from 2020/21) and the revised particle count threshold specified by the Euro 6c standard (2017), the test specifications used will place more demanding requirements on motor vehicles in the future. The NEDC (New European Driving Cycle) places far fewer dynamic demands on the combustion engine than the new WLTC (Worldwide Harmonized Light Duty Test Cycle). In the WLTP (Worldwide Harmonized Light Duty Test Procedure), the latter also includes Real Driving Emissions (RDE) measurements, whereby pollutant levels must also be complied with.

In gasoline engines, targeted thermal management has been standard for some time already. Since at least the introduction of the ULEV legislation, engine-related measures for raising the exhaust temperature have been used to heat up the catalyst quickly. The additional fuel consumption needed for this was deemed acceptable, as it only occurred during a cold engine start. As part of the discussions surrounding CO_2, this decision has had to be reconsidered in recent years. The electrically heated catalyst called Emicat has proven to be a practical alternative [1, 2, 3]. In the event of a cold engine start, an electric supply of heat enables the combustion engine to operate in the performance map with the optimum CO_2 consumption for this operating state with the lowest exhaust flow rate.

In addition, the position of the electric heating disc makes it possible to direct the heat toward the catalyst intake while also managing it effectively. This effective energy input means it is no longer necessary to heat the catalyst via the combustion engine and results in CO_2 savings for current production vehicles between one and two percent in the NEDC.

In addition to gasoline engines with reduced displacement, the growing electrification of drives is becoming extremely important in achieving the CO_2 targets set for 2020 and beyond. One advantage of hybrid energy converters is the ability to operate the engine with optimised efficiency in certain operating phases or to deactivate it entirely (engine-off phases). On a local level and to a limited extent, the hybrid therefore operates as a zero-emissions vehicle. However, since the combustion engine needs to be restarted more often depending on the concept, it is also necessary to design the catalyst system such that the pollutants limited by law are almost completely converted immediately following engine start-up. The more frequent the engine-off phases, the more important it is to keep the catalyst warm while the combustion engine is idle for longer periods.

The joint project between Schaeffler and Continental, the "Gasoline Technology Car" (GTC), was presented back in 2014 [4]. Thanks to a wide range of individual measures (hybridisation, downspeeding, thermal and exhaust management, combustion optimisation) it has been possible to reduce consumption below the 95 g CO_2/km limit in the NEDC for a mid-class family vehicle. Another objective was to homologate the Euro 5 vehicle, available as standard, for Euro 6c. Consequently, the Continental injection system was optimised for this engine and integrated. The electrically heated catalyst Emicat was chosen to make efficient use of recuperated electrical energy from the 48-V hybrid system (so-called Eco Drive system).

To secure the goal of an optimised hybrid operating strategy in conjunction with minimal emissions, the catalyst must be sufficiently heated both after a real cold engine start and after a restart following engine idling. The possibility offered by the electrically heated catalyst of injecting heat into the catalyst system even when the engine is idling and ensuring that the light-off temperature is reached as quickly as possible boosts the potential of the hybrid.

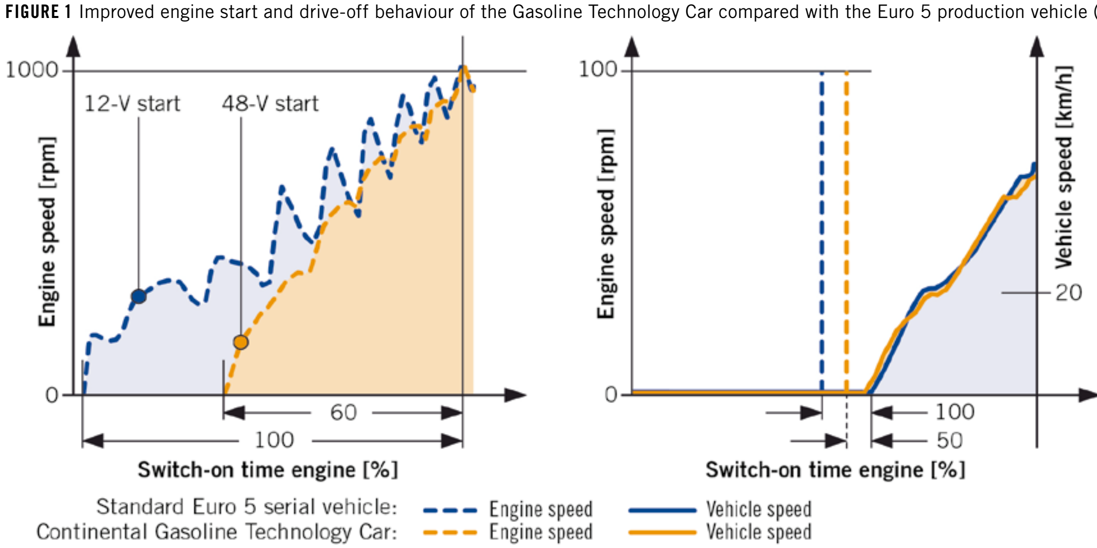
CO_2 SAVINGS THANKS TO CONSISTENT ENGINE-OFF STRATEGY

As explained in [4], the 48-V mild hybrid concept of the Gasoline Technology Car draws on numerous strategies for saving fuel. These include the hydraulic clutch actuator (HCA) on the electrified starter clutch and the electric motor with its range of functions, including generator, booster, and means of support for restarting and decelerating the combustion engine when the clutch is operated automatically. Overall, these sub-systems for the engine-off strategy lay the groundwork for maximum ride comfort.

This can be technically evaluated on the basis of the start-up behaviour of the combustion engine, for example. The duration of the rotary movement applied until a starting speed is reached is determined. The 48-V belt starter generator (BSG) is characterised by a fast, high torque with a very high degree of efficiency. Furthermore, much higher rotational speeds (factor > 10) are achieved in the combustion engine with almost no noise. This enables combustion to be dispensed with entirely during the start process, **FIGURE 1**, which results in excellent noise performance. This is visualised on the left-hand side of **FIGURE 1** by comparing the rotational speed build-up. The spontaneity of the vehicle behaviour is another significant comfort aspect. Halving the time between the driver's request to drive off and the actual vehicle movement is regarded as an important factor in high customer acceptance.

The engine-off strategy constitutes another central element of this mild hybrid design. In this process, the combustion engine is activated solely to propel the vehicle from the first second of a driving cycle. If the driver operates neither the brake nor the accelerator pedal, torque loss is minimised by disengaging the electrically actuated clutch. To implement a deceleration request, the clutch is engaged and the electric motor is used for braking energy regeneration. No fuel is injected provided the driver does not operate the accelerator pedal,

FIGURE 1 Improved engine start and drive-off behaviour of the Gasoline Technology Car compared with the Euro 5 production vehicle (© Continental)



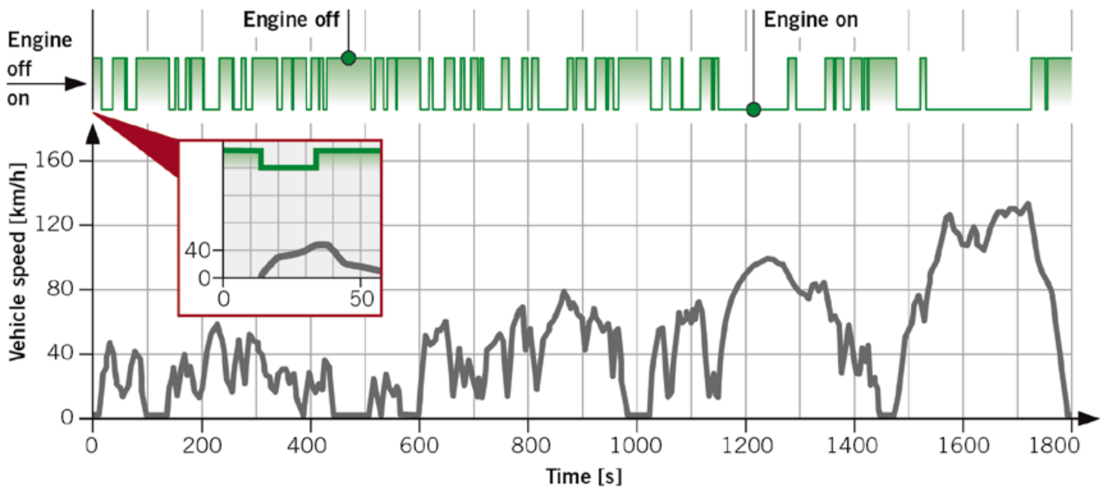


FIGURE 2 Engine-off strategy of a mid-class vehicle in the WLTC with enlarged detail of the first seconds (© Continental)

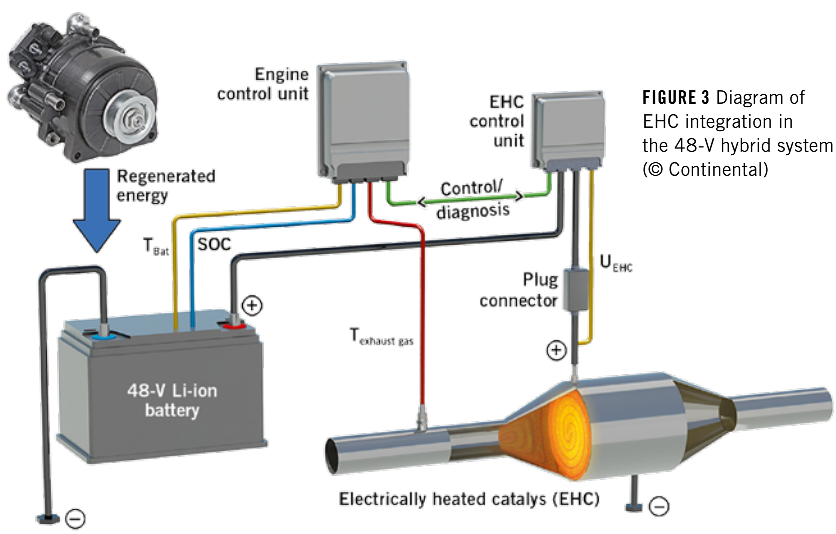


FIGURE 3 Diagram of EHC integration in the 48-V hybrid system (© Continental)

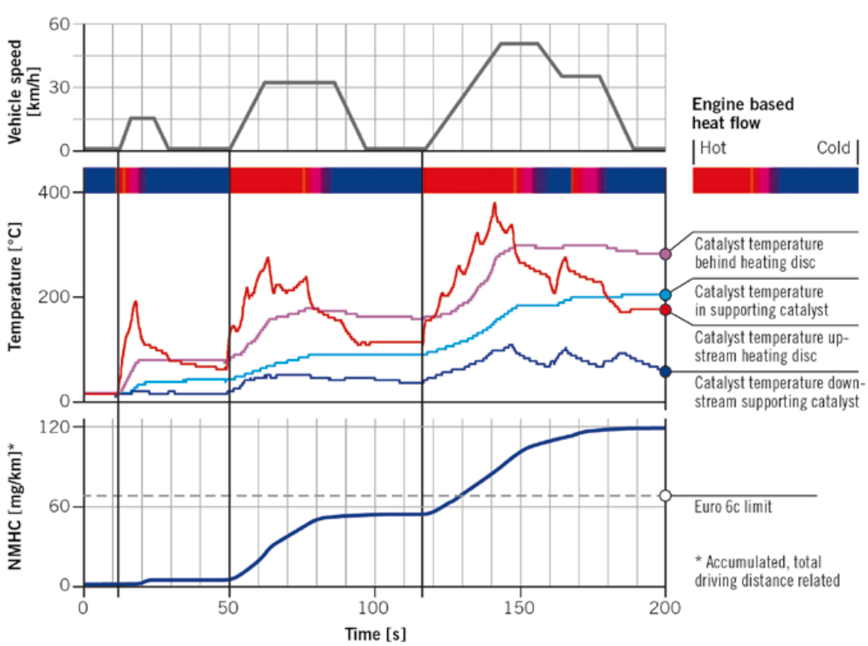


FIGURE 4 NMHC emission behaviour with a consistent engine-off strategy with Emicat compared with a conventional catalyst (© Continental)

either when the vehicle is coasting (engine off and disengaged) or during energy recuperation, where the combustion engine has to be motored due to the electric motor in the belt drive. When coasting with the clutch disengaged, the combustion engine is idle.

In a production vehicle certified according to Euro 5 with start/stop plus mode, coasting, and energy recuperation in the WLTC, the accumulated vehicle operation time without injection results in an estimated total duration without engine combustion of approximately 50 %. During this time, the vehicle covers a total distance of more than 7 km, representing almost a third of the total journey distance. The relative engine-off duration and distance are comparable in the NEDC. **FIGURE 2** demonstrates the high potential for CO_2 savings due to long deactivation phases up to a speed of approximately 80 km/h in the WLTC. The potential may be even higher in cases of low driving resistance, greater vehicle mass, or routes with downhill slopes.

The enlarged detail in the diagram in **FIGURE 2** shows a close-up of the consistent engine-off strategy from the first second. The previous engine mode, before implementation of a driver request for forward movement, served solely to warm up the system, which is unnecessary when the electrically heated catalyst is used. Potential CO_2 savings of 6 g/km as determined via the NEDC are around the amount that can be achieved, taking the homologation conditions into account. The apparent conflict of objectives between consistent CO_2 saving and

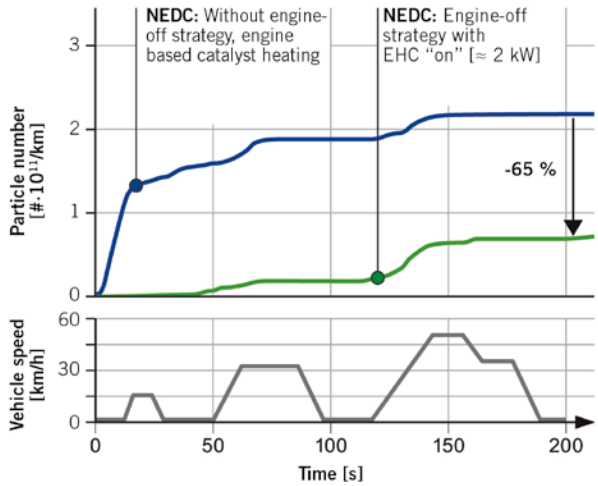


FIGURE 5 Particulate emissions during the first 200 s in the NEDC (© Continental)

heating the exhaust aftertreatment system can be resolved with the electrically heated catalyst.

THE 48-V ELECTRICALLY HEATED CATALYST

The electrically heated catalyst Emicat comprises a heating disc that is just under 10 mm wide and support catalyst. The support catalyst is fixed to the electric heating disc by means of electrically insulated support pins brased at high temperatures. An example showing the integration of an electrically heated catalyst in the 48-V hybrid structure is shown in **FIGURE 3**. It can be installed either close to the engine or in the underbody area.

The Emicat is electrically connected to the accompanying control unit and the positive terminal of the battery. The negative terminal is connected to the electrical ground of the vehicle. The power is provided by a 48-V Li-ion battery and directly by the 48-V BSG. The task of the catalyst control unit is to activate the heating current, monitor the system, and share the necessary data with the engine control unit. The operating strategy for the electrically heated catalyst is maintained in the combustion engine control unit.

PERFORMANCE FEATURES IN DRIVING CYCLES

The use of a heating disc with a heat output of approximately 2 kW, as used in the Gasoline Technology Car, leads to non-methane hydrocarbon (NMHC) emission behaviour that is considerably below the required limit in comparison with the use of a standard catalyst. This is clear from the measured temperature curve on the front side of the auxiliary catalyst in the following diagram. The light-off temperature is exceeded even from the first revolutions of the combustion engine, **FIGURE 4**. Despite the maximum delay to the engine start, immediate drive-off, and maximum engine-off time, a catalyst temperature adequate for converting the emission components is reached in this mild hybrid at 27 mm downstream on the front side of the catalyst under acceleration to the second speed peak.

As a result, the NMHC emission behaviour exhibits a significant reduction right from the initial drive-off. Even after the long engine-off phase between the first speed peak and the acceleration phase of the second speed peak, an emission level far below the limit specified in Euro 6c is reached with the consistent engine-off strategy. Thanks to the consistent engine-off strategy, total fuel savings of 4 % can be achieved in the NEDC, right from the first second.

There are also benefits with regard to particulate emissions, **FIGURE 5**. This is partly a result of the positive influence of the high-pressure fuel injection system with so-called XL 3.1 injectors in conventional driving mode. In addition, due to the absence of engine-based catalyst heating and the higher rotational speed at the start of combustion engine operation after starting, the particulate count is significantly reduced. The electrically heated catalyst therefore makes a significant contribution to the reduction of all emission components. The extent to which this added benefit can be achieved must be evaluated on a system-specific basis. Vehicle weight, friction losses, and vehicle rolling performance are examples of influencing parameters here.

The benefits of the electrically heated catalyst in the GTC in terms of emissions are also demonstrated in other driving cycles such as the WLTC and RDE_{max} (Real Driving Emission cycle, aggressive). **FIGURE 6** shows the average CO_2 benefit of the engine-off operating strategy in the WLTC. The entire benefit of a saving of 3.5 g CO_2/km is generated in the first 200 s or so. This aspect therefore gains much more significance in practice, as a cold engine start (vehicle temperature ≈ ambient temperature) followed by operation for a short distance in an everyday application is statistically dominant.

Falling below the HC limit is used as the top evaluation criterion for verifying the heat-up strategy in the RDE_{max} cycle. The calibration of engine-based catalyst heating measures is limited to 1 l of cubic capacity in the driving cycle for the chosen vehicle engine configuration. The time between the start of the cycle and the drive-off event is only 5 s, and the reserve for the additional heat output to be generated is limited due to the maximum cylinder charge. This situation is exacerbated by the fact that this lead time can be even shorter in practice. With the electrically heated catalyst, the combustion engine in the Gasoline Technology Car can remain off during these initial seconds without the emission target being jeopardised. The HC emission curve relating to the total distance produces a result more than 40 % below the limit, **FIGURE 7**.

THE ELECTRICALLY HEATED CATALYST IN 48-V MODE

Investigations have shown that the heat-up process for the heating disc plays a key role in terms of the driving cycles currently considered during the development process, such as the NEDC, WLTC, and RDE_{max}. The heat output is the central variable for the heat-up performance of the heating disc. Its effect is reflected directly in the heat-up curves when the vehicle is stationary and the engine is off. With a heat output of 1 kW, the light-off temperature in the heating disc is still not reached after 8 s. With a heat output

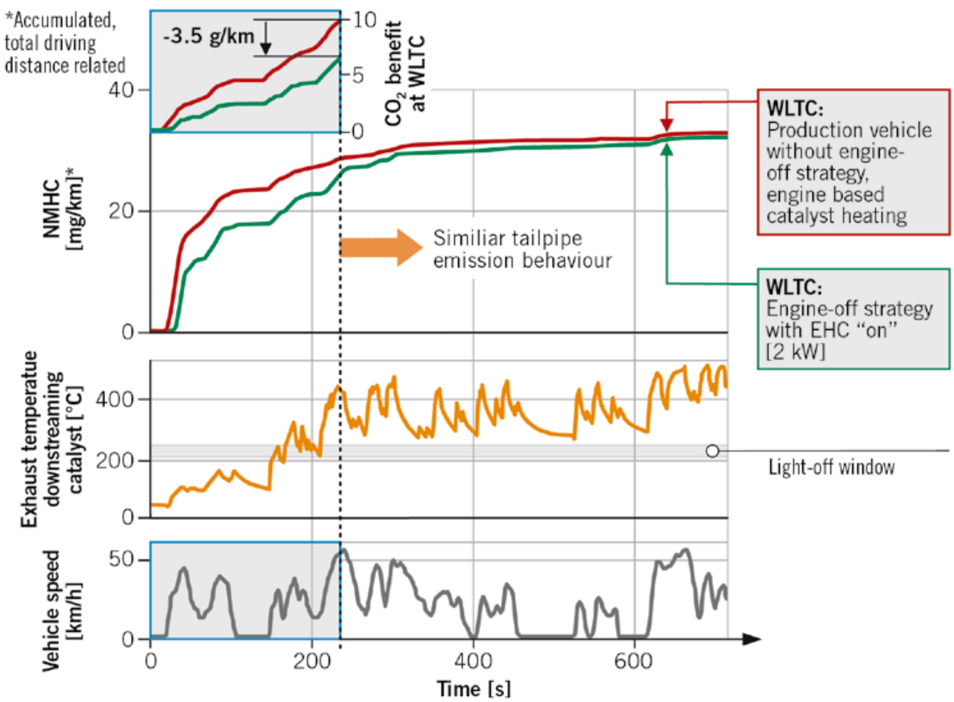


FIGURE 6 CO_2 benefit in the WLTC (© Continental)

of 2 kW, this is reached after around 5 s, **FIGURE 8**. This ensures that the RDE cycles considered during development are covered. These stipulate different degrees of acceleration for the vehicle after 5 s at a standstill. Assuming a current minimum period of 3 s between activation of the vehicle by the driver and the driver's initial drive-off request, this is covered by a variant with a heat output between 3 and 4 kW. This performance increase can be achieved in 48-V mode with an Emicat and represents yet another benefit in terms of emissions and fuel consumption.

SUMMARY AND OUTLOOK

The electrically heated catalyst constitutes a universally applicable tool for temperature management in the exhaust aftertreatment system. Not only does it significantly increase the effectiveness of exhaust aftertreatment (reduction in HC, CO, and NO_x), but it also offers potential for CO_2 reduction at the same time, thus saving fuel, in comparison with conventional measures such as engine-based catalyst heating. The electrical supply can work independently of the operating

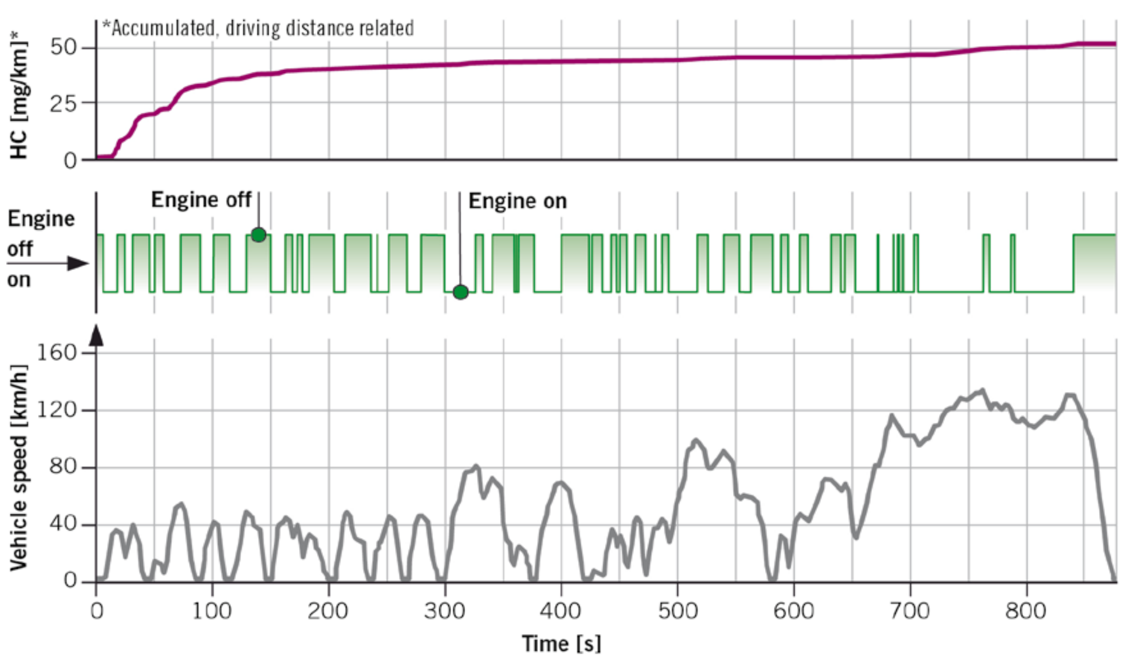


FIGURE 7 HC conversion in the RDE_{max} driving cycle with Emicat assistance (© Continental)

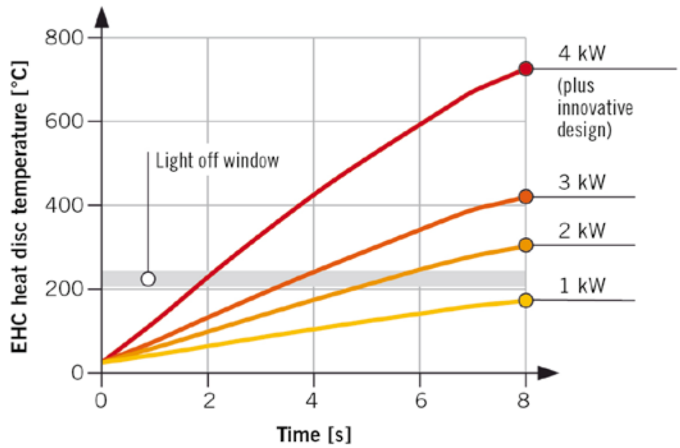


FIGURE 8 Heat-up performance of the 9-mm-wide heating disc in the Emicat (© Continental)

point of the engine. Consequently, it is possible to achieve further fuel savings with the consistent engine-off strategy.

At the same time as the measured CO_2 reduction of 6 g/km in the NEDC and more than 3 g/km in the WLTC, there is a considerable benefit in terms of particulate emissions. In the NEDC, the particle count was 65 % below the Euro 6c limit in the first 200 s. The RDE_{max} measurements yielded HC emissions values that were 40 % below the Euro 6c limit. In the case of shorter driving cycles, as occur in practice, the fuel-saving effect is correspondingly greater, as a cold start strategy has a stronger effect.

On the subject of 48-V technology, additional possibilities are now opening up for the cold start strategy. Compliance with future European and American limits represents a further challenge here. The use of an electrically heated catalyst with high outputs (up to 4 kW at 48 V) forms the emissions-related basis for an unrestricted engine-off strategy. Engine starts and the catalyst heat-up phase have optimum support and are extremely convenient from an NVH perspective. New hybrid driving strategies such as coasting are available from the first second of operation.

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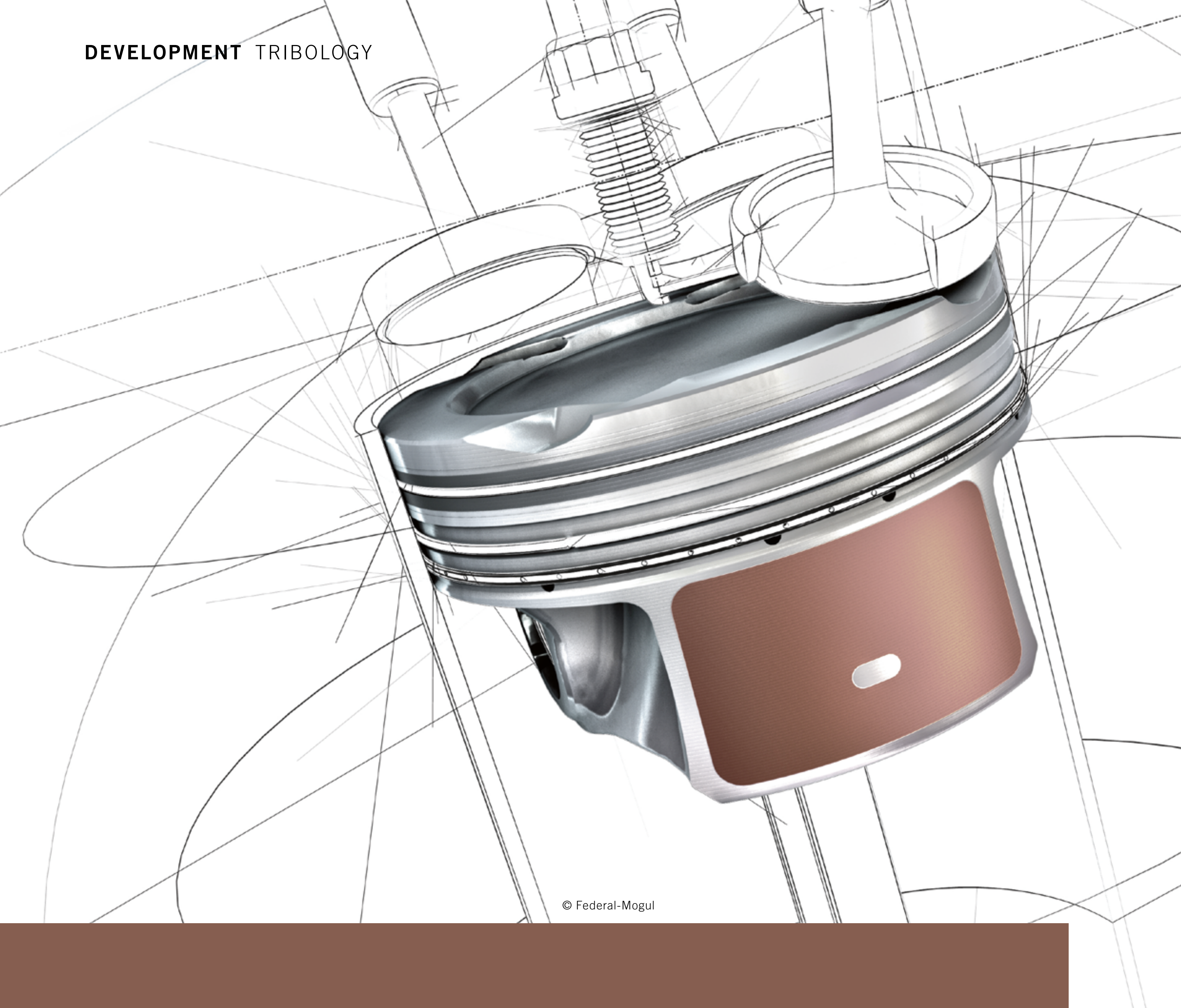

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Innovative Skirt Coatings for Gasoline and Diesel Engine Pistons

Piston skirt coatings are widely recognised as a means of minimising friction in a combustion engine, which is of growing importance to overall efficiency in both gasoline and diesel applications. To further reduce parasitic losses and in response to increasingly harsh combustion chamber conditions, Federal-Mogul Powertrain has introduced two new coatings.

REDUCING PARASITIC LOSSES

Pursuing improvements in the efficiency of a combustion engine places increasingly stringent demands on the components in the tribological system (piston, pin and ring package) while also requiring parasitic losses be reduced. Taking a 2.0-l, four-cylinder gasoline engine with direct injection and turbocharging as an example [1], a 37 % yield of usable mechanical work can be seen. One quarter of this is then lost via friction and in ancillary components, with the piston skirt and piston pin alone accounting for 17 of the 25 %.

In addition to controlling piston clearance and skirt geometry, skirt coatings have proved to be an effective way of meeting the interrelated targets of optimising friction and reducing wear. Federal-Mogul uses lifetime piston coatings to reduce friction and wear between skirt and cylinder surfaces in gasoline and diesel engines.

Higher thermal and mechanical loads emphasise the growing relevance this type of coating has to durability and running efficiency. The increasing loads necessitate innovation in coating design, as previously proven coatings may no longer have sufficient fatigue strength. This was the motivation behind Federal-Mogul's development of two high-performance coatings to meet even tougher requirements in gasoline and diesel engines. Gasoline and diesel engines were deliberately approached separately because irrespective of the fact that the operating conditions of both engine types are converging, they continue to pose specific, differing requirements in respect of formulating piston coatings.

SKIRT COATINGS FOR GASOLINE ENGINES

In gasoline engines, friction can be impacted by unburnt fuel diluting the oil on the cylinder running surface. When this happens, boundary friction conditions and metal-to-metal contact become more likely, leading in turn to an increase in friction between the tribological partners (piston ring and piston skirt) and the cylinder running surface. Vehicles with a start/stop function are particularly prone to this, the process causing boundary friction during engine re-start. In addition to reducing efficiency, this can cause greater wear and limit piston durability. The mechanism can also negatively impact noise emission.

In a direct injection gasoline engine with turbocharging (T-GDI) the trend towards continuously increasing ignition pressures (currently ≥130 bar) – and the resulting greater lateral forces – negatively impact friction losses and wear rates. In this respect, the turbocharged GDI engine tends to show greater similarity to the well-known and demanding conditions seen in diesel engines. Standard and so-called EcoTough Federal-Mogul coating systems have proven themselves in previous and current gasoline engines. Under extreme loads in T-GDI engines however, even these special coatings can reach the limit of their durability. To address the increasingly tough requirements of highly efficient engines, a new skirt coating named EcoTough-New Generation was developed. Immediately differentiated by its reddish-brown color – other skirt coatings are typically dark grey in appearance – the new coating is a metal oxide-reinforced resin with additional

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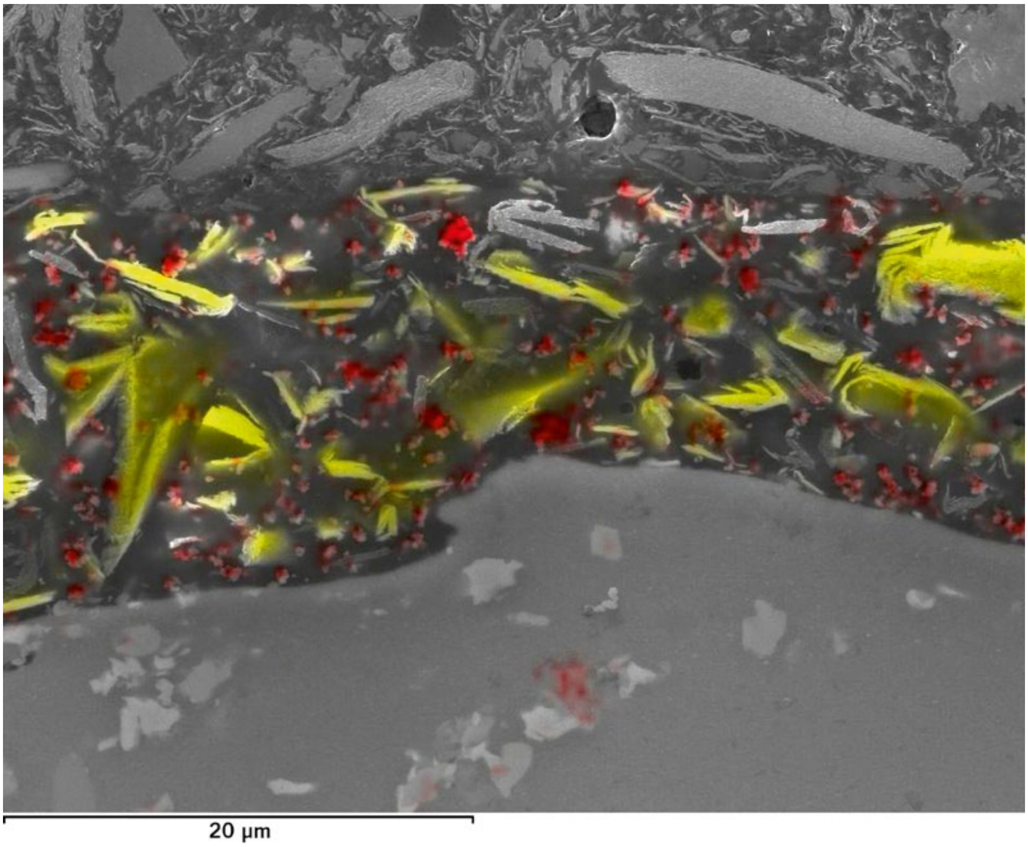


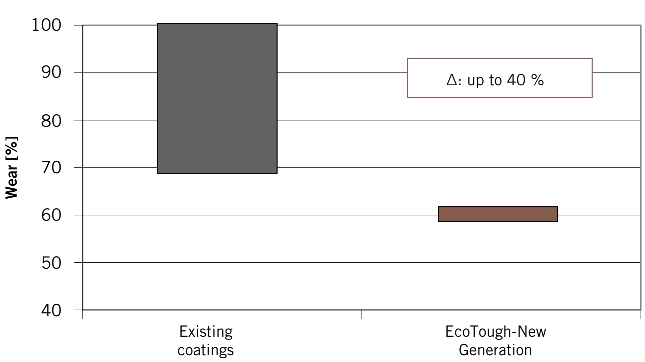
FIGURE 1 Micro section depicting the individual components of the coating EcoTough-New Generation (© Federal-Mogul)

embedded solid lubricant particles. The targeted layer thickness is 15 µm. **FIGURE 1** shows a micro section of the new coating, which is applied via a screen printing process. The individual components are clearly visible.

The coating composition provides both improved wear resistance and reduced friction losses. **FIGURE 2** depicts the wear characteristics of the EcoTough-New Generation skirt coating in comparison to the current market standard. Federal-Mogul's new coating reduces wear by up to 40 % compared to the market standard and offers considerably better fatigue strength under extremely harsh conditions. The new coating delivers an improvement in friction reduction of up to 15 % compared to standard coatings, contributing to the base engine's efficiency.

The properties of the new coating have been confirmed by comprehensive testing, which initially included non-engine rig-testing of the wear rate. The most promising coating variants were subsequently validated in a fired cold-start engine test. The engine used for this purpose is characterised by extremely harsh tribological boundary conditions: low piston clearance and a very rough cylinder running surface. The actual friction properties were ascertained in a floating-liner engine [2].

During the development and validation phase, the coating system was mechanically damaged before being exposing to a high pressure oil jet. Despite the damage,



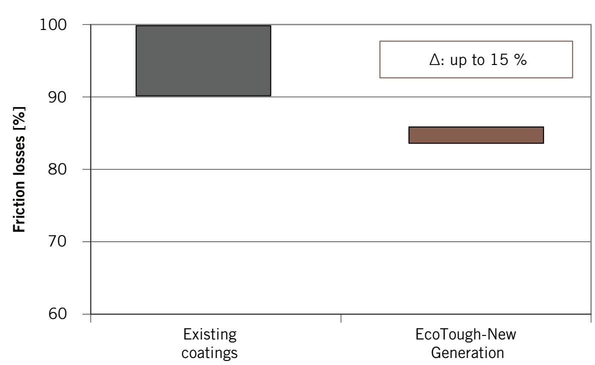


FIGURE 2 Wear and friction of the EcoTough-New Generation skirt coating for gasoline engines as compared to the market standard (© Federal-Mogul)

the coating's adhesion to the aluminum substrate and its cohesion were sufficiently strong for it to pass the oil jet test. The fact that the coating is applied to the piston skirt in a fully automated, large-scale production process means that the excellent wear and friction properties can be utilised at an optimised cost level, **FIGURE 3**. The new piston coating is currently being validated by a number of vehicle manufacturers.

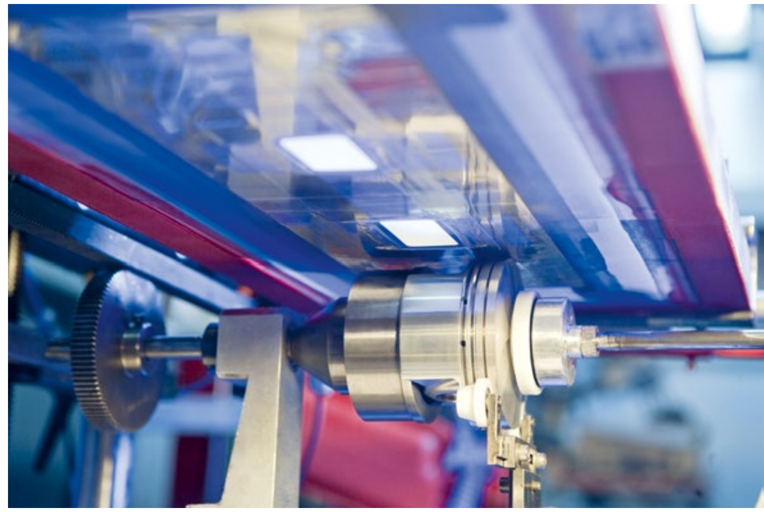


FIGURE 3 Description of the screen printing process used for applying the skirt coating (© Federal-Mogul)

SIMULATION TOOLS

Numerical simulation is integral to the development of a piston skirt coating and is particularly valuable for the validation of operating characteristics. The main purpose of the simulation is to optimise piston design in respect of lightweighting and a lower compression height, but simulation tools are equally beneficial when it comes to evaluating test results: In the case of the new coating, for example, the skirt contact pressure for the piston of the 1.6-l gasoline test engine was calculated prior to any physical engine testing. The numerical simulation contributes to the piston inspection process after the test because it reveals areas of high contact pressure, which are by nature more prone to show wear. As **FIGURE 4** shows there is no visible wear of the tested skirt coating in areas of high contact load. This ability to endure even local surface pressure ranks high among the prerequisites for a wear resistant piston skirt and cylinder running surface in highly loaded engines.

SKIRT COATINGS FOR DIESEL ENGINES

In a diesel engine it is primarily high peak pressures that can cause friction and wear at the piston skirt. In comparison to the structural design of a gasoline piston, high-performance diesel pistons have a much higher structural rigidity, plus a skirt design that is tailored to the diesel engine. The higher rigidity of the skirt increases the "fretting" tendency, which can be compensated by increased lubricant; this in turn leads to much lower friction levels than those that can be achieved with gasoline piston skirt coatings. With diesel fuel also having better lubricating properties than gasoline – and therefore reduced abrasion – it is possible to develop a diesel-specific skirt coating. The greater skirt rigidity allows the coating to contain different solid lubricants, which facilitates lower friction rates. The previous skirt coating for diesel pistons has been proven over many years but as the mechanical load level in diesel engines continues to grow in analogy to gasoline engines, an improved skirt coating wear resistance is required for diesel engine pistons. The so-called EcoTough-D coating (EcoTough-Diesel) now in production was developed to meet this requirement. The fact that it can be applied to both aluminum and steel pistons aligns it with an emerging trend in passenger cars and light duty commercial vehicles, **FIGURE 5**.

This polymer-based coating is reinforced with short carbon fibres and graphite is embedded in the coating as a solid lubricant. **FIGURE 6** shows wear and friction rates of the EcoTough-D coating in comparison to

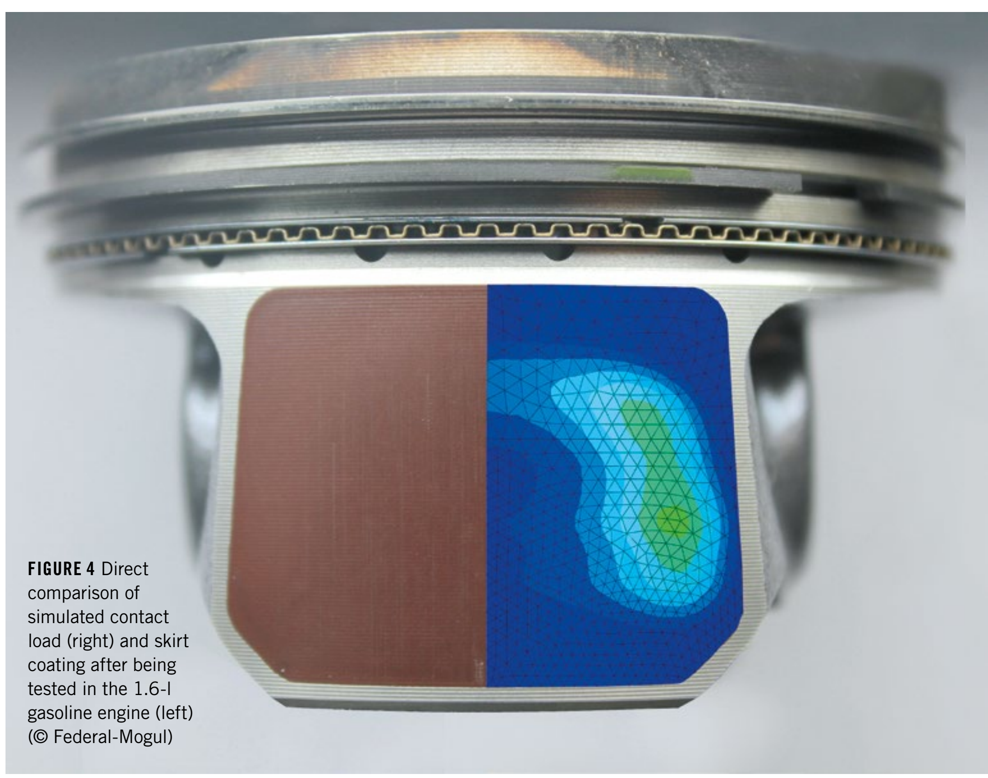


FIGURE 4 Direct comparison of simulated contact load (right) and skirt coating after being tested in the 1.6-l gasoline engine (left) (© Federal-Mogul)

FIGURE 5 Passenger car steel piston with the new EcoTough-D skirt coating for diesel engines (© Federal-Mogul)

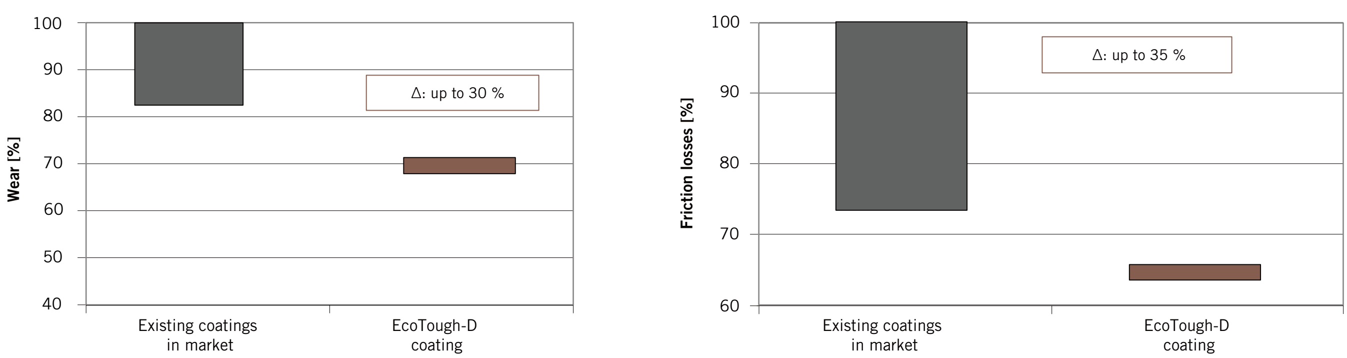


FIGURE 6 Wear and friction of the EcoTough-D skirt coating for diesel pistons, as compared to conventional graphite-based coatings (© Federal-Mogul)

conventional coatings. Friction losses are reduced by up to 35 % compared to standard coatings on the market and the wear resistance is improved by up to 30 %. The fully automated application process ensures the coating thickness required to prevent lateral piston movement and resulting noise issues, which might otherwise result from increased piston clearance.

SUMMARY AND OUTLOOK

Surface technology will continue to play a bigger part in on-going efforts to increase the efficiency of the combustion engine. Piston skirt coatings, in conjunction with piston design and piston materials, help to optimise friction and reduce wear in spite of ever more severe boundary conditions. The EcoTough-D coating can in addition make a contribution to noise optimisation in a self-ignition engine.

The new coating systems provide innovative skirt coating solutions for gasoline and diesel engines. Both coatings offer the appropriate wear resistance at lower friction that highly loaded engines require.

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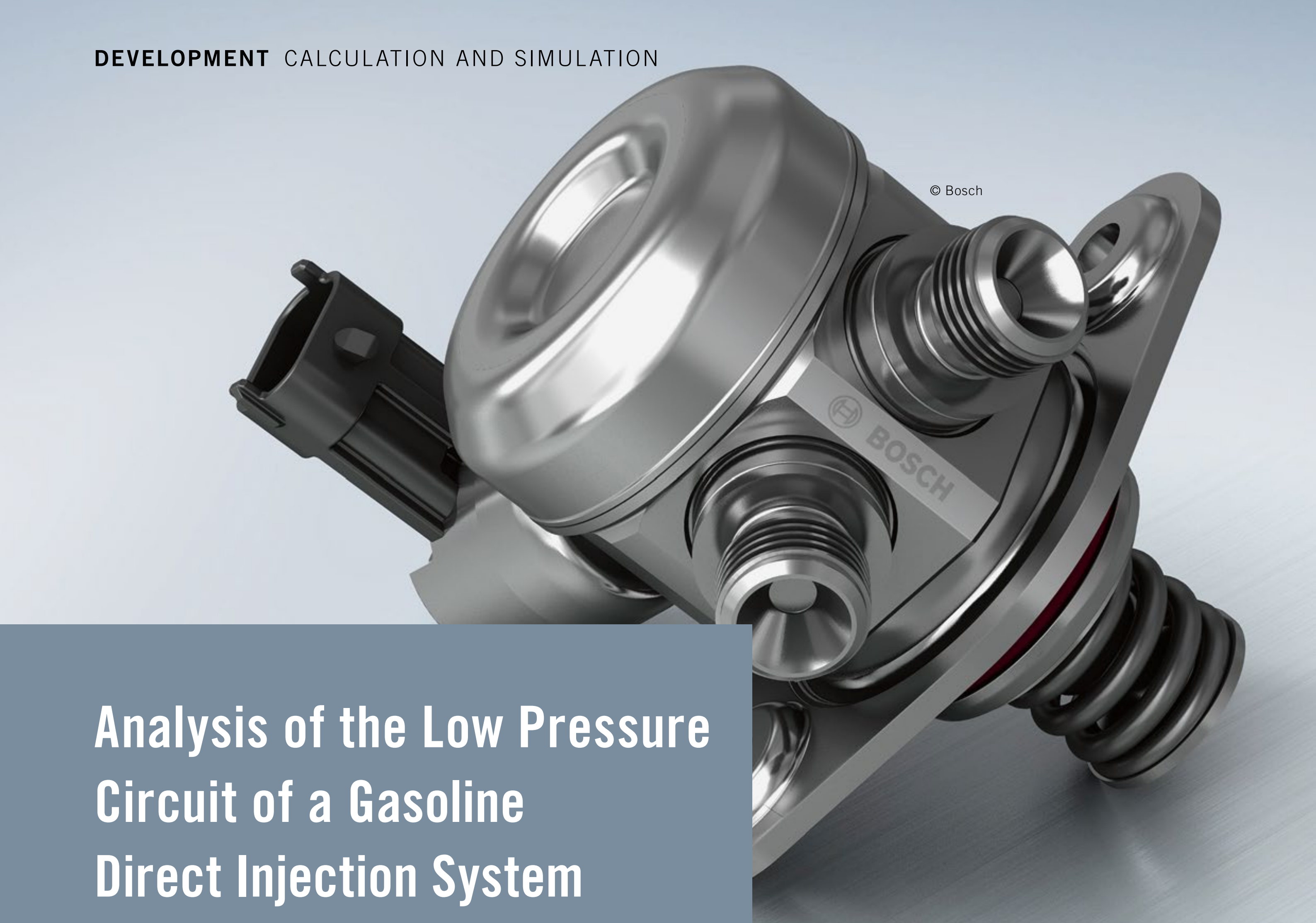

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Analysis of the Low Pressure Circuit of a Gasoline Direct Injection System

With gasoline direct injection (GDI) in combination with a turbocharger and downsizing of an engine, it's possible to reduce the gas mileage up to 15 %, compared to a similar power output naturally aspirated engine. More potential of fuel saving can be found with the optimisation of the entire system. Bosch analysed the pressure oscillation of a flexible low pressure line in a gasoline direct injection system, gaining new knowledge for the further development of simulation models.

MOTIVATION AND OBJECTIVE OF THE STUDY

To save fuel, the use of simulation models is increasingly important. Because of the high system complexity, these models help to predict the controllability of the whole system. Therefore, 0-D and 1-D simulations will be even more important in the current development, as well as in the future engine development [1]. Simulation models will need a high prediction quality. Only if the methods, which are used, show exactly all relevant phenomena, a reliable product development in terms of simultaneous engineering is possible.

In the present article all hydraulic conditions in the low pressure line of the GDI system will be schematically analysed. The focus is on the determination of the natural frequencies as well as on the representation of the hydraulic oscillation mode inside the line. A current GDI system, which has flexible lines to the high pressure pump, will be considered. Next to the analytic observations, experimental observations are performed, too. Based on this knowledge the simulation models are validated.

ANALYTIC OBSERVATION

FIGURE 1 displays a flexible line between the fuel supply module and the high pressure pump. Also all relevant variables are exemplary shown. On the assumption of a homogenous, friction-

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less fluid, as well as a constant cross section at the conduit system, the momentum equation of the fluid will get simplified to Eq. 1:

Eq.1 $$\frac{\delta v}{\delta t} = -\frac{1}{\rho} \times \frac{\delta p}{\delta x}$$

Therefore v is the velocity, p the pressure, ρ the fluid density. This relation shows that a local pressure drop is needed for acceleration of the flow [2]. Another assumption is, that the flow velocity is significantly lower as the speed of sound and because of that, convective factors can be neglected. The linear compression law in Eq.2 is a result of the mass-conservation equation in combination with the definition of the speed of sound

Eq.2 $$\frac{\delta p}{\delta t} = -E_{fluid} \times \frac{\delta v}{\delta x}$$

A local difference of velocity has a time based pressure change involved [2]. E_{fluid} the compression module of the fluid. Both of these relations represent a linear and partial differential system of equation, which can be solved with the separation approach. For a more detailed view refer to [3]. The solution of the differential system of equation is significant dependable from the boundary conditions.

Assuming closed ends at both sides of the line, the natural frequencies are noticeable, if the line length is a multiple of half the wavelength of the pressure oscillation, Eq. 3:

Eq.3 $$L = \frac{\lambda_i}{2} \times i$$

In this equation λ_i is the current wavelength from the pressure oscillation and L the length of the pipe. The index i represents each natural frequency. With the relationship, Eq. 4

Eq.4 $$f_i = \frac{c_{fluid}}{\lambda_i}$$

the i^{th} natural frequency in the line becomes Eq. 5:

Eq.5 $$f_i = i \times \frac{c_{Fluid}}{2 \times L}$$

The diffusion velocity of the pressure change can be described through the speed of sound c_{fluid} [3]. With that in mind it shall be considered that the pressure change, because of the softness from the flexible lines, has a much slower diffusion as in rigid lines. This influence can be calculated with respect to the overall modulus of elasticity E_{total} which is a series connection between pure fluid compression modulus E_{Fluid} and line elasticity, Eq. 6:

Eq.6 $$E_{total} = \frac{1}{\frac{1}{E_{fluid}} + \frac{1}{K_{line}}}$$

For thin-walled lines the line elasticity factor K_{line} is defined [4] with, Eq. 7:

Eq.7 $$K_{line} = \frac{E_{line} \times h}{d}$$

Like shown in **FIGURE 1**, d represents the inner diameter of the line and h the wall thickness. E_{line} stands for the modulus of elasticity of the flexible line. To define the natural frequencies and the corresponding oscillation, the speed of sound c_{total} of the line system can be calculated with Eq. 8:

Eq.8 $$c_{total} = \sqrt{\frac{E_{total}}{\rho}}$$

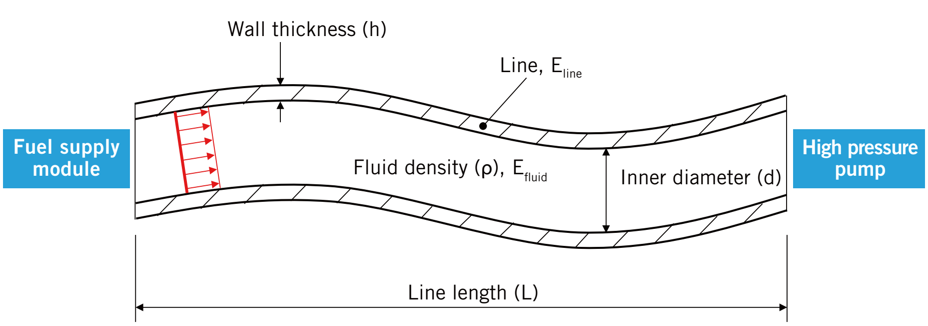


FIGURE 1 Flexible line between fuel supply module and high pressure pump (© Bosch)

EXPERIMENTAL ANALYSIS

The complete gasoline direct injection system is reproduced on a test bench, **FIGURE 2**. The fuel tank with the fuel supply pump is located on the left side. The low pressure lines are connected to the tank, which supply the fuel to the high pressure pump. With respect to the low pressure line, common vehicle applications have been chosen. The high pressure pump is mounted to the housing and driven by the camshaft. The high pressure pump and the rail are connected via a high pressure line. This is also where the pressure reduction valve is located. This valve simplifies and represents the mechanism of the high pressure injection valves.

Since the focus of this analysis is for the low pressure line, it is divided in four sections and equipped with piezoresistive pressure sensors. Also the pressure signal is captured on both ends of the line.

SYSTEM SIMULATION

With help of the commercial program Amesim, based on 0-D and 1-D sub models the entire GDI system can be built. For modeling, Amesim standard elements as well as Bosch specific developed models have been used.

In this analysis the modeling of a low pressure line becomes a key role. Like mentioned before, the pressure waves have, because of the softness from the flexible lines, a much slower diffusion than rigid lines. The effective line cross section increases and therefore the expansion velocity of the pressure wave decreases. This is a problem, which is known as the Fluid-Structure-Interface (FSI).

The model technical description of the fluid happens to use a FVM procedure, which is linked to a FEM solver. The used model is based on the model from reference [5] with consideration of additive dissipative effects.

INVESTIGATION OF NATURAL FREQUENCIES

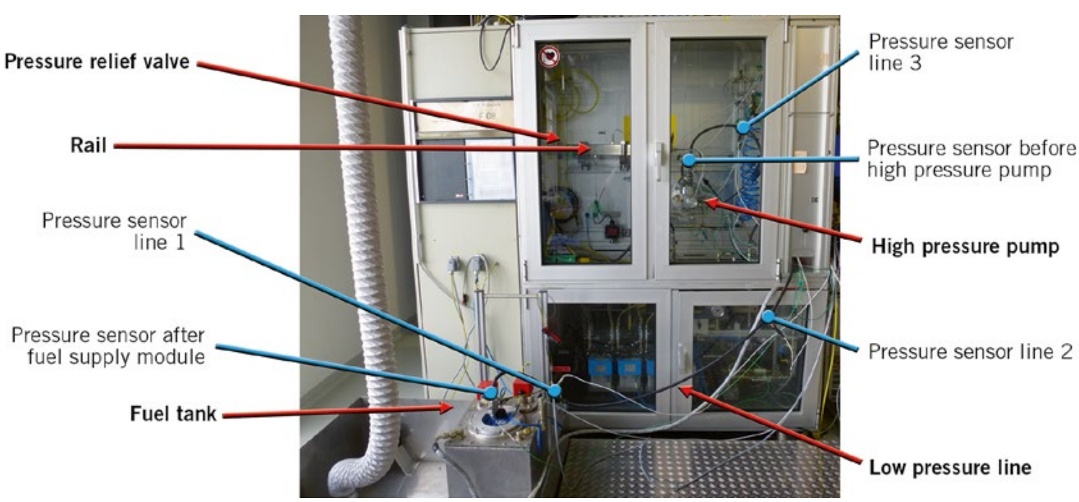
Based on the explained analytic view, natural frequencies and corresponding oscillation modes can be determined. In **TABLE 1** are the rotational speeds of the high pressure pump for the first three natural frequencies listed.

The characteristic values, which are needed for the calculations, have been experimentally determined. Like earlier stated, the length of the line at the first natural frequency has half of the wave length. If the rotational speed increases, the wave length of the oscillation will decrease inside the low pressure line.

FIGURE 3 displays the pressure amplitude of a pressure measure point inside the low pressure line over the high pressure pump rotational speed. In consideration of natural frequency from the pressure sensors, the measurement data has been low-pass filtered. Fast-Fourier transformation (FFT) was used to find the pressure amplitude. By applying a Hanning window, it was possible to reduce the so called leakage effect.

At about 700 rpm a significant rise of the pressure amplitude can be seen. At this point the analytic calculation, measurement and simulation are matching. Also the first natural frequency can be found at this rotational speed. According to **TABLE 1**, the second resonance vibration appears at the high pressure pump rotational speed of 1440 rpm. Simulation and measurement correspond as well,

FIGURE 2 Test bench of the GDI system (© Bosch)



Natural frequency	Rotational speed of high pressure pump [rpm]	Oscillation mode
1. Natural frequency	720	$0.5*\lambda_1$
2. Natural frequency	1440	$1.0*\lambda_2$
3. Natural frequency	2160	$1.5*\lambda_3$

TABLE 1 Natural frequency and oscillation modes based on analytic view (© Bosch)

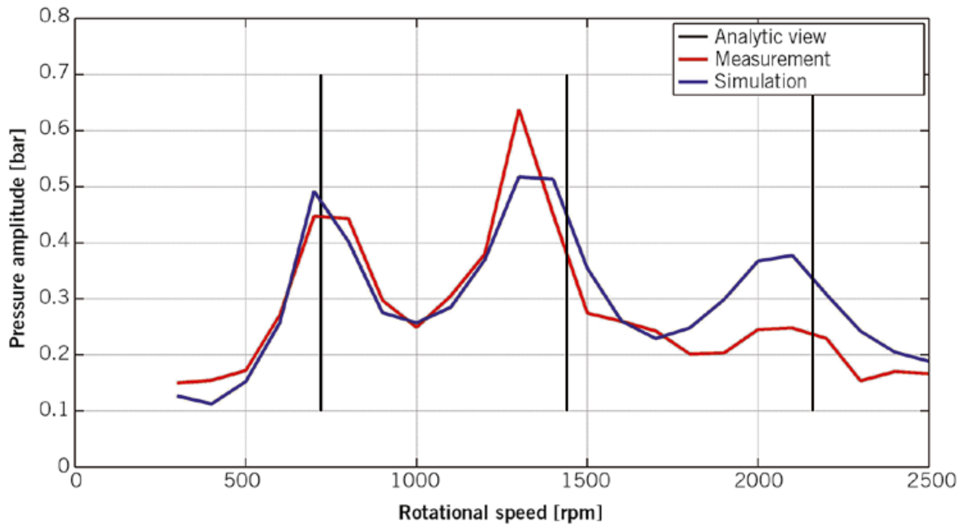


FIGURE 3 Pressure amplitude inside the low pressure line (© Bosch)

however the rotational speed has a less value (1300 to 1400 rpm). The reason for this is the frequency-dependent damping, which increases with growing frequency and rotational speed. Therefore the location of resonance moves to lower rotational speed, which isn't considered at the analytic calculations. Furthermore this effect is also at the third natural frequency at about 2100 rpm.

In **FIGURE 4**, pressure over normalised line length at four times is plotted. Displayed is each change of pressure with respect to the medium pressure in the line. The measured pressure profile over the line length has been determined on a base of five sampling points (measuring values, red points on each diagram) with a spline-interpolation. It's obvious that the oscillation in the line is equivalent to a half wave length. A pressure antinode exists at the median area of the line. The match between the measurement and simulation is very good.

At the high pressure pump rotational speed of 1400 rpm the wave length of the pressure oscillation corresponds to the line length. In **FIGURE 5** the relation is clearly noticeable. At the scaled line length of 0.4 an oscillation node is recognisable, so that there is almost constant pressure. Again the correlation between the experiment and the simulation is in order.

CONCLUSION

The pressure oscillation of a flexible low pressure line, in a gasoline direct injection system, has been analysed. Besides

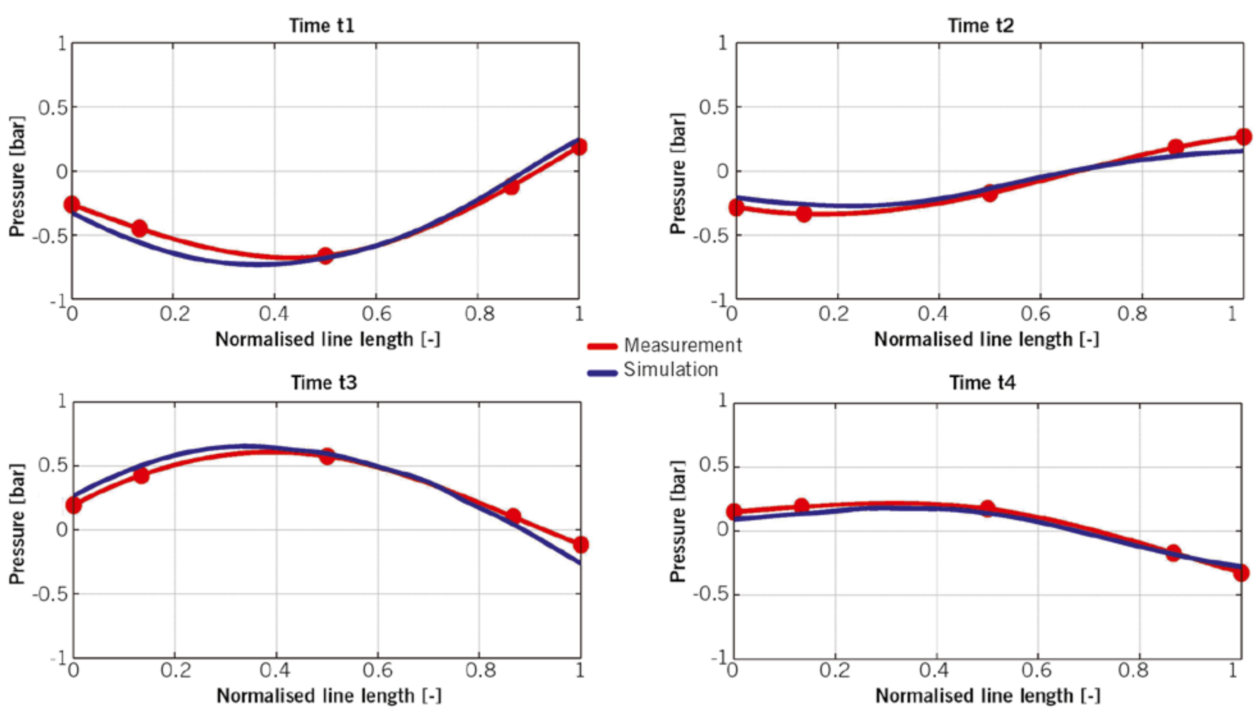


FIGURE 4 Display of the first natural frequency at about 700 rpm (© Bosch)

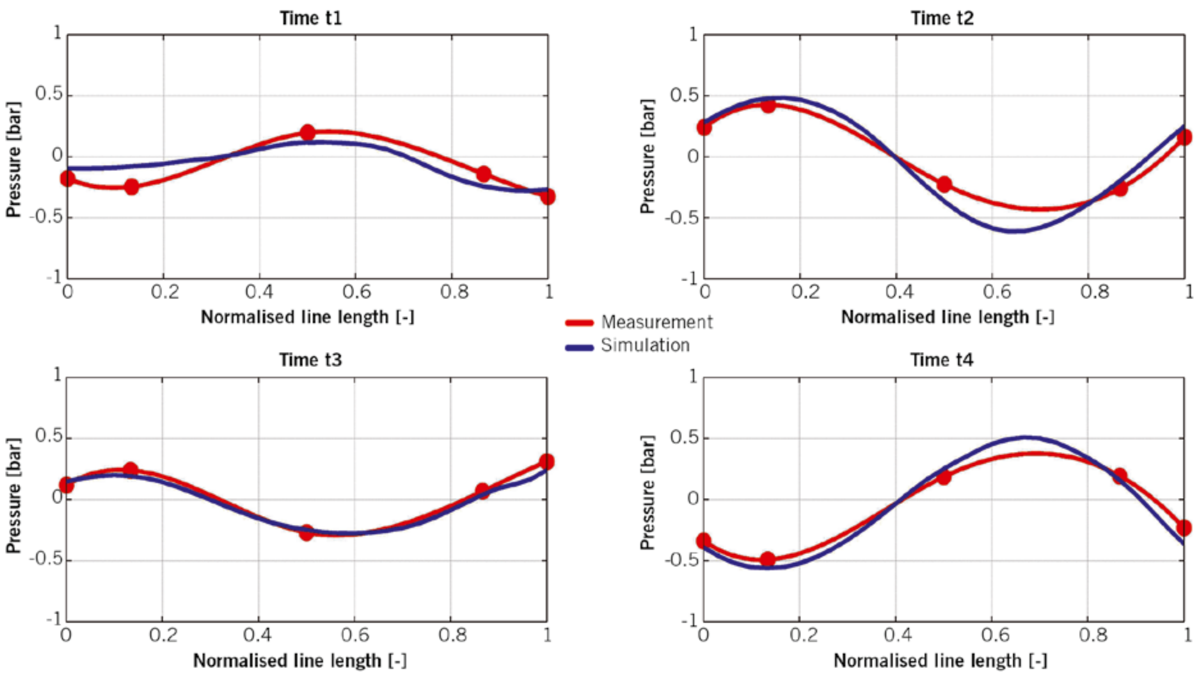


FIGURE 5 Display of the second natural frequency at about 1400 rpm (© Bosch)

an analytic approach, an observation of the system with a test bench was done. Beyond that, a system simulation with a commercial tool was realised.

The results from the analytic view and the 1-D simulation correspond very well with the experimental calculated data. Both, the natural frequencies and the related oscillation modes, could be determined for the first three resonance frequencies. The acquired understanding of the system will have an influence on the development and design of the future GDI generations.

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Rankine Fluids for Exhaust Gas Heat Recovery

The Rankine system has a high potential for reducing the fuel consumption and thus the CO_2 emissions of an engine. In other applications, the use of an ORC process (Organic Rankine Cycle) is already common practice, in the automotive sector the use of a Rankine system is certainly still considered innovative. At present, many different fluids are discussed for the ORC process for waste heat recovery, but a qualified assessment of their suitability for the evaporation and condensation process is missing. This fact leads to a wide variety of evaporator, condenser and expander concepts and a high variability of the interconnection possibilities of the waste heat recovery system. FVV now tested with own resources 18 fluids (eg water, ethanol, hexamethyldisiloxane (MM), iso-pentane, silicone oils, methyl pyridine, acetone, NovecTM, Otto-Fuel and refrigerant fluids) for suitability. In order to limit the number of potential fluids in advance, a list of criteria was created to evaluate the properties of the selected fluids: easy and safe handling, thermal stability, environmental sustainability, water pollution, global warming potential (GWP), ozone depletion potential (ODP), flammability, explosion hazard, material compatibility and last but not least cost and availability in the main export markets. With the five champions extensive simulations were performed. The assessment was carried out separately for two condensing temperatures of 100 and 40 °C. The fluids of acetone and ethanol (100 °C) showed a convincing performance. Furthermore, the fluids of n-hexane, methylcyclohexane, cyclohexane and toluene showed a good to very good overall picture. For the condensation temperature of 40 °C and the assumptions made cyclopentane and R1233zd could score. The obtained knowledge of the fluid properties will assist in particular small and medium enterprises (SMEs) in the development of optimised components and parts.

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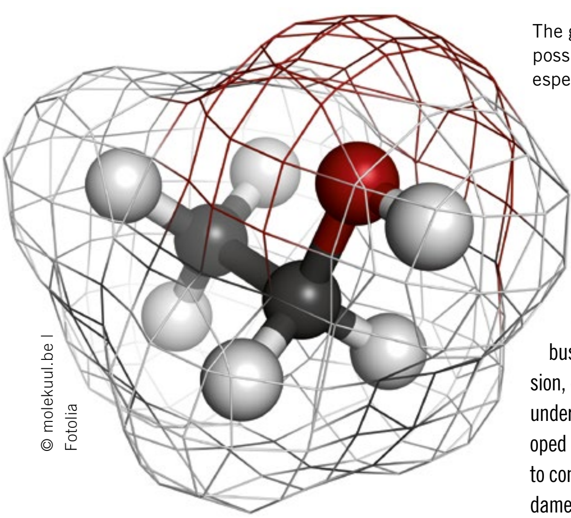
Anomalous Combustion Phenomena of Alternative Gasoline Fuels



The good knock sensitivity of ethanol makes it possible to increase the compression ratio, especially in supercharged gasoline engines

For the use of bioethanol containing fuels in modern combustion engines, especially in large-scale production, a further standardisation of fuel ratings is needed because the existing indicators (RON, MON) are not sufficient to describe anomalous combustion conditions. The good knock sensitivity of ethanol makes it possible to increase the compression ratio, especially in supercharged gasoline engines. With highly compressed and supercharged gasoline engines, however, in addition to the classical knocking other anomalous combustion phenomena such as glow-ignition and pre-ignition do occur. These anomalous combustion processes sharply increase the thermal and mechanical strain on the engine due to extremely high peak pressures and very high heat input into the components. Investigation into these phenomena is essential to further promote the downsizing technology. As part of an FVV research project partly funded by the Agency for Renewable Resources (FNR), the ignition and combustion anomalies of different fuels containing ethanol (e.g. surface-induced pre-ignition of hot combustion chamber deposits, pre-ignition by compression, evaporative cooling) were studied, a detailed understanding of the ignition processes was developed and the fuel behaviour evaluated in comparison to conventional gasoline fuel. The study covered fundamental investigations in a shock tube and in a combustion high pressure chamber to determine the fuel properties under defined conditions as well as engine tests for matching under realistic conditions. In addition, the investigations were accompanied by parallel simulations. The achieved test results can be used by any company involved in the engine development process as well as by mineral oil companies for the further development and implementation of future gasoline fuel standards.

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

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Lowering the Boiling Curve of Biodiesel by Metathesis

There exist some disadvantages when Biodiesel is used in vehicles equipped with diesel particulate filter (DPF). Especially during the regeneration phase, fuel bedabbles the piston walls and is taken over into the engine oil. Unlike fossil diesel fuel, biodiesel can not evaporate out of the engine oil because of its high boiling range. This leads to oil dilution and, furthermore, the formation of oligomers and oil sludge. The Thünen Institute of Agricultural Technology and the Technology Transfer Center Automotive Coburg (TAC) of the Coburg University of Applied Sciences modified the boiling behaviour of biodiesel by metathesis. This enables the new fuel to evaporate from the engine oil.

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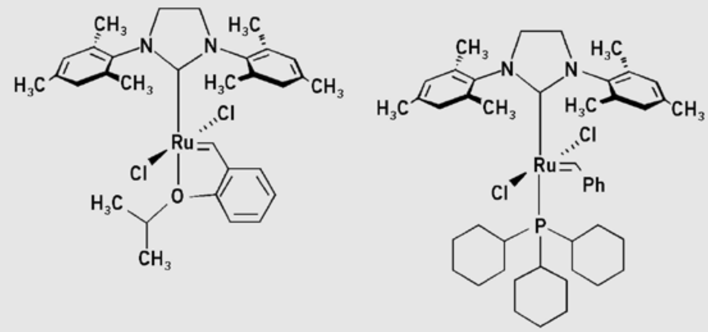

FIGURE 1 Structure of the Hoveyda-Grubbs second generation (left) and Grubbs second generation catalysts

1 MOTIVATION

Fuels from regenerative sources help to save fossil resources and therefore lower the anthropogenic greenhouse effect. In particular, fuels which can be used as drop-in fuels are of special interest. The fuels must be suitable for all generation of engines and therefore can be sold in the existing filling station network. Currently, biodiesel is the biogenic component predominantly used as blend component in diesel fuel. Unfortunately, the high boiling curve of fatty acid methyl esters (FAME) is not very well suited for modern passenger car engines with diesel particle filters (DPF). This is due to the post injection during the DPF regeneration phase which causes fuel to enter the piston walls and be taken to the engine oil by the piston rings. While the dominating part of diesel fuel can be evaporated from the oil pan, the biodiesel remains in the oil and leads to oil dilution [1]. If biodiesel stay over a longer period in the engine oil, it can lead subsequently to the formation of oligomers and polymers by thermal and oxidative processes. In extreme cases it results in oil sludge. We therefore decided to use metathesis to change the boiling behaviour of biodiesel and enable its evaporation from the engine oil [2]. The new metathesis fuel has been tested for material compatibility as well as for its burning behaviour and its emissions in a 20 % blend with fossil diesel fuel.

2 METATHESIS REACTIONS TO MODIFY BIODIESEL

The mechanism of metathesis reactions was first described by Yves Chauvin in 1971. In 1990, Richard R. Schrock developed a more effective catalyst and two years later Robert H. Grubbs described ruthenium- based catalysts, which are also effective and more stable towards water and oxygen. All three scientists were awarded the Nobel Prize in Chemistry in 2005 [3]. Two of the catalysts developed by Grubbs are shown in **FIGURE 1**. The active center is the central ruthenium metal atom. During the metathesis reaction, two alkenes interchange their alkylidene rests. In case of only one alkene, the reaction is called self-metathesis. Alternatively, if two different starting alkenes are used, the reaction is called cross-metathesis, **FIGURE 2**. Depending on the percentage of the educts, an equilibrium of products is obtained including self-metathesis products.

To approximate the boiling curve of the biodiesel to that of diesel fuel, the cross-metathesis was used. Self-metathesis changes the

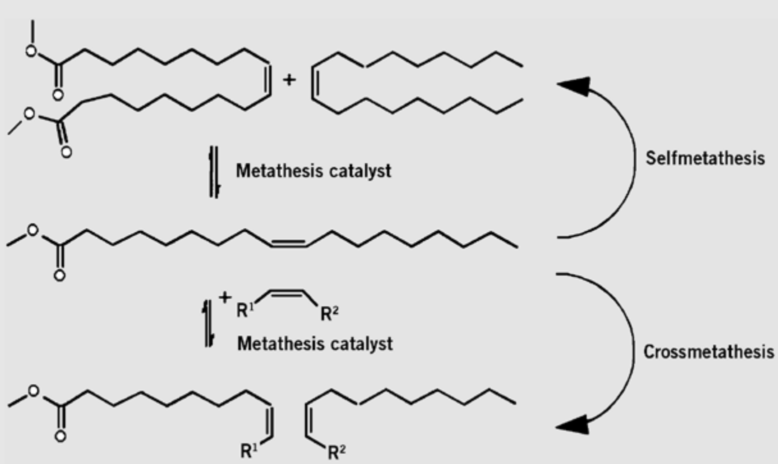

FIGURE 2 Self- and cross-metathesis reactions of oleic acid methyl ester (© Thünen Institute of Agricultural Technology)

alkylidene rests of unsaturated methyl esters in biodiesel. Using self-metathesis, the products have both lower and higher molecular weight. The higher molecular products have higher boiling points than biodiesel and are therefore tentatively undesired. Therefore, the cross-metathesis is better suited to lower the boiling curve, whereas the reaction partners must have a clearly shorter chain length compared to the methyl ester used. Therfore α-olefins are a good choice. They can easily be obtained by cracking processes in refineries.

1-hexene was used for metathesis reactions with biodiesel. Theoretical considerations have shown that the product mixture should have a boiling temperature of about 230 °C. **TABLE 1** shows the main components of the metathesis reaction from rape seed oil methyl ester (RME) and 1-hexene, measured by gas chromatography-mass spectrometry (GC-MS). Next to the listed molecules, also substances with a molar mass higher than that of biodiesel were formed in the reaction. These products could not be measured by GC-MS but were detected by size exclusion chromatography (SEC).

The metathesis reaction of biodiesel with 1-hexene was carried out with different catalysts, different catalyst loadings, different equivalents of hexene and under different reaction conditions. While the choice of catalyst and the reaction parameters influenced mainly the speed of response, the selection of the ratio between biodiesel and 1-hexene had the greatest influence on the boiling line. Overall, more than ten different metathesis fuels were generated. The boiling curves of these fuels were more or less comparable to the boiling curve of fossil diesel fuel. In **FIGURE 3**, the comparison of the boiling curves of biodiesel, fossil diesel fuel, and six metathesis fuels are shown. The boiling curves were obtained by simulated distillation (SimDis).

3 COMPATIBILITY OF MATERIALS

To get an impression of the impact of the new fuel on plastics, a durability test according to DIN EN ISO 175 was carried out with self-metathesis fuel using two polymer samples. Samples of polyamide (PA 66 Ultramid A3K) and high density polyethylene (HDPE Lupolen 4261) were stored for a period of seven days at a temperature of 70 °C in 70 mL of metathesis fuel (self metathesis, Metathesis$_{0,0}$). As reference samples were stored in fossil diesel fuel and rapeseed oil methyl ester. In addition, reference samples were stored at 22 °C and 45 % humidity in a climatic chamber. After this time, changes in mass, elastic modulus and tensile strength according to DIN EN ISO 527-2 was determined, **TABLE 2**.

The reference samples in the climatic chamber at 22 °C and 45 % humidity didn't change significantly. The polyethylene samples (HDPE) stored in the fuels showed a significant increase in sample mass, while the increase during the storage in diesel fuel showed almost twice as compared to rapeseed oil methyl ester and metathesis fuel. In relation to the mass of a test piece of about 8.8 g, the increase was just below 10 % for diesel fuel. The PA-samples showed a significantly lower swelling. Comparing the sample mass of 11.2 g, the mass growth during the fuel storage of less than 0.1 g was below 0.1 % of the original mass.

Between the reference sample in air and the samples stored in the fuel only slight differences in the modulus of elasticity and

Product	Boiling temperature [°C]	Content [%]
5-Decene + 1-Decene	172	13.3
5-Undecene	192	2.7
5-Dodecene	213	0.9
5-Tetradecene	251	15.2
4-Decenoic acid methyl esther	215	18.1
9-Octadecene	314	2.5
Methyl myristoleate	306	31.8
Hexadecanoic acid methyl ester (C16:0)	332	6.3
9-Octadecenoic acid methyl ester (C18:1)	351	9.2

TABLE 1 Reaction products of the cross-metathesis reaction of RME with 1-hexene (© Coburg University of Applied Sciences)

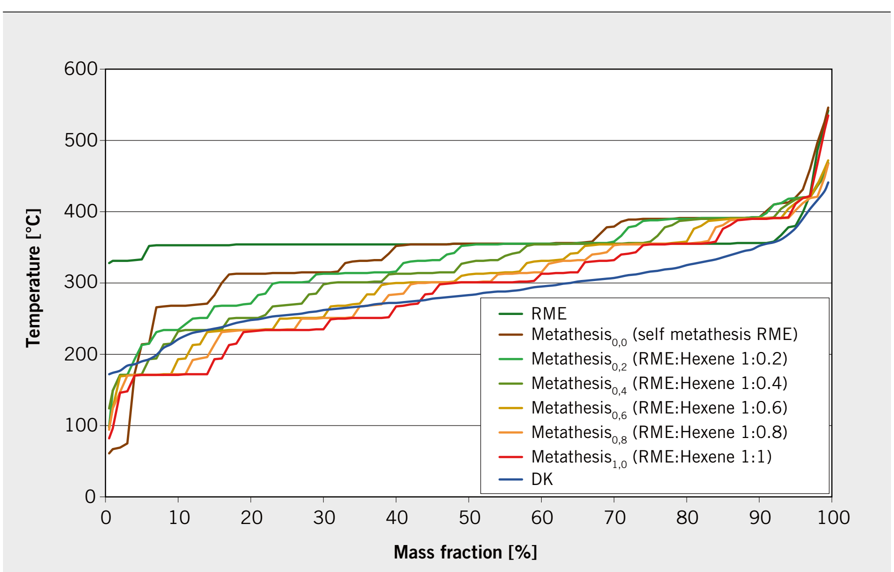

FIGURE 3 Boiling curves of biodiesel, fossil diesel fuel and a metathesis fuel (SimDis) (© Thünen Institute of Agricultural Technology)

Stored in		Reference (Air)	DF	Metathesis fuel	RME
Changes in mass (mass of sample)	PA (11.2 g)	0.01	0,04	0.05	0.07
	HDPE (8.8 g)	0.00	0.78	0,45	0.40
Elastic modulus	PA	2434	2076	2108	1906
	HDPE	793	420	553	566
Tensile strength	PA	65	64	64	61
	HDPE	27.2	23.2	24.5	25.0

TABLE 2 Results of material compatibility tests (© Thünen Institute of Agricultural Technology)

tensile strength were observed. The modulus of elasticity decreased slightly after storage in fuel. Thus, the samples are somehow more flexible than before. This trend can be seen in both materials. The tensile strength of PA didn't change significantly. In contrast, the tensile strength of HDPE decreased during storage in all fuels, whereas diesel fuel led to the greatest decrease. In summary, the metathesis fuel showed no higher influence on material properties as compared with RME and diesel fuel.

4 EMISSION TESTS

Since metathesis fuels will probably not be available as neat fuels in the near future, blends of 20 % metathesis fuel in diesel fuel were produced and tested. From 10 different metathesis blends, two blends were chosen for extended emission tests in a heavy-duty truck engine (Mercedes OM 904 LA, Euro IV) by a selection process that took into account: the boiling behaviour, the biogenic content and the regulated emissions from a single-cylinder engine (Farymann 18 W). The highest biogenic content had the metathesis fuel obtained from the self-metathesis. At 20 % blend of Metathese$_{0,0}$ this fuel will be called M20. According to emission behaviour in the single cylinder engine, the fuel Metathese$_{0,8}$ showed the best results. At 20 % blend of Metathese$_{0,8}$ it will be called N20.

In addition to the regulated emissions (NO_x, CO, HC and PM), the non-regulated exhaust gas components ammonia, polycyclic aromatic hydrocarbons (PAH), aldehydes, as well as mutagenicity of the exhaust and the particle size distribution were tested as well. Fossil diesel fuel (DF), biodiesel from rape seed oil (RME) and a B20 blend of RME in DF were used in comparison with the metathesis blends (M20 and N20).

In operation with metathesis fuel blends, the emissions of the OM 904 LA only showed very slight deviations from B20, **FIGURE 4**. The nitrogen oxide emissions for RME were much higher than for DF, and also the B20 or metathesis blends showed a slight increase. The opposite effect was observed with particle mass, where the use of RME led to a reduction of 25 %. However, this trend was not observed for the blends. Their particle masses were within the order of magnitude of DF at 0.01 g/kWh and within the standard deviation. A significant reduction in hydrocarbon and carbon monoxide emissions was also observed for RME. For the mixtures, a reduction was only found for HC emissions of the B20 blend. In contrast, the carbon monoxide emission of B20 and N20 showed a slight increase. Only one of the metathesis fuels showed no increase compared to diesel fuel. However, almost all regulated emissions were within the Euro IV specification that applied to the engine used. All specifications were attained for three of the four fuels used. Only the nitrogen oxide emissions of RME slightly exceeded the threshold value of 3.5 g/kWh. For non-regulated exhaust gas emissions, only slight differences between the metathesis blends and B20 could be found. The carbonyl emissions were in the same order of magnitude and therefore no significant differences between the fuels used were recognisable. In the particle size distribution, little difference could be found. The metathesis fuel blends showed a slight increase in the number of particles in the size range from 28 nm to 1000 nm compared to the B20 blend. In the range of 2 µm to 10 µm, the emission of the B20 blend was higher, **FIGURE 5**.

The individual emissions of 15 measured PAHs showed no clear changes because of high standard deviations. Therefore, the environmental effect was determined by calculating the benzo[a]pyrene

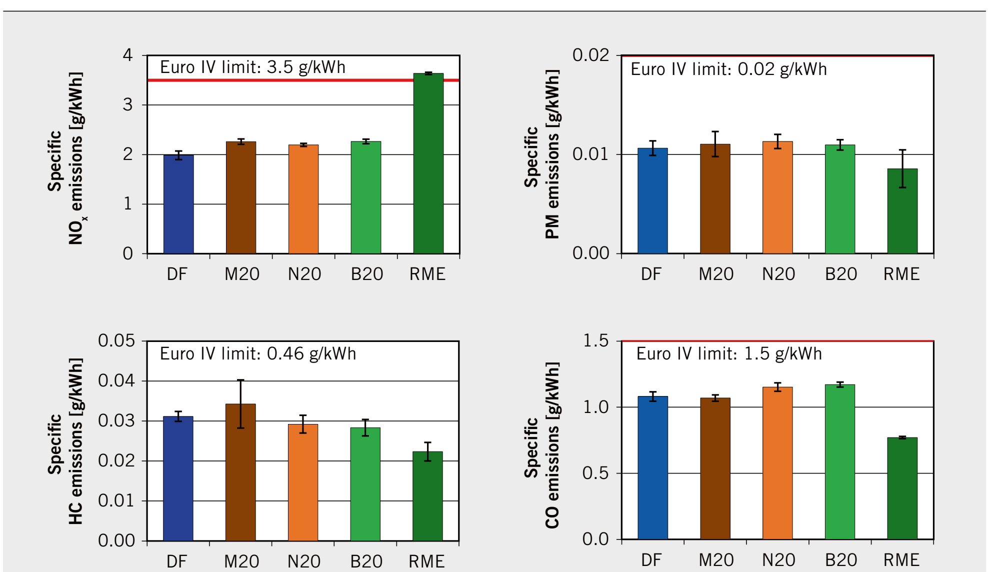

FIGURE 4 Emission of fossil diesel fuel, 20 % blends of both metathesis fuels and biodiesel in DF, and neat biodiesel, tested in an OM 904 engine with SCR catalyst (ETC test) (© Thünen Institute of Agricultural Technology)

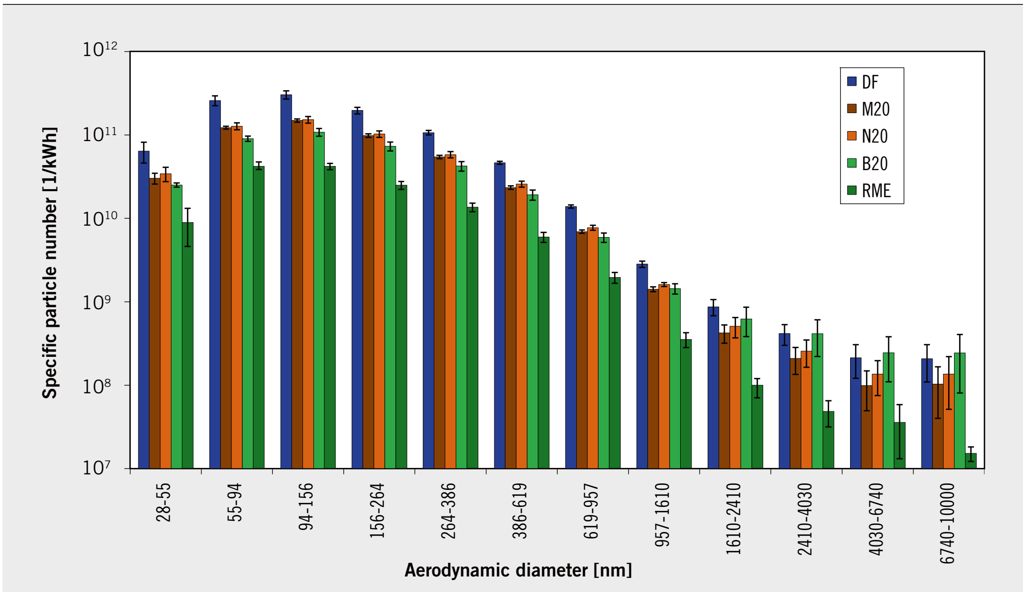

FIGURE 5 Particle size distribution of fossil diesel fuel, 20 % blends of both metathesis fuels and biodiesel in DF, and neat biodiesel, tested in an OM 904 engine with SCR catalyst (ETC test) (© Thünen Institute of Agricultural Technology)

equivalent effect [4]. This effect sums up all individual PAH emissions, multiplied by a factor depending on the health effects of the PAH, **FIGURE 6**. In addition to the effect equivalent sampled after the exhaust after-treatment system, the effect equivalent of the raw exhaust gas was also determined. Here, the benefits of the SCR catalyst system could clearly be shown. The effect equivalent of diesel fuel and the blends decreased from 30 to about 10. This decrease can be explained by the significant reduction of organic-soluble fraction by the catalyst. Together with the organic-soluble fraction, the polycyclic aromatic hydrocarbons in this fraction were also eliminated to a large extent. The RME equivalent effect in the raw exhaust gas was already below the other four fuels and the reduction by the SCR system was higher than for the other fuels. After the SCR system also the metathesis blend N20 showed a reduced effect equivalent. However, in considering the standard deviations of the PAH measurement, this behaviour could not be safely confirmed.

Regarding mutagenicity, it was to assume that a use of an SCR catalyst leads to low emissions of mutagenic substances. This is because the SCR system has a built-in oxidation catalyst, which eliminates the PAH and other mutagenic substances. Therefore, like the PAH sampling, the mutagenic samples were taken from the raw exhaust gas and after the SCR system. The determination of mutagenicity was carried out using the Ames test with the salmonella strain TA98 [5,6]. The direct mutagenicity was measured as well as the indirect mutagenicity from metabolites using rat liver enzymes (S9 fraction). The admixture of biogenic fuels tends to a decline in direct mutagenicity in the raw exhaust gas, **FIGURE 7**. RME and also the metathesis blend M20 showed fewer mutations. The indirect mutagenicity of all fuels tested showed no significant differences. After the SCR system there was almost no mutagenic potential. Only for diesel fuel, a very low mutagenicity could be detected. In summary with regard to the mutagenicity, no negative effect on emissions was observed by using metathesis fuels.

Furthermore, studies with metathesis blends compared to diesel fuel were carried out using an AVL single cylinder research engine based on an MAN D28 engine with respect to emissions and combustion behaviour. The test engine with a displacement of 2059 cm^3 was equipped with four valves per cylinder and a Bosch second-generation common-rail injection system. In addition, the motor had a supercharging using an electrically driven screw compressor, a flow heater for intake air conditioning and a temperature-controlled external exhaust gas recirculation (EGR).

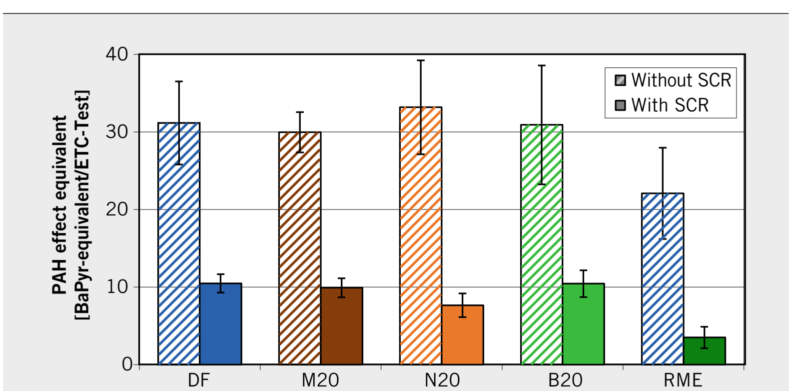

FIGURE 6 Effect equivalent of PAH emissions from particulate and condensate of the OM 904 LA in the ETC test (© Thünen Institute of Agricultural Technology)

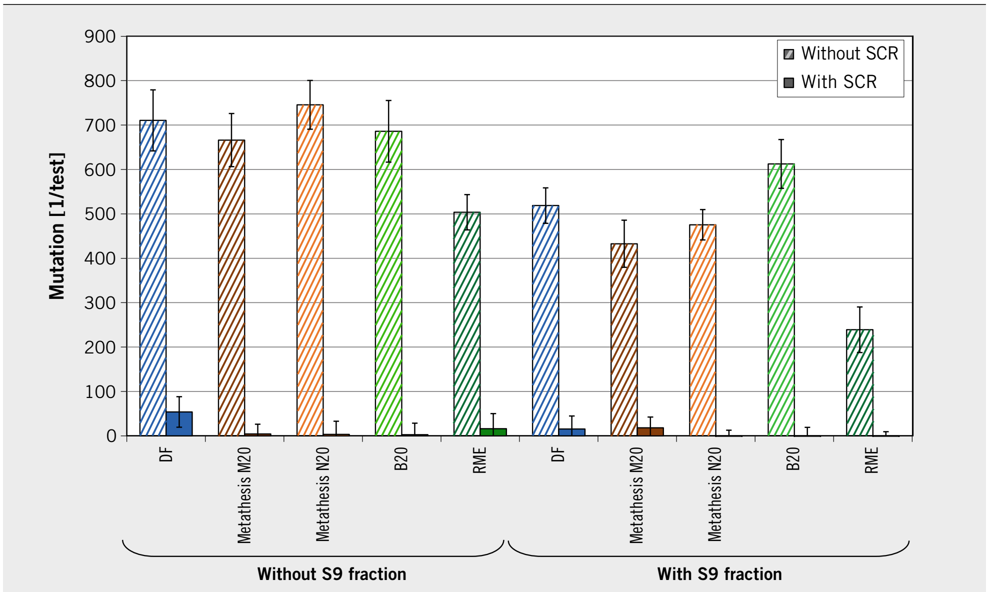

FIGURE 7 Sum of the mutagenicity in particulate and condensate from DF and RME compared to three blend fuels at the OM 904 LA in the ETC test with the bacterial strain TA98 (© Thünen Institute of Agricultural Technology)

Due to the limited availability of metathesis fuel, only the operating points 1, 3, 5, 7 and 9 of the ESC test were made. All points without the idling point 1 were tested both without and with exhaust gas recirculation.

In summary, the motor behaviour of all investigated fuels was very similar and therefore the emissions of all fuels were comparable to those of conventional diesel fuel. The particulate emissions from points without EGR were very low for all fuels. With an EGR rate of 25 %, the particulate emissions rose as expected. The metathesis blends showed a trend of lower particulate emissions than other fuels. Without EGR the nitrogen oxide emissions showed almost no differences, however, a slight increase for the metathesis blends could be found with exhaust gas recirculation. The carbon monoxide and hydrocarbon emissions were very low for almost all operating points. A slight advantage was apparent for the fuel blends. In addition, the combustion process using the different fuels showed no significant differences within the measurement accuracy of the available metrology. Slight variations in the pressure gradients can be explained by the different boost pressures with the same starting air ratio due to variations in the minimum air consumption. Differences in the ignition and the energy release could not be seen clearly, suggesting small differences in fuel-mixture generation, ignition and burnout behaviour of the investigated fuels.

5 SUMMARY

By using the metathesis reaction, the boiling curve of biodiesel can be lowered. The best fit to the boiling curve of conventional diesel fuel can be reached by using 1-hexene as reactants. The resulting metathesis fuel has been extensively studied and tested in three different diesel engines with regard to the resulting emissions.The investigations showed, that metathesis fuels are suitable for use in internal combustion engine. Boiling behaviour and material compatibility of pure metathesis fuel and also the regulated and non-regulated emissions and the burning behaviour of 20 % blends with diesel fuel demonstrated that metathesis fuels can be used without limitations.

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8th MTZ Symposium **Charge Exchange in the Combustion Engine**

Achieving future CO_2 goals alongside high performance values and a good dynamic response depends on optimising the charge exchange in diesel and gasoline engines for passenger and commercial vehicles. This is a process for which system-wide optimisation of all components involved in the charge exchange process is crucial. Around 150 experts gathered to discuss charge exchange in combustion engines at the 8th MTZ Symposium on 20 and 21 October 2015 at the Mercedes-Benz Museum in Stuttgart, devising solutions which are now proving their worth.

SEPARATING HOT AND COLD

In future, combustion engines will be increasingly supplemented or even replaced by alternative drive systems. Both vehicle makers and automotive suppliers are tackling the issue of how best to manage this process and determining which approaches to follow for conventional combustion engines in the meantime. The central issue of the keynote speech given by Dr. Joachim Schommers from Daimler was, therefore, "Over 125 years of automotive combustion engines – how to sustain the success story?" Dr. Schommers sees the future in "emission-free combustion via electric traction". The car industry is working with universities to find sustainable solutions. However, the widespread use of electric vehicles is currently hindered by their limited range and high cost. Hybrid drive systems have been deployed to solve the range problems and, while they beat electric-drive only models on price, they are still more expensive than straight combustion engines. "This explains why we cannot yet talk in terms of 'widespread use'," said Dr. Schommers. "This is also why Daimler will continue to support the combustion engine. Any swift, economic changes we target in future will have to be achievable with the combustion engine. Nevertheless, we are also optimistic that significant untapped potential still remains in this field." When developing new diesel engines, the aim has to be to cover the entire range of vehicles while minimising variation among engines to ensure minimised costs while maintaining high quality. In response, Daimler has developed the new OM654 diesel engine. This is the first in a new series of engines set to be deployed in the majority of Daimler vehicles in the final stage of development. "The new engine features strict separation of hot and cold charge exchange units. The objective in this case was to design the entire exhaust aftertreatment as a component of the engine itself. The advantage here is eliminating the need to take different vehicle models into consideration."

DECARBONISATION OF ROAD TRAFFIC

Over time, the handling of "combustion air" in combustion engines has become more and more complex. On the one hand, this is attributable to ever-increasing drive power densities, but also to ever more stringent legal requirements. Given proposals and initiatives to uncouple road traffic from the "natural" carbon cycle (decarbonisation), the question arising nowadays concerns the future of air path technology and its production. The second keynote speech of the symposium, given by Dr. Simon P. Edwards from Ricardo Deutschland, thus explored the issue of "Decarbonising road traffic – Historical challenge or a new opportunity for air path development?" He responded to the question by

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providing an insight into the future perceptions, proposals and plans of bodies in Brussels dealing with powertrain technologies. Dr. Edwards concluded as follows: “Within a market where combustion engines look set to remain the dominant drive technology for some decades, and given the constraints which equate boosting efficiency to directly reducing fuel consumption and contributing directly to decarbonisation in the process, the need to further develop air path systems in the short- and medium-term must be acknowledged. Overall, therefore, sufficient challenges remain for air path systems in future.”

TIME FOR DISCUSSIONS

The first day closed with an opportunity for all participants to discuss the numerous technical innovations on show and enjoy networking over good food at Mahle Inside. At the end of the second day, many participants took advantage of the offer of a free visit to the Mercedes-Benz Museum. This year, experts from the charge exchange sector will have the opportunity to learn about the very latest industry developments and trends. The conference, organised with in cooperation with Mahle will be taking place on 25 and 26 October, 2016, once more in the Mercedes-Benz Museum in Stuttgart.

Andreas Fuchs

QUOTATIONS

Dr. Joachim Schommers, Daimler:
“There is plenty of life left in the combustion engine!”

Dr. Simon P. Edwards, Ricardo Deutschland:
“Sufficient challenges still remain for air path system in future.”

Dr. Jochen Müller, Bosch Mahle Turbo Systems:
“Combustion engine requirements have become increasingly stringent due to the introduction of RDE and WTC.”

PHOTOS: Uli Regenscheit

Scientific Director of the conference, Prof. Wilhelm Hannibal (on the right) moderated the panel discussion at the end of the first day (© Uli Regenscheit)

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COVER STORY

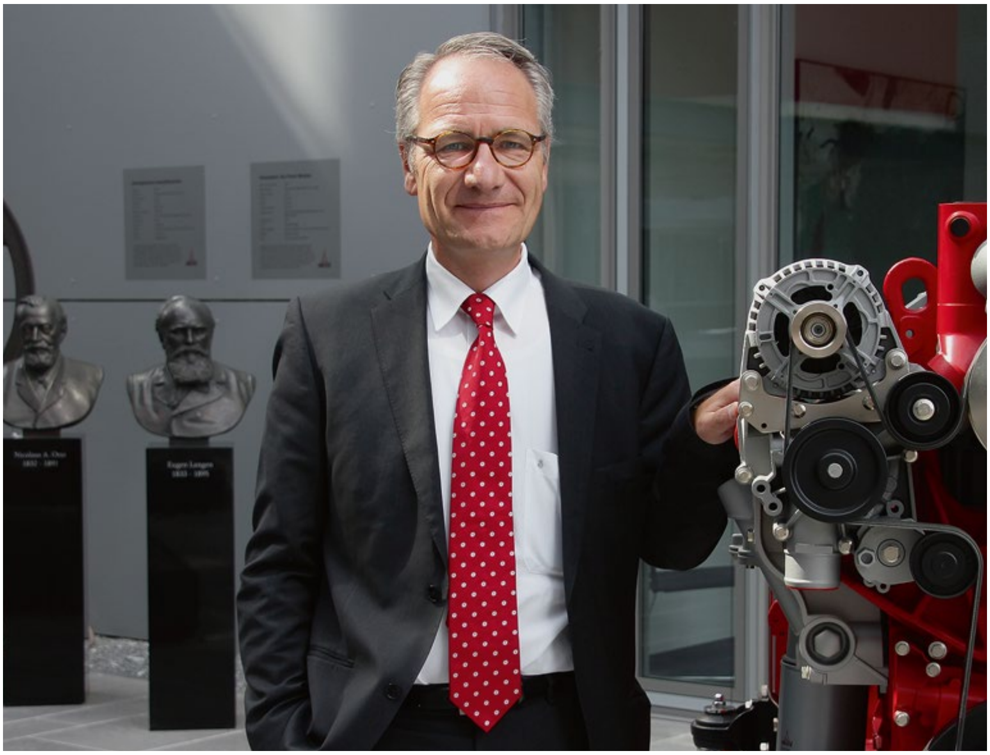
48-V Electrical System

The standard operating voltage of 12 V established in the 1960s is reaching its limits for modern passenger cars with their many electrical loads. This makes a new higher-voltage standard unavoidable. The 48-V electrical system is the next logical step – opening up new possibilities in the powertrain.

AVL and Kia Hyundai have integrated a 48-V mild hybrid system into a Kia Optima with a 1.7 l turbo diesel engine and consequently reduced consumption by up to 15 %. The system comprises a belt-driven e-motor for energy recovery and transient support and an electric supercharger.

The Institute for Powertrains and Automotive Technology at the Vienna University of Technology has developed a concept vehicle to demonstrate that it is even possible to develop a hybrid with a fully-fledged drive system with 48 V using an ultralight vehicle design.

In our interview, Alexander Kruse, Developer in the Powertrain Electrification department, explains Audi's 48-V strategy: 2016 will see the launch of the first vehicle with electrical supercharger – and mild hybrid models will be successively added to the entire model range from 2017 onwards.



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Fit for the Future

Combustion engines are perfect for mobile machines. And this is where they come into their own with their durability, compactness, fuel efficiency, extensive range and, last but not least, a beneficial price/performance ratio. This is true of small engines used in auxiliary units for units conveying oil north of the Arctic Circle as well as high-performance diesel engines in large tractors used by major agricultural enterprises. Emission legislation represents a key challenge to driveline development in the off-highway field and has become increasingly stringent worldwide in recent years. Stage V, set to come into force in Europe in 2019, imposes the most significant constraint – the threshold value for the number of particles requires a closed particulate filter. All Deutz engines, with cubic capacity from 2.9 to 7.8 l and equipped with diesel particulate filters, already meet this emission limit and thus constitute a sustainable drive solution for the entire range of mobile work machines. In the process, the control unit software handles exhaust after-treatment across the entire engine map. Package solutions have also been developed that integrate the exhaust after-treatment into the entire vehicle range, from earthmovers to tractors.

In other words, the combustion engine has done its "homework" for the next ten to 15 years. However, electrification can also benefit mobile machines. For example, mild hybrids with 48 V technology and 15 kW electrical output can enhance the function of start/stop systems, or hydraulic units within the machine can be replaced with electrical alternatives. Whether or not electrification will proceed to the next stage, as with on-highway use, very much depends on price trends and battery performance. Key among the requirements imposed by off-highway use is the increased durability of the unit and the required range.

Networking (Internet of things) is another interesting area for mobile machines and is being developed intensively for agricultural and construction machinery. The engine, including an exhaust system, also has a powerful software package in which a multitude of key data is generated for the machine. Of course, the engine control unit is also interconnected with the vehicle control unit and using telemetry, the fleet-wide deployment to all vehicles can be optimised. Conversely, having direct access to the data software included in the engine control unit can open up a whole new range of potential for the user.

The combustion engine will remain the dominant force in mobile working machines for the coming decades – with electrification and networking set to boost the functional scope considerably.