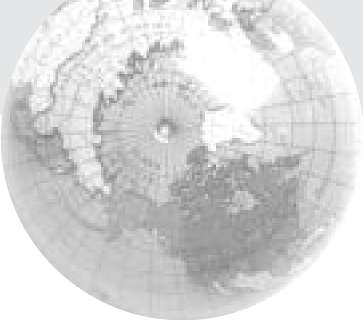

You will find the figures mentioned in this article in the German issue of
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Der neue 4,0-l-V8-Dieselmotor
von Mercedes-Benz

The New Mercedes-Benz 4.0 l V8 Diesel Engine

With the new V8 diesel engine of the E420 CDI, Mercedes-Benz is introducing an engine that is a balanced, powerful overall motor. Its consistent optimizations and excellent specific values reached in its class, more than make up for its lower displacement of 4.0 l, compared with its competitors. It will be offered exclusively as the Euro 4 model with a particulate filter. Starting with the E-Class, this engine, a basic though enhanced development of the familiar V8 diesel engine, will replace its predecessors in the S-Class, as well as in the M-Class and G-Class. The production location at Motorenwerk Berlin was kept.

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1 Introduction and Objective

In 2000, Mercedes-Benz unveiled its first V8 diesel engine, which was initially offered in the S-Class. It was subsequently introduced into the E-Class as well as the M-Class and G-Class SUV's, a move that contributed greatly to its success in this particular market segment. Therefore, it was clear that the conceptual design of a successor to the V8 diesel must incorporate the requirements of these vehicle model series.

In addition, the following development goals were defined:

- remarkable driving performance through increased power and torque
- compliance with the Euro 4 emissions standard
- Diesel particulate filter (DPF) as standard equipment
- regeneration of the particulate filter without use of additives
- improved fuel economy compared with predecessor
- better acoustic properties (NVH).

Of course, these goals had to be achieved while maintaining the trend-setting lightweight concept in this segment.

2 Engine Parameters

The **Table** summarizes the main engine data for the E-Class model. At 4.0 l, the displacement is the same as its predecessor; it was not increased in order to rule out negative impacts on weight, installation space, and fuel consumption. The power and torque values, **Figure 1**, are particularly noteworthy with respect to the displacement because the highest specific value of an 8-cylinder engine is reached at a mean pressure of 23 bar. These demanding objectives could only be achieved by steadily developing all the components in the predecessor engine.

3 Engine Description

3.1 Air Ducting, Turbocharging and Exhaust Gas System

Particularly characteristic of this further development is the unthrottling of the entire air and exhaust gas section, which results in a higher turbocharging level, **Figure 2**.

The proven basic version of the predecessor including engine-mounted air filter, engine-mounted water/charge air cooler and twin turbocharging is highly compact and was therefore retained.

Supported by extensive flow calculations, the design solution found for air ducting reduces pressure loss by 30 % before the compressor and 62 % after the compressor compared with the predecessor, while simultaneously increasing the air flow rate at.

The air is guided to the engine-mounted air filter through clean air intakes around the radiator seal. The air filter contains two filter cartridges, which are separated from the clean air side by a partition wall with switchover valve. The size and position of the switchover valve were fully optimized with regard to full load and acoustics.

The cleaned air is guided to the two mass air flow sensors (MAF) through two guide ribs. This prevents deviations of the air flow sensor signal as a function of the air filter charge. Precise measuring of the air mass is a prerequisite for exact exhaust gas regulation in order to comply with the Euro 4 exhaust gas limits.

Upstream volumes located right before the exhaust gas turbocharger compressor unit contribute considerably to the higher torque curve in the lower rpm range, as shown in **Figure 3**.

The compressed air is then guided to the joint water charge air cooler, which was also unthrottled and its cooling performance improved.

The electrically operated intake air throttle is located directly downstream the charge air cooler upstream the EGR inlet area. This component, similar to an electronic accelerator actuator, regulates the necessary pressure drop in EGR mode, as well as the charge pressure during DPF regeneration.

The charge air manifold, which is connected to the cylinder heads via rubber elements, distributes charge air to the two cylinder banks. The rubber elements allow for better tolerance offset between the cylinder heads and reduce noise emission of the air manifold.

The exhaust gas temperature resistance and the maximum wheel assembly rpm were enhanced in both VNT turbochargers. Additional supports reduce the vibration stress of the turbochargers in all operating ranges.

The cambered vanes further enhance turbine efficiency. The vane bearings as well as the nozzle ring together with the insert improve the heat expansion properties.

An electric actuator motor changes the position of the guide vanes. The high positional accuracy and adjustment speed that can be achieved with the electric actuator are a prerequisite for exact and fast charge pressure regulation, positively influencing agility and exhaust gas emissions.

The exhaust manifolds also provided potential for reducing pressure losses, which actually were lowered by more than 65 % despite difficult installation conditions.

Another development goal was reducing component weight, so that lower thermal capacities would assist the catalysts close to the engine to start faster. As an alternative to a cast-iron manifold, an air-gap isolated sheet metal manifold was examined. Since a sheet metal manifold has improved the heating properties of the catalytic converters only slightly without achieving the design possibilities and cost advantages of the cast version, this development was not pursued further.

Like the predecessor, the exhaust gas is returned via two EGR valves (controlled by the engine map). To improve combustion stability and reduce HC+CO emissions during warm-up, the exhaust gas is guided past the EGR cooler through a switchable bypass. The entire exhaust gas recirculation is shown in **Figure 4**.

3.2 Injection System and Engine Control

As in the new Mercedes-Benz OM 642 V6 engine, this one uses a third generation common rail injection system with a maximum rail pressure of 1,600 bar and Piezo injectors.

The vehicle interface, exhaust gas aftertreatment, and T3 regulation in the CR5 engine control represent an improvement over the familiar CR4 engine control.

Unlike its predecessor, the engine does not need a valve block to distribute the fuel to the rails of the two cylinder banks. A redesigned rail pressure regulation allows the fuel to feed from the high-pressure pump directly to the left-hand rails, where the pressure regulating valve is located, and from there to continue to the right-hand rail, where the pressure is measured.

The injectors, which allow up to 5 injections per duty cycle, are equipped with hydraulically optimized 7-hole nozzles.

Piezo technology reduces the amount of leaking oil in the return section of the common rail system to almost 0 mm^3. The intake-regulated high pressure pump and the coupled pressure control (CPC) significantly contribute to the favourable fuel economy of the OM 629. The hydraulic components eliminate the need for a fuel cooler.

3.3 Cooling

The coolant guide system is very similar to that of the predecessor. Various customizations and optimizations were performed with the goal of meeting the increased requirements due to the higher loads and to boost EGR cooling to stay safely below the Euro 4 emissions limits.

The water pump is mounted on the face of the crankcase. A capped impeller increases efficiency and power for the necessary flow rate.

The 10 % reduction in resistance can be attributed primarily to optimized water flow in the cylinder heads, as well as unthrottling in the crankcase and thermostat.

The design of the ducts in the crankcase ensures even distribution of water to both cylinder banks. The flow around the wet cylinder liners in the crankcase is optimized, which results in little thermal distortion.

After that, the cooling water enters the cylinder heads through the passageways in the cylinder head gaskets. These are matched so that the water cools all cylinders evenly; the flow can be directed to the critical areas within each cylinder. The

two-part design of the cylinder head water jackets does a good job of cooling the valve lands and the areas around the injector shafts. The water first flows through the bottom water jacket, which lowers the temperature by 30 K in the critical area between the exhaust valves.

The top water jacket then guides the water flow to the thermostat, which is located on the water-outlet in the front of the crankcase.

After the cylinder heads, cooling water is directed to the EGR cooler, the water cooling jacket of the EGR valves, and the heater core.

The oil/water heat exchanger, which is mounted on the inner V of the crankcase, is supplied by the line between water pump and cylinder space. **Figure 5** shows the engine coolant circle.

3.4 Cylinder Head / Valve Train

Except for the split water jacket, the design of the cylinder heads is based on the familiar 4-cylinder inline engine OM 646, **Figure 6**.

During the engine planning phase, numerous simulations showed that the advocated increase in peak pressure would mean adapting the rigidity of the cylinder head. The intermediate cover in the water jacket significantly contributes to this.

The cylinder heads are die cast from a high-temperature aluminium alloy. To achieve the required material properties and to keep them highly consistent, the cylinder heads are heat-treated with the same process that was also used on the new Mercedes-Benz V6 diesel engine.

The valve train is familiar from the OM 646, with bucket tappets and hydraulic valve clearance compensation.

The camshaft is driven by the proven double-bush timing chain, **Figure 7**. To extend the service life of the chain, the high-pressure pump was moved to the left cylinder bank, where it is driven by the intake camshaft gear.

3.5 Crankcase and Drive Unit

All components subject to combustion pressure are designed for a peak pressure of 180 bar.

The crankcase, **Figure 8**, uses the familiar bedplate concept of its predecessor, featuring cylinder banks arranged at a 75° angle and inserted wet cylinder liners. The top part is a sand-cast, high-strength aluminium alloy, AlSi7Mg0.3.

Unlike traditional gravity die-casting, this process guarantees reproducibility and, by applying pressure dwell from the time the mould is filled to solidification, it ensures a cavity-free cast.

The gate takes place from both cylinder-head flanges of the crankcase. In the high-stress areas of the thrust bearings and the cylinder head bolts, the solidification process is influenced with cooling irons, in order to achieve high strength and sufficient ductile yield.

Subsequent T7 heat treatment of the blank (annealing, chilling, artificial aging) achieves the thermal structural stability that is necessary to make the material properties permanent.

When designing the top part, special attention was paid to achieving a rigid structure. This goal was reached with ribs on the outer sides and between the cylinder banks.

As is the case with all high-stress V-engine crankcases, the design of the main oil channel was a true challenge. Intensive FEM analysis during the development process allowed a significant reduction in stress level around the die-cast channel. Parallel to that, material properties have been consistently improved, **Figure 9**.

Additional structural rigidity is achieved with the integral gas exchange ducts, which enable pressure compensation between the chambers of the crankcase, thereby reducing pump losses.

The base section, made of AlSi9Cu3 with integral GGG60 inlays in the five thrust bearings, is gravity sand-cast. Besides various other functions, the base section is fitted with an integral oil catch tray, a stripper edge that removes the engine oil from the bearings and oil nozzles, thus separating it from the drive unit roller, and guide ribs that direct it into the oil pan.

The crankcase with a crankpin offset of 15° is forged from 46MnVS6. The properties of this steel are similar to heat-treated steel, yet it has the advantage of being easier to machine.

For acoustic reasons, the rigidity of the crankcase was improved using larger main bearing diameters. Further emphasis was placed on a dynamically optimized oil supply of the con-rod bearings, since the large bore in combination with a 180 bar peak pressure subjects them to extremely high loads.

The top half of the main bearing is a ternary bearing with a groove; the bottom half is a sputter bearing.

The 70 MnVS4 forged connecting rod with a cracked large eye is supported by a sputter bearing on its high-stress end and a ternary bearing on its cover end.

The pistons with a 3mm higher head land are made from an optimized aluminium alloy 174+. By integrating a sealed cooling duct in the reinforced ring groove, it was possible to further improve the of the piston.

A balancer shaft, which rotates at engine speed against the rotating direction of the engine, offsets the unbalanced torques of the first order, which occur at a 75° cylinder bank angle. The shaft bearing in the main oil channel optimizes the space in the crankcase. The timing chain drives the balancer shaft through a guide sprocket.

4 Friction Loss

Since the demanding power, torque, and exhaust gas emission requirements on the engine had to be met while at the same time improving fuel economy, there was no way around reducing friction loss.

It was possible to reduce the mean friction pressure of the drive unit including ventilation losses by 35 % compared to the predecessor, despite the increase in bearing bore. These improvements were achieved primarily using the following measures:

- optimization of piston with ring package
- introduction of gas exchange ducts on the sides
- optimization of the timing chain drive.

It was possible to keep the friction loss of the valve train at the level of the predecessor engine, despite increased requirements resulting from higher exhaust gas counter-pressure due to the particulate filter.

5 Measures for Acoustic Optimization

Optimizing acoustics at low loads and rpm in a large displacement diesel engine is always a challenge. Customers drive disproportionately often in this operating range. Therefore, the new V8 diesel engine was designed to appear pleasant and unobtrusive under partial load and sound powerful under full load without being loud. The Campbell diagrams in **Figure 10** show that at a partial load point at 1,700 rpm, the new engine has a much more harmonious acoustic pattern compared with the predecessor.

The best values in acoustics and smoothness are achieved by the following measures:

- especially rigid crankcase with bedplate for additional stiffness
- crankcase with larger main bearing bore
- balancer shaft
- considerably more rigid engine mount and connection to crankcase
- rigid, charge air lines made of aluminium with low volume, due to the location of the charge air cooler on the engine
- decoupling of the charge air manifold
- optimized chain guides with rubberized crankshaft wheel
- closed inner V due to EGR valve holders with optimized acoustic insert
- decoupling of the intake pipe fastening before the exhaust gas turbocharger
- decoupled securing of the low pressure fuel lines
- fuel injection at 1,600 bar with dual-pilot injection

– covering of entire motor, in particular injector shaft areas, with sound-absorbing foams under the air filter and the design cover.

Because of theses measures and the optimization of each component in terms of NVH behaviour, the new E 420 CDI claims a top position in its class.

6 Exhaust Gas Results and Exhaust Gas Aftertreatment

In the E-Class, the new 8-cylinder 420 CDI comes standard with a diesel particulate filter as the Euro 4 model.

After the catalytic converter, the exhaust gas from the two cylinder banks is directed towards a joint diesel particulate filter (DPF) located in the under-floor area, **Figure 11**. To reduce heat losses, pipes with insulated air gaps are used between catalytic converters and the DPF.

As in all Mercedes-Benz passenger car diesel engines, the DPF are purged without additives to aid regeneration. With the filter being positioned "far away from the engine" and the large displacement engine, which is operated mainly in the low load range, a specially matched heating strategy was necessary to quickly provide the temperatures necessary for carbon black regeneration. Up to five injections are deposited; the exhaust gas temperature values before the exhaust gas turbocharger and after the catalytic converter are used as control variables for the double post injections. This helped optimize the duration of regeneration and carbon black conversion rates significantly.

7 Fuel Consumption, Driving Performance

At 9.3 l per 100 km, the fuel consumption of the new E 420 CDI is 0.1 l / 100 km below the fuel consumption of the predecessor model E 400 CDI

– despite noticeably better driving performance
– despite superior engine acoustics
– while complying with much tougher Euro 4 emissions standards.

This could only be achieved through consistent unthrottling of air passageways, friction loss reductions in the entire drive unit, optimized fuel stream preparation, and use of a 7-speed automatic transmission.

Its performance figures include a 0 to 100 km time of 6.1 s; 60 to 120 km in 4.8 s, which is an improvement of 12 % and 28 %, respectively, compared with the predecessor model, **Figure 12**. The top speed is electronically limited to 250 km/h.

8 Summary

Consistent focus on features that the customer can experience helped this new V8 diesel engine rise to the top position in its class. During its design, special emphasis was placed on specific power and torque values, in order to realize advantages under high absolute full load values, even though displacement had been kept the same.

Despite drastic boosts in performance and torque, the engine acoustics and fuel economy are superior to those of the predecessor model.

Naturally, the Euro 4 model of new E 420 CDI will be offered exclusively with particulate filter. ■

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