The New 2.0l 4-Cylinder BiTurbo TDI® Engine from Volkswagen

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Abstract

The twin turbocharged I4 2.0l TDI BiTurbo is currently the top diesel engine in the new Passat range. With an output of 176 kW at 4,000 rpm and 500 Nm of torque from 1,750 to 2,500 rpm, it has a specific power of 88 kW/l. This means the new Volkswagen engine achieves the highest specific power of all four-cylinder series-production diesel engines.

The basis of the high-performance four-cylinder engine is Volkswagen’s Modular Diesel Engine System (MDB), introduced in 2012. A compact charging assembly with two turbochargers enabling charge pressures of up to 3.8 bar (absolute) was developed for this purpose. A further major innovation in respect of extremely efficient combustion is the common-rail injection system with piezo injectors for injection pressures of 2,500 bar. The crankcase, crankshaft, conrods and pistons have been reinforced for the combustion pressure of 200 bar, which is higher than that of the base engine.

In order to achieve the high specific power output, it was necessary to conduct a systematic optimisation of the air and exhaust paths. The de-throttled, low-swirl, high-performance cylinder head has been designed from scratch. The close-coupled exhaust gas aftertreatment components achieve light-off temperatures extremely quickly, thus ensuring compliance with Euro 6 limits.
1 Introduction

1.1 New high-performance diesel engine

With the eighth-generation Passat, Volkswagen is presenting numerous innovations in many fields of technology. They include a top diesel engine in a new performance class that combines a high level of drive refinement with familiar Volkswagen economy.

The development of the biturbo unit incorporated components from the Modular Diesel Engine System (MDB), which enables the realisation of engines of varying power and emissions classes. The line-up currently encompasses TDI engines with three and four cylinders and displacements of 1.4, 1.6 and 2.0 litres.

With the 2.0l BiTurbo, Volkswagen is setting new competitive benchmarks in the field of four-cylinder diesels, after having already increased the output of mono-turbo engines to as much as 140 kW (190 hp). The elements of the Modular Diesel System hold a great deal of potential for further performance increases in future, too.

1.2 Specifications

The specifications for the 2.0l TDI BiTurbo in the new Passat are:

- a power output of 176 kW, equating to a specific power of 88 kW/l, which is previously unattained in four-cylinder diesel engines,
- torque of 500 Nm, equating to a specific torque of 250 Nm/l,
- sporty performance on a par with the full-size class, combined with best-in-class acoustics,
- compliance with Euro 6 emissions limits,
- low fuel consumption,
- the cost-effective use of components from the MDB,
- a compact construction suitable for transverse mounting.

The key technical data of the 2.0l TDI BiTurbo are summarised in Figure 1.
2 Basic Engine

![Technical data of the new 2.0l 176 kW TDI BiTurbo](image)

<table>
<thead>
<tr>
<th>Engine type</th>
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<tbody>
<tr>
<td>Rated power</td>
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<tr>
<td>Max. torque</td>
<td>500 Nm at 1,750 - 2,500 rpm</td>
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<tr>
<td>Specific output</td>
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<tr>
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<td>Emissions standard</td>
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<tr>
<td>Conrod length [mm]</td>
<td>144</td>
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</table>

Fig. 1: Technical data of the new 2.0l 176 kW TDI BiTurbo

2.1 Crankcase

The crankcase of the 2.0l TDI BiTurbo is based on that of the mono-turbo engine, which is cast in GJL-250. In order to ensure the best tribological characteristics with low oil consumption and blow-by figures, the cylinder walls are honed with a torque plate bolted to the cylinder head interface.

The crankcase of the biturbo engine varies from the technical starting point, with modifications in a number of areas to allow for the higher loads. The connection of the main bearing seats around the crossflow openings for minimising pulsation losses have been stress optimised through higher wall thicknesses. Longer crankshaft bearing cap screws absorb the increased tensile forces, while modified bores achieve improved oil supply to the two turbochargers. Further structural measures optimised the connecting points for the turbocharger assembly, as well as acoustic radiation.

2.2 Pistons, Conrods and Crankshaft

Due to the high ignition pressure, the lower compression ratio of 15.5:1 (110 kW mono-turbo: 16.2) and the new combustion process, the 2.0l TDI BiTurbo features newly developed pistons, on which bowl-rim remelting further increases hardness in the areas subject to highest loads. The cast-in salt-core cooling channel has been optimised for the new piston geometry. The second piston ring is shaped as a taper-faced Napier ring. The height of the third ring, a double-bevelled ring with spiral-type expander, has been lowered from 3.0 to 2.0 mm to reduce tangential forces.
Increasing the piston-pin diameter from 26 to 29 mm achieves a considerable reduction in surface pressure and tension in the piston pin axis. The piston pins are DLC coated, as is already standard practice for the entire Modular Diesel System. The conrods were reinforced around the shafts. The crankshaft is forged from 42 CrMoS4 high-strength steel alloy. The eight-hole flange is a carry-over part from the 2.0l TDI with 140 kW.

2.3 Oil Supply

The higher loads of the 2.0 TDI BiTurbo compared with the mono-turbo engines necessitated adaptation of the oil system. The increased piston cooling requirements are met by enlarged piston spray nozzles with a higher oil flow rate. In view of the increased volumetric flow, the pressure level was reduced to minimise pulsation within the oil circuit.

The oil pump, a volumetric-flow controlled, two-stage, seven-chamber, vane-type pump, generates 1.8 bar pressure in the low stage and 3.3 bar in the high stage. Its rotational speed has been increased by ten percent compared with the mono-turbo engines, in order to optimise oil supply at lower revs. The oil pressure switch has been adapted accordingly. The oil filter and the oil cooler are carry-over parts from the base engine.

3 Cylinder Head

3.1 Mechanical Design

Due to the swirl layout of the combustion process, in combination with the two-stage turbocharging assembly, it was possible to dispense with variable valve drive. The valve layout in the biturbo engine is parallel to the axis (fig. 2). The integrated valve drive module (iVM), a central element of the Modular Diesel System, remains largely unchanged. The highly temperature-resistant material is likewise identical.

The main adaptations made to the high-performance concept are improved cooling through additional water channels between the inlet ports, as well as reinforcement of the base plate, the oil chamber, the area around the injectors and the landings for the cylinder head bolts. The cylinder head bolts are in hardness class 12.9 (mono-turbo: 10.9).
The cylinder head gasket, with carrier plate and four active layers, also has a smooth plate as the top layer facing the cylinder head. The oil separator in the cylinder head cover has been increased in size and the separation process modified to take account of the higher blow-by rate.

### 3.2 Low-Swirl High-Performance Head

In order to realise the target output, a major focus during the design of the intake and exhaust ports was on minimum pressure loss and maximum air flow rate. Compared with the mono-turbo engines, this delivers an increase in flow rate of approx. 30% for realisation of the target output. In the reduced-swirl, high-performance head, the form and cross sections of the inlet and exhaust ports are extensively de-throttled (fig. 3).

Mixture preparation is handled largely by the newly developed Bosch injection system with its maximum injection pressure of 2,500 bar. Charge movement has been adapted accordingly through swirl chamfers on the inlet valve seats. Compared with the mono-turbo engine, the swirl level has dropped by more than 50 percent.

The inlet valves on the biturbo engine are made from X85 valve steel. The exhaust valves are bi-metal valves, with the shafts made from X45 and the heads from 3015D. On both the inlet and exhaust sides, valve lift has increased by 0.5 mm to 9.5 mm.
3.3 Belt Drive

The belt drive and toothed belts remain unchanged in their geometry. However, the belt has been specified with increased stiffness to accommodate the higher loads being transmitted. This was achieved through thicker wound glass-fibre cords and a stronger elastomer mixture for the teeth. The belt spring tensioner has also been modified accordingly.

3.4 Coolant Micro-Circuit

The coolant micro-circuit, which provides cylinder-head cooling when the main water pump is switched off, is a carry-over part from mono-turbo engines. In order to increase heat transfer in the area around the combustion chambers and to spread the cooling effect as evenly as possible among the cylinders, the water jacket has been divided into an upper and lower core. As well as the EGR cooler and the heat exchanger for the heating system, the coolant micro-circuit also supplies the bearing casing of the low-pressure turbocharger. In contrast to the pumps used in the mono-turbo engines, the coolant is circulated by a more powerful electric pump.

4 Common-Rail Injection System

One of the major innovations of the new 2.0l TDI BiTurbo is the common-rail injection system from Bosch (fig. 4) with a maximum injection pressure of 2,500 bar. Only with this system was it possible to achieve the desired power output. Volkswagen’s application of this system in the new Passat marks its premiere on the market.
Fig. 4: Common-rail injection system with twin-plunger pump and piezo injectors

4.1 Twin-Plunger Pump

Rail pressure is generated by a twin-plunger pump from the Bosch CP 4 range, which is integrated into the engine’s belt drive. The two high-pressure pistons are arranged at ninety degrees to one another. Two strokes are actuated for every rotation of the camshafts, meaning that delivery is synchronised with injection. To reduce CO₂ emissions in the area around idle, injection pressure can be lowered to approx. 230 bar. The low injector leakage also has a positive impact on this.

In order to reduce the force peaks in the belt drive, caused in part by drive torque, the pump drive gear on the crankshaft side is designed as a quadruple-oval gear. The complete injection system has been optimised for increased stiffness - the rail and its feed lines are made from high-strength steels. The rail is produced using the autofrettage process, which increases stiffness even further.

4.2 Injectors

The piezo injectors in the common-rail system achieve an extremely high level of dosing precision, combined with high actuation force. A hydraulic coupler, which also serves to even out tolerances, transmits the forces generated by the piezo stack to the switching valve.

The blind-hole nozzle has ten conical injection holes, leading to highly efficient preparation and homogenisation of the fuel spray and mixture. There are up to eight individual injections per cycle - two pilot injections, one main injection and up to five post-injections. The smallest possible injection volume is around 0.5 mm³.
5 Turbocharger Assembly

5.1 Mechanical Design

The two exhaust gas turbochargers (EGT) on the 2.0l TDI BiTurbo (fig. 5) are located between the engine block and the front bulkhead. The high-pressure charger is a VTG charger that generates up to 1.5 bar charge pressure (relative) and reaches a maximum rotational speed of 240,000 rpm. Its electric actuator requires a maximum of 300 ms to open the guide vanes completely.

The low-pressure EGT produces up to 3.8 bar charge pressure (absolute). Its rotor spins at a maximum speed of 165,000 rpm. To avoid overspeeding and excessive charge pressure, it is equipped with a pneumatically actuated wastegate control. The compressor housing has a cooling jacket that enables pre-cooling of the charge air. The turbine rotors of both chargers are machined. The compressor rotors are coated with a layer of nickel-phosphor around 25 μ thick that protects them from thermal overload arising from the low-pressure EGR. The flow damper incorporates four chambers that are connected to the air path via slits.

The material used for the manifold is highly heat resistant D5S steel. The T3 sensor that measures the exhaust temperature upstream of the high-pressure EGT has been changed to the robust SENT protocol (SENT: Single Edge Nibble Transmission).

5.2 Interaction of the Two Turbochargers

The high-pressure EGT and the low-pressure EGT (fig. 6) are connected to one another on the turbine side by a pneumatically actuated bypass valve measuring 35 millimetres in diameter and with position feedback. In two-stage operation, the valve is closed at low revs, so that the high-pressure EGT is initially supplied with exhaust gas. Fresh air flows into the low-pressure EGT compressor, where it is slightly pre-compressed, before being sent to the high-pressure EGT, which handles the main compression.

Fig. 5: Turbocharger assembly
Fig. 6: Flow through the turbocharger assembly (main flow) in two and single-stage operation

In the rev range between around 2,500 and 3,500 rpm (fig. 7), the turbine bypass valve opens continuously in line with engine load. The flow of exhaust gas to the high-pressure EGT is gradually reduced. In parallel, the passive, spring-loaded compressor bypass valve on the fresh-air side opens. Single-stage operation begins by 4,000 rpm at the latest with the turbine bypass valve fully open and the majority of the exhaust gas flowing directly into the low-pressure EGT. The remainder continues to flow into the high-pressure EGT, which is now no longer compressing.

Fig. 7: Charger operating strategy in the engine map
5.3 Intercooler Integrated into the Inlet Manifold

The intercooler integrated into the inlet manifold is an element of Volkswagen's Modular Diesel System (MDB). For use in the 2.0l TDI BiTurbo, it has been enlarged in accordance with the increased demands. In contrast to the cooler in the mono-turbo engines, which has 10 plates, the new integrated intercooler has 13 cooling plates. The width of the flow has risen from 200 to 240 mm, while flow length remains the same at 120 mm.

With its high degree of efficiency, the intercooler in the inlet manifold plays a key role in the high-performance concept of the biturbo engine. Under full load, the compressed charge air enters the cooler at around 210 degrees Celsius. The cooling effect of 40 kW achieves a temperature reduction of 160 K, meaning that the air exits at just under 50 degrees Celsius.

The pipes and hoses are generously dimensioned, with the hoses being highly heat resistant. The charge-air hose is produced via a process used in motorsport, to guarantee even greater resilience.

5.4 Low-Temperature Circuit

The inlet-manifold intercooler is incorporated into the vehicle’s low-temperature cooling circuit (LT circuit), the main task of which is on-demand cooling of the charge air. The partial volumetric flows of the LT circuit also incorporate the AdBlue metering module and the compressor housing of the low-pressure EGT.

5.5 Untreated Air Intake

The principle of flow with the lowest possible losses also applied to the periphery of the 2.0l TDI BiTurbo. Under the bonnet, the intake side has a pressure loss at rated power output of just 30 mbar. At Vmax, the temperature increase relative to ambient air is just three degrees Celsius.

The untreated air channel uses the full width of the radiator grille and is completely sealed. The channel is largely straight and unimpeded. The air filter, which occupies the space of the starter battery that has been moved to the rear of the vehicle, offers a filters surface of around 3 m2 – twice as much as for the mono-turbo engines. The airflow meter is likewise significantly larger at 92 mm diameter.

6 Close-Coupled Exhaust Gas Aftertreatment

The 2.0l TDI BiTurbo uses principally the same exhaust gas aftertreatment components as the mono-turbo engines, although they are specifically designed for high throughput. The oxidation catalyst and the diesel particulate filter with SCR coating are connected to one another in a very compact unit via a de-throttled transfer funnel (fig. 8).
Following cold start, the close-coupled layout of the components guarantees the fastest possible conversion with high throughput rates, meaning that catalyst heating is not required. The 2.0l TDI BiTurbo complies with the limits of the Euro 6 emissions standard and, due to the SCR technology, is already prepared for the forthcoming RDE test procedure (Real Driving Emissions).

**6.1 Oxidation Catalyst**

Due to its location close to the engine, the oxidation catalyst offers high HC/CO conversion very soon after cold start. Furthermore, it provides the optimum NO/NO2 ratio for the downstream SCR system. For use in the Passat 2.0l TDI BiTurbo, its volume was increased by 40%. The substrate was switched from ceramic to metal technology in order to minimise system pressure loss.

**6.2 Diesel Particulate Filter with SCR Coating**

The SCR coating is applied to the particulate filter, while its position close to the engine means it reaches operating temperature very quickly following cold start and maintains it for a long period when operating under low load. The volume of the particulate filter with SCR coating for the 2.0l TDI BiTurbo is 10% higher than for the 2.0l TDI mono-turbo. The catalyst is a Cu-Zeolite coating with high thermal stability.

The SCR-coated diesel particulate filter is downstream of a separate slip catalyst located in the under-floor area. Like the oxidation catalyst, it features a metal substrate optimised for pressure loss, in order to ensure a high throughput.

**6.3 AdBlue Metering Module**

The AdBlue metering module, which has a modular concept in the Modular Diesel System, is located on the transfer funnel between the oxidation catalyst and the SCR-coated DPF. This close-coupled mounting position necessitates a coolant-water jacket on the module, which is incorporated into the LT engine-cooling circuit.
Due to the demanding packaging requirements, the spray pattern was optimised in several steps. The mixer is adapted to the oval cross section and flow conditions in the transfer funnel.

### 6.4 High and Low-Pressure EGR

As in the mono-turbo engines of the Modular Diesel System, the dual-circuit exhaust gas recirculation consists of the cooled low-pressure EGR system (LP EGR) and the uncooled high-pressure EGR system (HP EGR). The high-pressure EGR is primarily for lowering emissions after cold start and, at very low loads, reduces overcooling of the exhaust gas aftertreatment components. The low-pressure EGR handles pollutant reduction in the remainder of the operating cycle, which has a beneficial impact on engine acoustics.

### 6.5 Flow-Optimised Exhaust System

The exhaust system of the 2.0l TDI BiTurbo has also been systematically designed for low-loss flow, in order to enable the high airflow of 850 kg/h with an exhaust back pressure of just 700 mbar. The pipe cross section, which measures 55 mm on the mono-turbo engines, has been increased to 65 mm. The exhaust flap, which, like the slip catalyst, is located in the front pipe, has been adapted to this dimension. The middle silencer was not required.

The rear silencer has been modified to accommodate acoustic requirements. Despite the complicated packaging conditions (all-wheel drive, multi-link suspension, SCR tank), a solution optimised for pressure loss was achieved at the rear of the vehicle. The exhaust system is rounded off by two end pipes with chromed fairings that emerge through the bumper.

### 7 Engine Management

For all the engine control units in the Modular Diesel System, the software and the gas system models on which it is based has been structured to be modular and scalable. For the 2.0l TDI BiTurbo, Volkswagen is using the Bosch CP74 control unit for the first time.

The software takes into account the torque demands of driver, assistance systems, direct-shift transmission and ESP. All engine control parameters are calculated via this torque path. Moreover, the software has been expanded by a further model that regulates the dual turbocharging. The operating mode coordinator also incorporates the gear shifts of the 7-speed direct-shift gearbox, as well as the further developed start/stop system. Interacting with the direct-shift gearbox, the engine is switched off when coasting before the vehicle has come to a halt.
A major element of the engine management for the 2.0l TDI BiTurbo is also the cylinder pressure regulation, which measures the combustion pressure at one cylinder using a pressure-sensor glow plug. EGR regulation and fill control were conceived specifically for the biturbo.

8 Transmission

In the new Passat, the new top diesel engine comes to market paired exclusively with the DQ 500 7-speed direct-shift gearbox and 4Motion all-wheel drive (fig. 9). A centrifugal pendulum on the dual-mass flywheel enables a reduction in engine speed to little more than 1,000 rpm, which has a very positive impact on CO₂ figures.

9 The 2.0l TDI BiTurbo in the New Passat

The new Passat is the first vehicle in the Volkswagen Group to use the new 2.0l TDI BiTurbo (fig. 10). It accelerates the saloon from zero to 100 km/h in 6.3 seconds, taking it to a top speed of 241 km/h. In the sixth gear of the 7-speed direct-shift gearbox, the sprint from 60 to 100 km/h takes just 6.9 seconds. In the NEDC cycle, the fuel consumption of the most powerful Passat diesel is just 5.3 l/100 km, equating to CO₂ emissions of 139 g/km.
10 Conclusion

As the top engine variant for the new Passat, the new 2.0l TDI BiTurbo fulfils all requirements set by the specification. It offers:

- the highest specific power and the highest torque of all comparable engines,
- excellent consumption figures combined with powerful performance
- and compliance with the Euro 6 emissions limits.

This development is an impressive demonstration of the enormous technical potential of the Modular Diesel System, which addresses the combined challenges set by performance, fuel consumption and emissions across the spectrum from the three-cylinder 1.4 TDI in the new Volkswagen Polo to the 2.0l TDI BiTurbo high-end diesel engine in the new Passat.

11 Literature

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