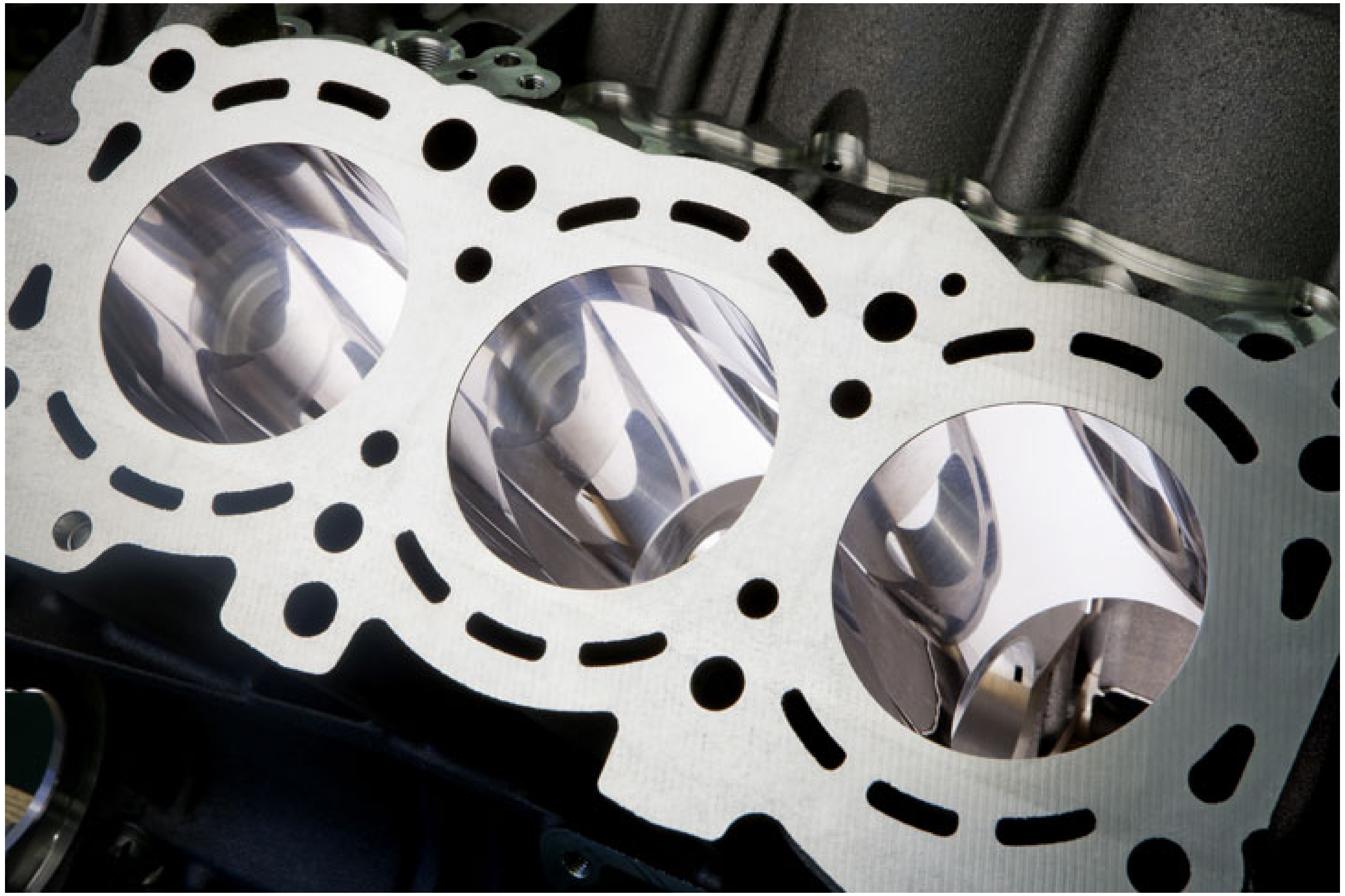

Mercedes-Benz Diesel Engines

Finding further potentials within the constraints imposed by physics

In the medium term, the internal combustion engine will maintain its dominant position as a vehicle drive system while acting as a pathfinder towards electric mobility. MTZ interviewed Bernhard Heil, Head of Development Passenger Car Engines and Powertrain at Mercedes-Benz, what to expect up to the year 2020.

Bernhard Heil, born in 1960, believes that his central managerial function is to promote the high technical creativity and Swabian inventiveness of his employees in the best way possible. This is because the development of innovative powertrains is the essential factor which will allow fuel consumption and driving emissions to be reduced in future. Born in the German state of Rhineland-Palatinate, Bernhard Heil completed his studies of mechanical engineering at Kaiserslautern Technical University in 1985, after which he stayed with the Daimler company. After various positions at what was then Daimler-Benz AG, he took over responsibility for the department of V-Engine Design in 1994, and in 1999 he became head of Spark-Ignition Engine Development. In 2003, he moved to commercial vehicle development. In 2010, Bernhard Heil returned to passenger car development, taking over as head of Programme Management and Development of Passenger Car Engines and Powertrain.

MTZ: In the light of the electrification debate, is it even worth still investing in conventional powertrains with a petrol or diesel engine?

Heil: Absolutely. In the past five years alone, we have made quantum leaps in the development of powertrains. In our 7G-Tronic automatic transmission, we have succeeded in reducing fuel consumption by up to 7 % due to a wider gear ratio spread and friction optimisation. And development is not at a standstill. We are already working on the next generation, in which we will use the benefits of this transmission even more consistently. As far as the engines are concerned, we have introduced the third generation of DI engines with piezo injection and lean combustion. In these engines, we have succeeded in extending the map area of the lean combustion process to an extent that we didn't believe possible at the beginning. This enabled us for the first time to certify a spark-ignition engine on the same CO2 level as a diesel engine.

Which further developments can we expect from Mercedes-Benz by the year 2020?

We will continue to optimise the combustion process in the spark-ignition engine in order to improve the lean running capability of the engine. This will require intensive further development on the injection system. Today, Mercedes-Benz is the only manufacturer to offer spark-ignition engines with jet-guided combustion processes and centrally arranged piezo injectors in series production. From our point of view, that is the right way. We are the leaders in combustion efficiency and intend to remain so. Furthermore, supercharging is becoming increasingly important. We are much more committed than our competitors, for example through our joint venture with IHI, in which we are actively promoting further developments with our partners. As a third element, we are continuing to focus on the subject of exhaust aftertreatment, in both diesel and spark-ignition engines.

In spark-ignition direct injection systems, system pressures are currently 200 bar. What will be possible, and worthwhile, in the future?

We are constantly examining further developments in fuel injection systems very precisely to check whether we can further increase the stratification capability of the engines by increases in pressure. From today's perspective, we are in a very good position with our 200 bar systems. At the moment, we are concentrating on making even better use of the possibilities that the piezo system offers with regard to multiple injections in order to further extend the stratification capability of the engines.

What are the limits to downsizing in spark-ignition engines?

With the comfort demands that we formulate for ourselves, I would say in the magnitude of 100 kW/l, or perhaps a little higher.

In the 1990s, you used compressor supercharging in spark-ignition engines. Are you still working on mechanical supercharging alongside turbocharging?

At that time, compressor supercharging was the best technology, also because our transmissions did not have such a wide gear ratio spread as today. The driveaway behaviour and non-steady-state characteristics of a turbocharged engine did not fully meet our comfort requirements. Today, our transmissions have a wider spread, the turbochargers have been considerably further developed and we can also further optimise the combustion process for turbocharging by using variable camshafts and direct fuel injection. For that reason, our focus is on exhaust gas turbocharging.

Dual-clutch transmissions or automatic transmissions with a torque converter which system will be predominant in the future?

For our classic model series, we will continue to offer our torque converter automatic transmissions. Firstly, an automatic transmission with a torque converter offers unsurpassed comfort when pulling away from a standstill. Secondly, the increased driveaway torque is a further comfort aspect, as we do not have to work with the very shortest driveaway gear ratios. What is more, torque converter automatic transmissions can be very well integrated into our standard powertrain package. From a fuel consumption point of view, all measurements show that the torque converter automatic transmission is the most efficient solution in our classic series. For model series with front-wheel drive, the installation space available determines the technical possibilities. A torque converter automatic transmission is approximately 30 to 40 mm longer than a dual-clutch transmission, so it does not make sense to integrate it into the front-end structures. Therefore, for cars with front-wheel drive, we will focus on dual-clutch transmissions in the future.

We are now hearing much less about the Diesotto engine, which was greatly publicised a short time ago. Are you still working on it?

Our aim is to make petrol engines as efficient as diesel engines and make diesel engines as clean as petrol engines. As far as diesel engines are concerned, the use of particulate filters and our BlueTec technology have enabled emissions to be reduced almost to the level of spark-ignition engines. We are now working on making the spark-ignition engine as fuel-efficient as the diesel. We included all these aspects under the working title "Diesotto". The spark-ignition engine is benefiting from many technology components that were previously familiar from the diesel engine. For example, these include turbocharging and direct injection. In other words, there is already a great deal of Diesotto in our new BlueDirect engines.

How great is the potential for CO2 reduction as a result of the system optimisation of all powertrain components by 2020?

We will not be able to change the limits of the Carnot Cycle, so our aim will be to find further potentials within the constraints imposed by physics. I am sure that we can achieve further improvements by optimising stratification processes and downsizing, for example to achieve the power output of current six-cylinder engines with four-cylinder engines in the future. With regard to transmissions, we are considering gear ratio spreads and numbers of gears. For larger vehicles, further potentials can be found in hybridisation and, for smaller vehicles, in electrification.

What will be the dominant engine in the future, the petrol or diesel engine?

We can see a further increasing trend towards petrol engines. The growth markets of India, China or Russia in particular are classic petrol engine markets. Diesel fuel will be concentrated very strongly on goods traffic, in other words trucks, trains and ships. For these applications, any solution away from the diesel engine is very unlikely. In Europe, the situation is completely different. The high proportion of diesel vehicles was one of the main reasons for progress in fleet fuel consumption and CO2. What is more, the diesel engine is unbeatable with regard to torque. This will contribute to the fact that modern and clean diesel engines will continue to enjoy a high level of popularity.

Will there still be any powertrains at all without electrification?

We can argue about the market penetration of hybridisation. I am sure that we will see a considerable proportion of hybrid vehicles in 2020. We at Mercedes-Benz also see a market for large premium vehicles in the future, provided that they are environmentally compatible. For that reason, our approach is to further improve the efficiency of our vehicles by an increasing use of electrification and to continue to offer our customers comfortable, safe and dynamic premium cars in the future.

Do you see pure electric mobility coming more from the lower end of the market?

Electric mobility will initially have relevance in the segment of smaller vehicles because, in that segment, the required driving ranges are not as great as to demand an additional internal combustion engine as a range extender. This means that we can open up the subject of electric mobility to a relatively large customer group. An electric vehicle with a range of 100 km being used purely as a second car seems to me to be a perfectly reasonable proposition. For the classic Mercedes model series, I see a different route: initially, further optimisation of the internal combustion engine, then hybridisation, and then the plug-in hybrid, to enable people to drive in zero emission zones.

Bernhard Heil, thank you very much for this interview.

THE NEW V6 DIESEL ENGINE FROM MERCEDES-BENZ

Mercedes-Benz has further enhanced the efficiency of its V6 diesel engine with the internal code OM 642. By using a turbocharger with anti-friction bearings for the first time in a passenger car diesel engine and an extensive package of measures to reduce fuel consumption, the manufacturer has succeeded in combining high power output and torque with high fuel economy.

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HIGHER POWER AND TORQUE, LOWER FUEL CONSUMPTION

The Mercedes-Benz product portfolio has included a 3.0-l six-cylinder diesel engine since 2005. Since then, far beyond one million customers have opted for a V6 diesel engine in the various vehicle applications. Stricter emission regulations coupled with own requirements for ecologically compatible products in the premium class call for a further reduction in the emissions and fuel consumption in the vehicles offered. This is accompanied by the desire for enhanced performance to ensure their attractiveness to the customer.

This article presents the measures which were implemented during the revision of the engine bearing the internal designation OM 642 LS and which enabled an increase in the engine's power and torque of 18 % and 22 % respectively. With a headline figure of 620 Nm, this V6 diesel sets a new benchmark in its class. Fuel consumption was reduced by up to 21 %.

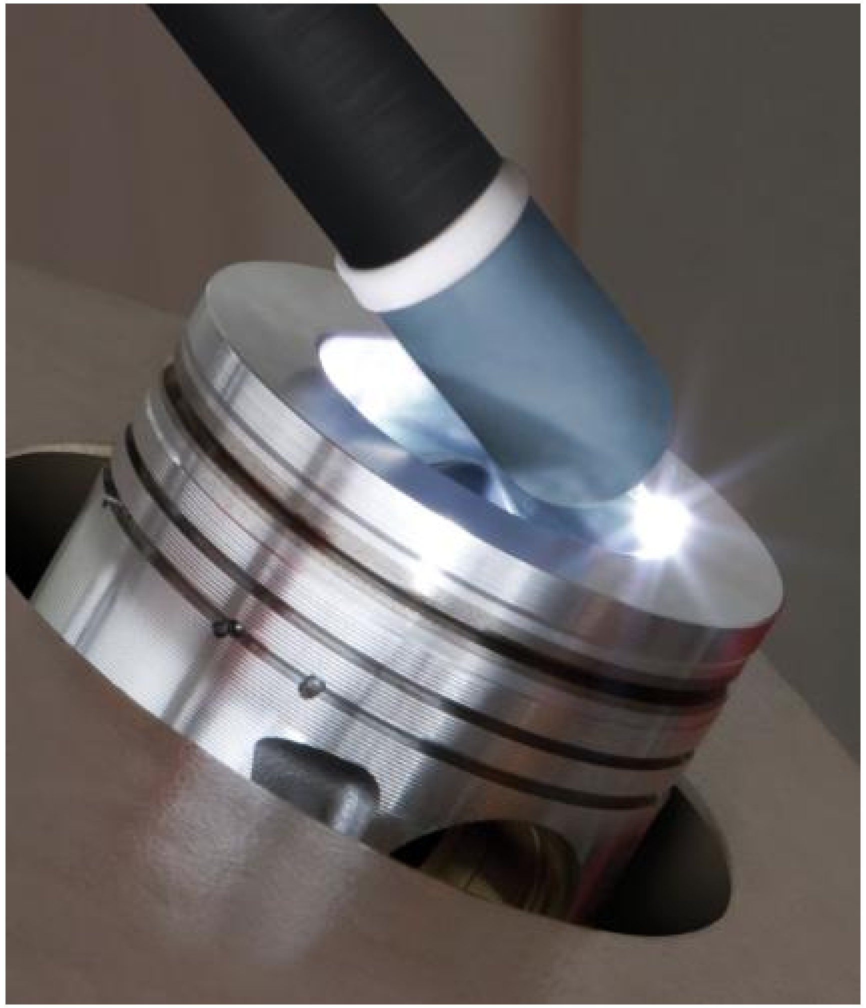
The new V6 diesel engine has been used in the E-Class and R-Class at Mercedes-Benz since fall 2010, ❶. It is also available in the S-Class in conjunction with the successful Mercedes-Benz BlueTec system. In 2011 the launch in further model series will follow.

MAIN TECHNICAL EMPHASIS

The greater mechanical load resulting from the higher performance as well as the associated rise in temperature in the engine required the component modifications described below. They are summarized in ❷.

ENGINE AND CRANKCASE

Following the example of the four-cylinder diesel engine, pistons with bowl lip remelting are used. This involves using an electric arc to melt the bowl lip. During the subsequent rapid solidification of the aluminum-silicone alloy, the sizes of the silicone crystals and of the intermetallic phases are significantly reduced. Thanks to this finer and more uniform microstructure, susceptibility to cracking is significantly reduced. The strength values increased in this way enable an emission-optimized design of the combustion chamber cavity.



INDUSTRY DIESEL ENGINES

		OM 642 EU4 3.0 L V6 DIESEL	„NEW“ OM 642 LS EU5 3.0 L V6 DIESEL
Number of cylinders	-	V6	
Bank angle	degree	72	
Valves / cylinder	-	4	
Displacement	l	2,987	
Bore	mm	83	
Stroke	mm	92	
Cylinder offset	mm	106	

low engine oil consumption by some 40 %. This was accompanied by a further reduction in the level of wear. The resulting benefit in terms of fuel consumption amounts to approximately 1 % in the NEDC.

With the following development step a thermally sprayed-on layer on the cylinder wall is used for the first time in a production diesel engine in order to further reduce friction losses. Thus the molded, precision-

Cylinder offset	mm	106	
Compression	-	17.7	15.5
Connecting rod length	mm	163	
Main bearing diameter	mm	76	
Bearing width	mm	23	
Crank pin diameter	mm	64	
Bearing width	mm	16.8	
Piston compression height	mm	45.65	
Rated power	kW	165	195
at rpm	rpm	3800	3800
Rated torque	Nm	510	620
at rpm	rpm	1600 – 2800	1600 – 2400

❶ Comparison of the key data of the OM 642 LS in the R-Class with the key data of the predecessor engine

The mechanical stresses in the piston are reduced by the use of a hub case and the temperature lowered by increasing the flow rate of cooling oil. The higher volumetric oil flow rate through the piston-cooling units is provided by a compound oil pump, the drive capacity of which is lower compared with that of the previous standard oil pump.

The new Mercedes-Benz precision honing of the cylinder wall was developed for the tried-and-tested aluminum crankcase with molded roughcast cylinder liners manufactured in the core package system. The characteristic structural height of the honed surface was reduced by approximately 50 % in comparison to the predecessor series [1]. The resulting reduction in the oil retention volume of the surface enables the piston ring stress to be reduced. In the process, it was possible to cut the already honed roughcast cylinder liners are replaced. Extremely positive experience of sprayed-on cylinder walls in series production has been gained by AMG using the crankcase in the successful 6.3 l V8 engine since 2005. The new cylinder wall has led to a further reduction in friction loss and a lowering of engine weight by 4.2 kg. The additional benefit in terms of fuel consumption is 1.5 %.

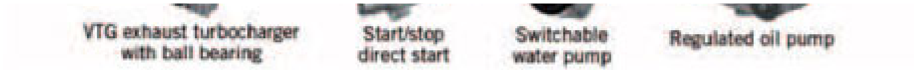
The twin-wire-arc spraying (TWAS) system developed by Mercedes-Benz is used, ❸. This involves using an electric arc to melt an iron-based cylinder wall material and applying the material to the preconditioned aluminum cylinder wall with the aid of an inert gas. Surface structuring and activation is achieved using a high-pressure water jet process. In the process used to date, the surface is then provided with a honed structure.

The TWAS overlay enables frictionally optimized pairing of the piston ring and cylinder wall material. The TWAS-specific pores create the required oil retention volume in the surface. This enables an even smoother honing structure, which in turn permits a further reduction of piston ring stress and therefore a lowering of friction loss.

As additional measures aimed at reducing friction loss in the engine DLC-coated piston pins (Diamond-like Carbon) and a revised oil catch tray attached to the bearing block are used. The latter reduces windage loss and lowers the level of oil foaming significantly.

CYLINDER HEAD

The duct routing and valve gear are carried over from the predecessor. Additional measures were required to combat higher levels of heat introduced into components exposed to exhaust gases as a result of the modified



❷ Technologies deployed with the OM 642 LS

combustion application. Consequently, the outlet valves and seating rings are manufactured from higher quality materials.

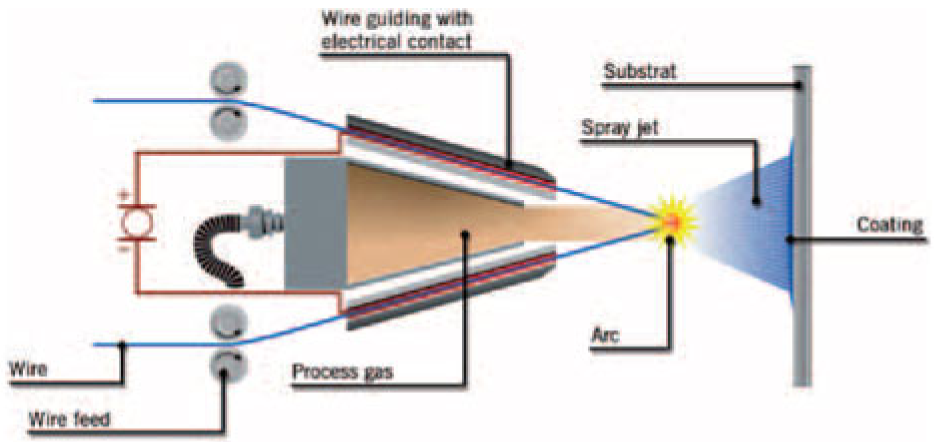
24

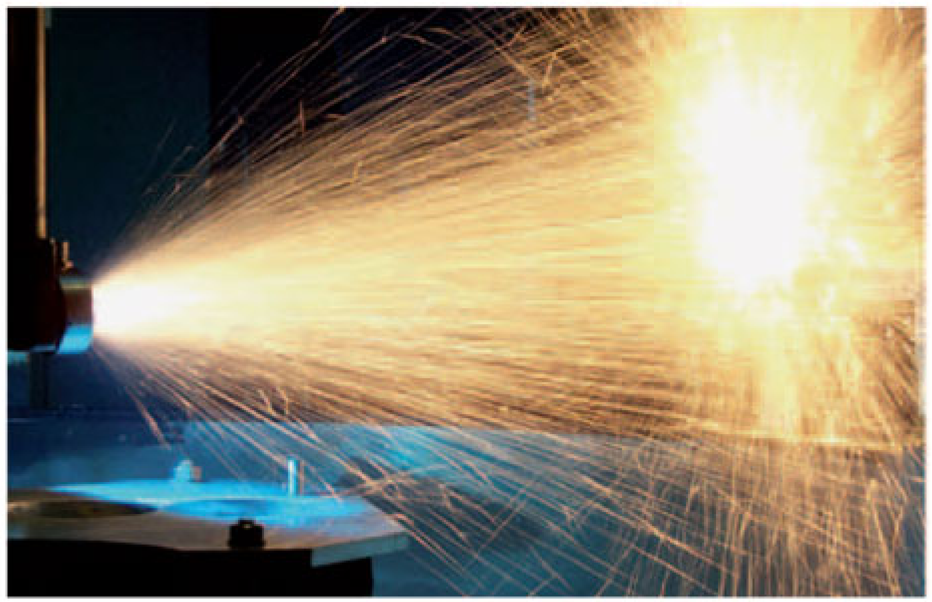
Division of the water jacket brings about a reduction in the temperatures at the critical web areas of the inlet and outlet valves and of the exhaust ports. This results in a high coolant flow speed close to the combustion chamber plate and therefore to excellent cooling of the areas at risk. Fluid flow and uniform distribution in the cylinder head are optimized in terms of temperature by means of modified discharge openings in the cylinder head gasket. The critical web temperatures of the inlet and outlet valves are reduced by up to 20 K, ❹ (right). The risk of cracking at the valve land is significantly reduced as a result.

The two-piece water jacket also increases the rigidity of the cylinder head. This enabled the already excellent closing characteristics of the outlet valves to be improved along with the further reduction in their wear performance.

WATER CIRCUIT AND THERMAL MANAGEMENT

To reduce raw emissions during the cold-running phase in particular and to reduce consumption, a pneumatically activated water pump was integrated. The pump action can be prevented by a cylindrical barrel that slides over the impeller. Due to the swifter heating of the cylinder head in particular, the engine reaches the favorable combustion range in terms of emissions at an earlier stage. The emission of hydrocarbons (HC) and carbon monoxide (CO) is reduced in this way. In the zero delivery state, the required operating





❸ The TWAS overlay process for creating ferrous overlays in aluminum crankcase housings

EXHAUST GAS RECIRCULATION

The arrangement of the exhaust gas

issue of vehicle agility. Furthermore, the turbocharging system exerts a strong influence on engine emissions as well as gas energy for the water pump is significantly reduced.

AIR INTAKE

The intake of air takes place via the air filters mounted on both sides of the engine. A manifold fitted with two integrated hot-film air-mass sensors (HFM) conducts the purified air to the exhaust gas turbocharger mounted in the inner V.

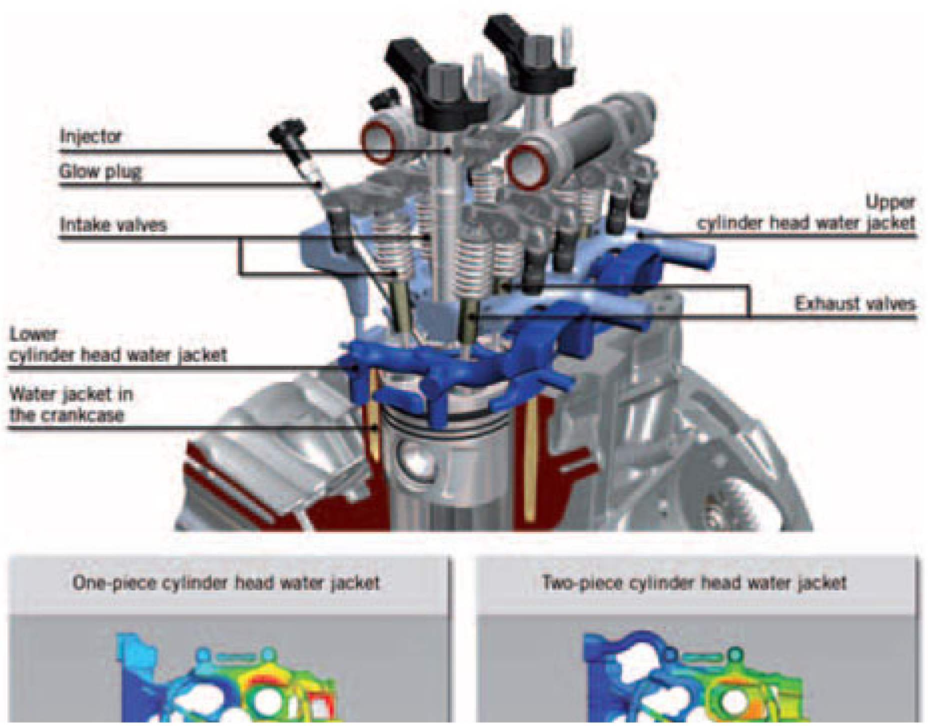
A 33 % reduction in pressure losses in the air intake system thanks to the use of enlarged flow cross-sectional areas and optimized flow properties contributes to the increase in power and torque. Modifications to the inlet of the HFMs improve the accuracy of the air mass measurement – irrespective of the air filter load condition. recirculation with an electric EGR valve, the EGR cooler in the inner V and intake air throttling upstream of the point of release in the charge air distribution line is carried over from the EU4 engine. On the one hand, the formation of nitrogen oxide is effectively reduced by a 60 % improvement in EGR cooling performance. On the other hand, the HC and CO emissions are minimized by operating-point-dependently selectable integrated bypassing of the radiator during the engine warm-up phase.

EXHAUST GAS TURBOCHARGING

In addition to achieving ambitious power and torque figures, the turbocharging concept also places great importance on the cycle efficiency and, therefore, on fuel consumption. Comprehensive evaluation of various turbocharging concepts has identified an advantage in retaining the turbocharging concept introduced, ❺, which uses a single turbocharger, as compared with staged turbocharging concepts.

In order to boost the performance, the turbocharger, ❻, is qualified to withstand exhaust gas temperatures up to T3 = 860 °C while throughput capacity is increased thanks to an enlarged compressor or rather turbine wheel. The resulting higher moment of inertia has been compensated for by reducing the bearing friction to avoid sacrificing agility.

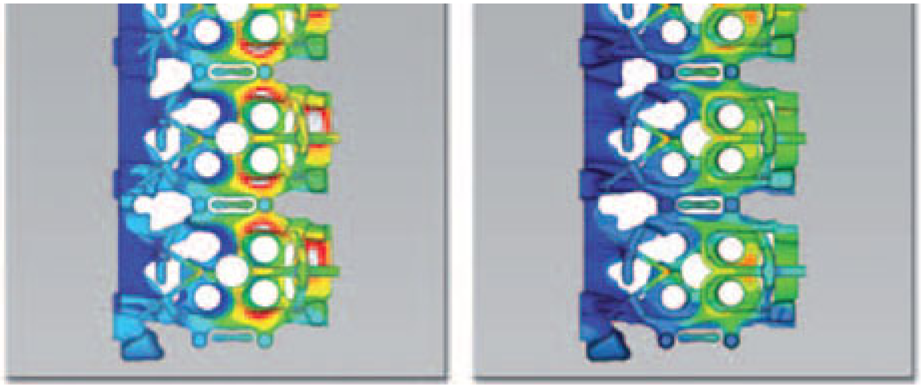
The process of upgrading the turbocharger to cope with higher exhaust gas temperatures required material and design



chargers respectively from standstill after 4 m, 20 m and 60 m. As can be seen from the graphs, the vehicle equipped with the ball-bearing turbocharger maintains an increasing lead.

The target EGR rate is reached at a higher lambda in the turbocharger fitted with a ball bearing, which results in lower emissions (HC, CO and particulate) as well as fuel consumption benefits (CO_2).

In order to retain the familiar low noise level in spite of the higher mass flow rate, the resonators in the air ducting were optimized and enhanced. The multi-chamber wide-band damper fitted in the front area of the engine, whose effective volume was enlarged by approximately 20 % while keeping the overall dimensions unchanged, is cited as an example of this. The new



❹ Cylinder head with a two-piece water jacket; comparison of the temperature distribution in a one-piece and in a two-piece design

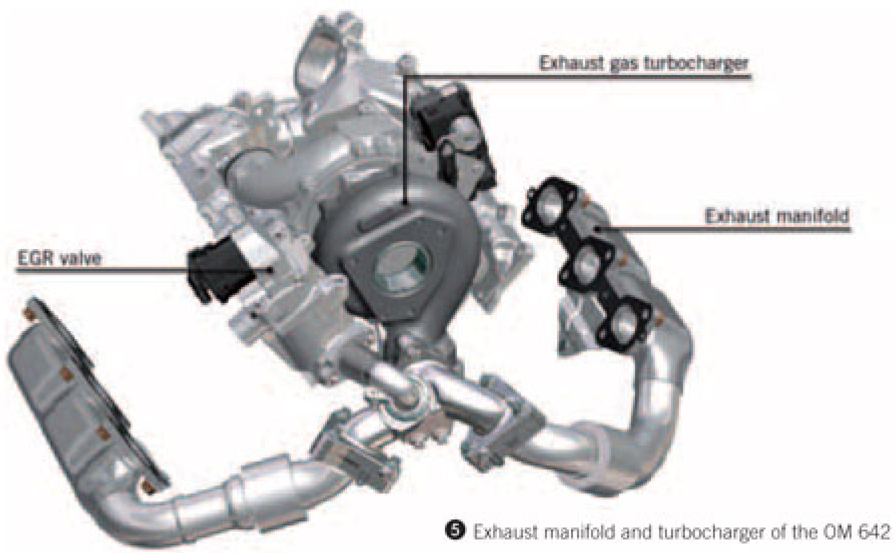
modifications on the exhaust gas side. Higher-quality materials are used for the bearing casing and the blade contour ring. The blade contour ring in the turbocharger is no longer bolted. Instead, it is clamped between the turbine and bearing casing.

In order to reduce bearing friction, the bearing used was changed from a plain bearing to a ball bearing for the first time in a passenger car diesel engine. As a result, higher turbocharger speeds are reached particularly at low partial loads. The higher moment of inertia is also overcompensated. The maximum permissible turbocharger speed is still determined by the peripheral speed of the compressor turbine wheel. The ball bearing has a lower oil throughput than the plain bearing. The resulting lower heat dissipation is offset by integrating the turbocharger in the cooling water circuit. The reduced bearing friction has a particularly positive impact on transient response. ❼ plots the different accelerations of two E-Class vehicles with plain- and ball-bearing turbo-

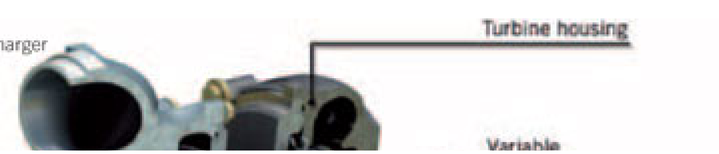
damper is designed as a two-piece casing made of temperature- and pressure-resistant PA 46 GF40.

INJECTION HYDRAULICS

The OM 642 LS uses Bosch common rail piezo injection technology developed to handle injection pressures of 1800 bar. A key element is the piezo injector, which has proven itself over many years, combined with the latest generation of eight-hole blind-hole nozzle. It excels with ultra-precise timing, high switching speeds and a further improved microquantity capability and delivery stability. High pressure is generated by the established, weight-optimized three-cylinder pump, the drive system of which was carried over unchanged despite the increase in operating pressure.



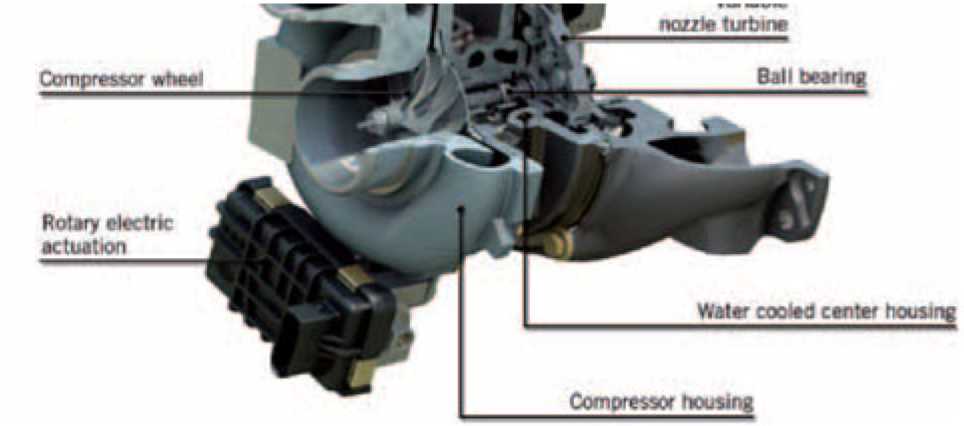
❺ Exhaust manifold and turbocharger of the OM 642 LS



❻ Exhaust gas turbocharger of the OM 642 LS (source: Honeywell)

relevant conditions, and especially in cold weather and at high altitude.

The tried-and-tested inlet port design incorporating a spiral and tangential swirl duct in a non-rotated configuration, which excels by virtue of a high swirl ratio when the spiral swirl duct is shut off (inlet port shutoff) and excellent throughput (filling) in two-channel operation, was carried over unchanged.



A regulated in-tank fuel supply pump is employed as a CO_2 measure. In order to relieve the on-board power supply at extremely low outside temperatures, an on-demand electric fuel filter heater is used. The control function is performed by the existing sensor system in the fuel circuit.

COMBUSTION SYSTEM

The redesign of the compression ratio and combustion chamber geometry played an essential role in the evolution of the OM 642 towards meeting EU5/EU6 emission values. After comprehensive investigations that took account of raw emissions, consumption, combustion noise and cold-start capability, a significant reduction in compression from 17.7 to 15.5 has been realized. The reduction in bowl taper and the use of enlarged radii at the bowl lip enabled the piston bowl for the compression ratio of 15.5 to be configured in a way that allowed particulate emissions to be lowered.

In order to adjust it to the changed combustion chamber geometry and the increase in injection pressure to 1800 bar, the injection nozzle was modified with regard to the spray height angle and the spray side angle. Due to the stricter emissions requirements and higher injection pressure, the blind-hole volume was also reduced. This was accompanied by a reduction in the nozzle hole length and an increase in the flow coefficient (Cv value) in order to improve the spray quality.

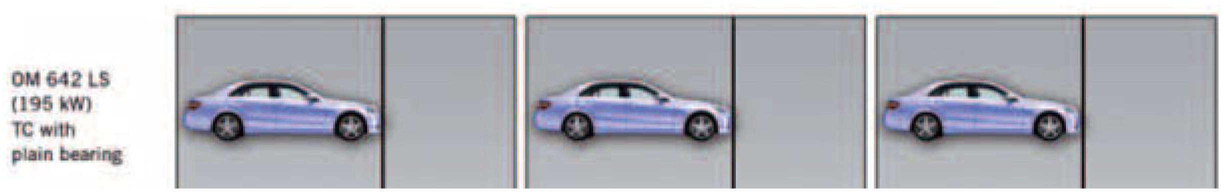
The lowered compression ratio necessitates the use of the ceramic glow system already tried and tested in the BlueTec engines. This ensures that cold starts with extremely short glow periods and stable engine operation are achieved under all

EXHAUST GAS AFTERTREATMENT AND EMISSIONS

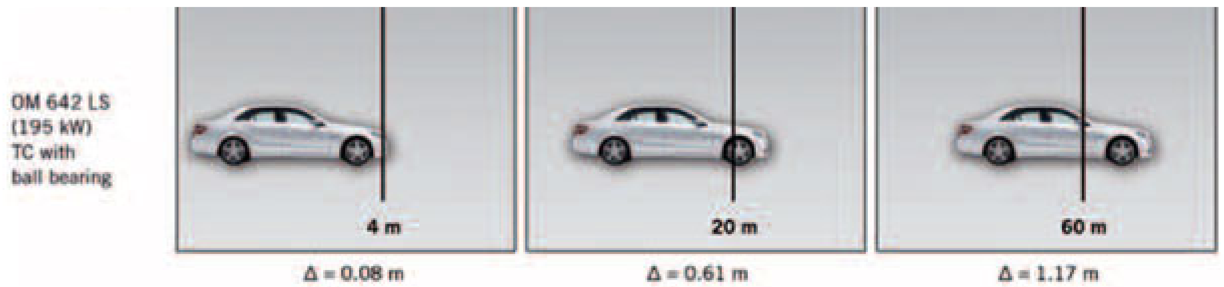
As part of the evolution, a further reduction in emissions was achieved. This means that as well as complying with the current EU5 legislation in the BlueTec version already in use in the S-Class, the OM 642 LS also meets the EU6 limits due to come into force in 2014 and is prepared for worldwide use.

The Mercedes-Benz additive-free particulate filter regeneration strategy was further developed for the OM 642 LS in the S 350 BlueTec. A model-based filter loading analysis in the engine control system that was developed in-house led to an increase in regeneration efficiency. The model's high accuracy enables reduced particulate filter volumes while at the same time retaining regeneration intervals of up to 1000 km. Thanks to a two-stage exhaust gas temperature controller, the desired regeneration temperatures are adhered to with even greater accuracy, ensuring swift and safe soot burn-off and reducing the thermal load on the particulate filter and SCR (Selective Catalytic Reduction) catalytic converter.

BlueTec is a technology developed by Mercedes-Benz to reduce emissions from diesel engines, particularly of nitrogen



❼ Comparison of exhaust gas turbocharger with plain bearing with a turbocharger with ball bearing



(acceleration from stand still – E-Class with automatic transmission)

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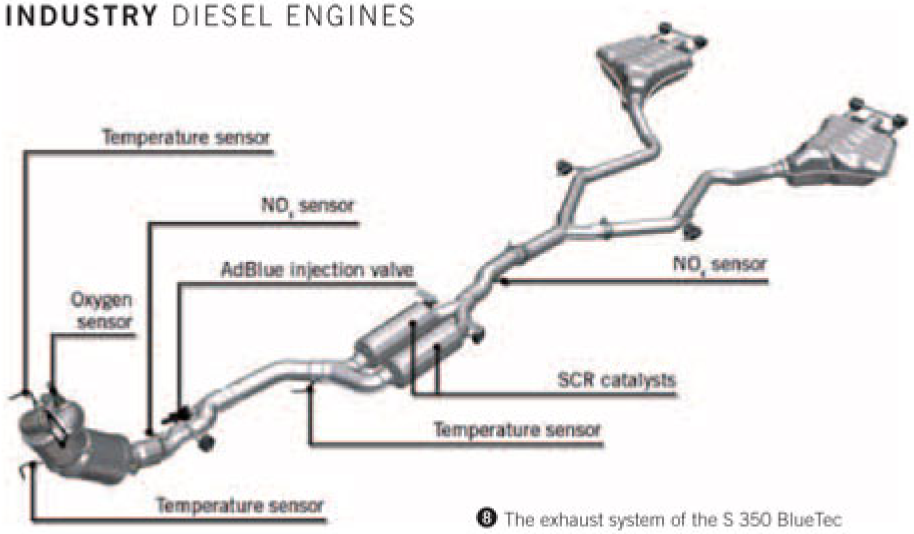
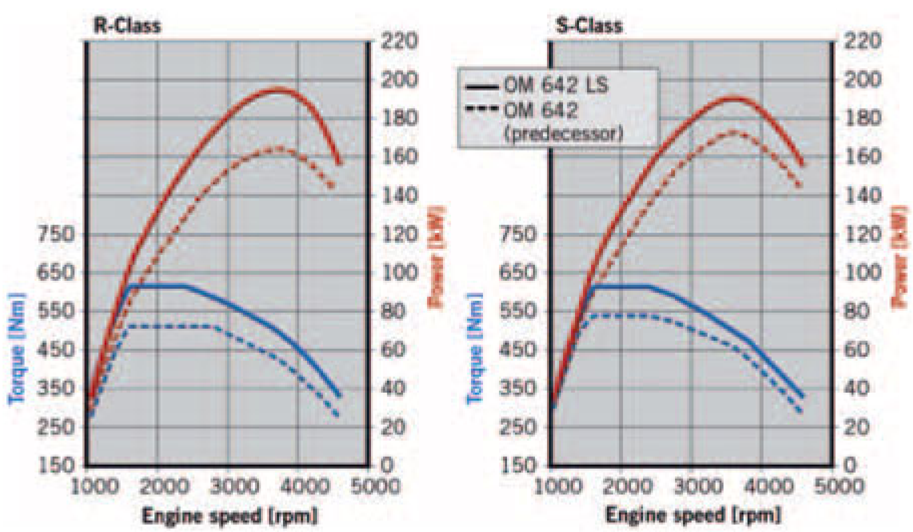


❽ The exhaust system of the S 350 BlueTec

with the temperature and pressure sensors, O_2 and NO_x sensors for controlling and providing OBD monitoring of the emission-relevant functions are also used.

As a result, the new OM 642 LS in the S 350 BlueTec is not only one of the most efficient six-cylinder diesel engines in the luxury class, but also ranks among the cleanest diesel engines in the world thanks to the AdBlue emission control technology.



ENGINE RESULTS AND SUMMARY

With regard to the EU5 applications, the performance compared with the predecessor engine is increased by 18 % to 195 kW and torque by 22 % to 620 Nm, ❾. A power output of 190 kW is achieved in the S-Class designed to meet EU6 limits – despite the higher back pressure in the SCR exhaust system.

Thanks to the evolved engine, optimized transmission and the exhaust gas aftertreatment featuring a DPF and SCR (S-Class), a significant improvement in the emission and fuel consumption figures is achieved, ❿. The higher power and torque also enabled a significant im-

❾ Power and torque of the OM 642 LS in the R- and S-Class compared with the predecessor

oxides. The technology involves injecting AdBlue, a harmless aqueous urea solution, into the exhaust gas flow. This process releases ammonia, which then reduces up to 80 % of the nitrogen oxides in the downstream SCR catalytic converter to harmless nitrogen and water.

The exhaust system, ❽, which is optimized in terms of emissions and back pressure, features a twin-pipe SCR catalytic converter configuration in the underfloor. This is in addition to the near-engine mounted oxidizing catalytic converter and particulate filter. Along

provement in driving performance. Taking the S-Class as an example, the time taken for the 0 to 100 km/h sprint has dropped by 10 % – from 7.8 to 7.1 s. The top speed is limited to 250 km/h.

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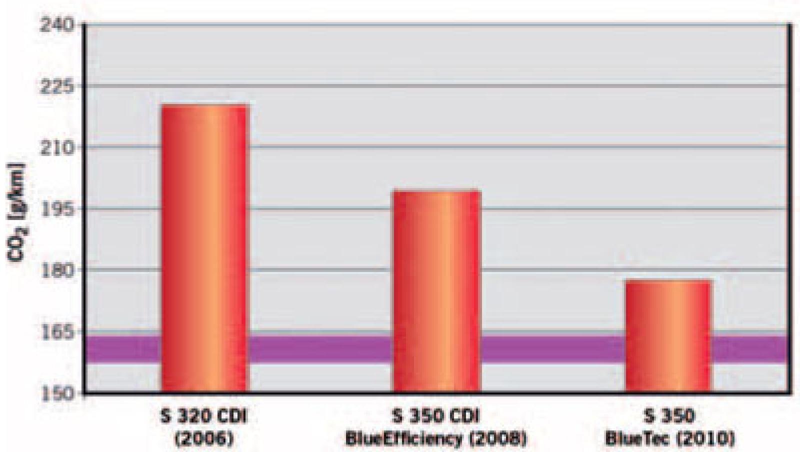

❿ Development of the fuel consumption of the V6 diesel engine in the S-Class

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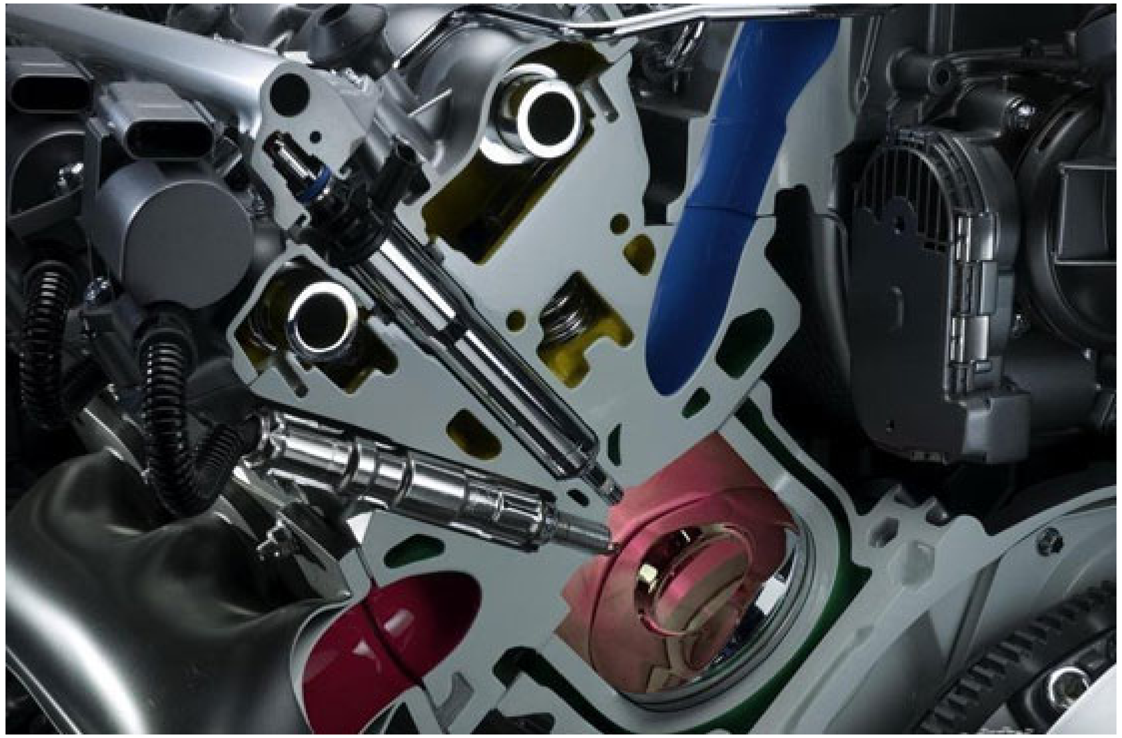

Mercedes-Benz 3.0 liter V6 turbodiesel info file: pdf file, 11 pages
2005

World record for Mercedes-Benz new V6 turbodiesel OM642 (in E320 CDI)

- 100,000 miles at an average speed of 224.823 km/h / 139.696 mph
- Record distance equal to four times around the world
- Endurance test for the Mercedes E 320 CDI, 30 days of relentless, round-the-clock punishment
- Proof of the performance of the diesel particulate filter

Three E320 CDI using the new OM642 3.0 liter V6 turbodiesel were driven 100,000 miles within 30 days at the 5 mile oval racetrack in Laredo, Texas and set several FIA world endurance records to demonstrate the reliability and efficiency of the new common rail direction injection turbodiesels. The engine oil was changed 10 times, every 15,000 kilometers.
2005

4.6 million kilometers: new record
A Greek taxi driver, Gregorios Sachinides, presented the Mercedes-Benz museum in Stuttgart with his trusty cab - a 1976 Mercedes 240D diesel with 4.6 million kilometres on the clock.
2004

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