The Mercedes-Benz Diesel Engine Powertrains for the new A- and B-Class –
An Innovative Integration Solution

Abstract

The new B-Class has successfully established itself on the market since the end of last year. Now Mercedes-Benz is launching from this summer onward a total of five diesel powertrains in the form of the new A-Class. The new Mercedes-Benz OM 651 4-cylinder diesel engine is offered in three performance levels in combination with a 6-speed manual transmission and with the new Mercedes-Benz 7-speed dual-clutch transmission.

To achieve an optimum drive concept, particular importance was attached to successfully developing engine and transmission drive components as well as integrating and applying them to form an optimum powertrain unit.

The focus is on the new TopType output variant in combination with the new dual-clutch transmission as well as the NVH optimization measures. In particular, this paper describes the different application and operating strategies of the powertrain layout, the purpose of which is to achieve the demanding consumption targets and an attractive drive in terms of driving performance and agility.

The new Mercedes-Benz diesel powertrains are designed to meet the requirements of traditional B-Class customers with regard to comfort and the requirements of future A-Class customers with regard to sporty driving characteristics.
1 The Diesel Engine Portfolio in the New Mercedes-Benz A- and B-Class

In 2011, the first displacement variant with 1.8 l for the new compact vehicle platform was presented as a front wheel drive variant on the basis of the OM 651 4-cylinder diesel engines, which had been in use in various Mercedes-Benz models since 2008.

As of late 2012, the engine family will feature the TopType 2.2 l (Figure 1). This top-of-the-line engine, with an output of 125 kW and a torque of 350 Nm, propels the vehicle into the power and sport segment. In addition, emission category EU 6 is achieved in the compact vehicle platform for the first time.

Figure 1: The OM 651 4-cylinder diesel engine portfolio from Mercedes-Benz

The development goals for the OM 651 in the new Mercedes-Benz A-Class were as follows:

- To achieve a significant reduction in consumption / CO₂ emissions compared to the predecessor
- To increase the specific performance and torque values as well as agility in all performance classes
- To achieve the current performance levels of 80 kW and 100 kW on the basis of an OM 651 1.8 l variant as emission category EU 5 without active denoxification
• To add a 2.2 l variant as a TopType with 125 kW and in early compliance with emission category EU 6
• To achieve a high degree of commonality with the basic engine, requiring few new parts
• To create a standardized engine for front wheel and optional all wheel drive as well as for left- and right-hand drive
• To achieve a high level of quality and maturity by maintaining a design affinity with the basic engine
• To achieve a driving performance that underlines the vehicle’s sporty character

The modular structure of the OM 651 made it possible to create the TopType variant with little need for adaptation. The technical data of the 4-cylinder diesel engine family are shown in Figure 2.

![OM 651 Engine Family](image)

**Figure 2: Technical data of the OM 651 4-cylinder diesel engine family in the A- and B-Class**

The OM 651 powertrain variants that are used are compatible between the individual body variants (car/north-south installation, car/transverse installation and installation in commercial vehicles). This enables a fast and cost-effective technology transfer from the existing basic variants to the drives of the new Mercedes-Benz Front wheel drive Architecture (MFA) as a future compact vehicle platform. In addition, newly developed powertrains can be retrospectively standardized and thus benefit the entire fleet.
The main features of the new TopType engine in the new Mercedes-Benz A- and B-Class are (Figure 3):

- Engine capacity increased to 2.2 l as a result of the increased stroke (from 83 to 99 mm)
- Lanchester balancer adjusted in line with the increased mass of the 2.2 l engine
- Use of an exhaust gas turbocharger specially adapted for the increased requirements regarding output and torque
- The modular system has been expanded to include an additional low-pressure exhaust gas recirculation (EGR)
- Use of a crankshaft decoupler with integrated vibration damper

Figure 3: Main change scopes of the new Mercedes-Benz OM 651 DE22 TopType

The new 2.2 l diesel engine already fulfills the EU 6 emissions targets that will be in force as of 2014 and 2015.

To achieve the EU 6 limiting values, the following measures have been implemented:

- The high-pressure exhaust gas recirculation system has been expanded to include a low-pressure EGR path, including an exhaust flap for controlling the gas cycle (Figure 4)
The air path model has been improved so that it can better describe – in stationary and dynamic mode – the combustion chamber conditions of the O₂ concentration.

The mixture formation process has been optimized through the use of an eight-hole injection nozzle and modifications to the tangential inlet duct.

Figure 4: The EGR system in the new Mercedes-Benz OM 651 DE22 TopType

In the low-pressure exhaust gas recirculation system, exhaust gas purged of soot particles is extracted downstream of the particulate filter and conveyed to the low-pressure system via the EGR line. Here, the exhaust gas flows through the exhaust gas recirculation cooler and electrical EGR valve. In the clean air chamber, the recirculated exhaust air is optimally mixed via a special inlet contour with the air that is drawn in and fed to the compressor.

Here, the exhaust flap further increases the naturally prevailing differential pressure downstream of the diesel particulate filter to the pressure upstream of the compressor in order to ensure that the purging gradient is sufficient for the required low-pressure EGR mass flow rate.

The continuously variable low-pressure EGR valve then regulates the required low-pressure EGR component. The low-pressure EGR mass flow rate is determined by means of a flow model on the basis of the differential pressure and the respective flow properties of the low-pressure EGR section. The model is continuously adjusted and ‘taught in’ during operation to ensure precise feedback regarding the low-pressure EGR mass flow rate. The
low-pressure component is calculated as the optimum value from consumption and emissions requirements.

The effect of the low-pressure EGR can be described in two primary development strategies:

- As a measure to reduce fuel consumption
- As a measure to reduce NOx

The ability to set fuel consumption parameters to achieve optimum fuel consumption levels (no throttling for high EGR components, center of combustion, charge temperature) and improved charging leads to benefits in terms of thermodynamics. This increases the effectiveness of the high pressure cycle biHD (indicated high pressure effectiveness), which leads to overall improvements in terms of consumption (Figure 5). The improvement in supercharging performance through the use of low-pressure EGR instead of high-pressure EGR also enables consumption-optimized switching strategies due to low engine speeds.

Figure 6 shows an example of engine performance in the NEDC for an extra-urban acceleration phase from 50 km/h to 70 km/h. The improvement in supercharging performance through the use of low-pressure EGR instead of high-pressure EGR enables fuel consumption-optimized switching strategies (low engine speeds and early upshifts), whereby in this situation higher EGR rates and/or higher excess-air factors (lambda) can be achieved. Depending on the operating point, therefore, this results in stationary and transient benefits when it comes to consumption and/or emissions with different weightings.
Figure 5: Advantage (neg.) of biHD compared with EU 5 [%]

Figure 6: Air path characteristics in the acceleration phase from 50 km/h to 70 km/h
2 Engine results

The main development targets of the new Mercedes-Benz TopType 4-cylinder diesel engine are derived from the values of the Mercedes-Benz brand:

- Outstanding fuel consumption values
- Cultivated sportiness with outstanding torque and output values as well as excellent NVH characteristics

The output and torque curves for the new A- and B-Class in the 80 kW and 100 kW performance levels and the new TopType in the 125 kW performance level are shown in Figure 7. The new TopType 220 CDI extends the product range upward.

All engines already deliver high torque at very low speeds, a feature that is maintained across a broad speed ‘plateau’. This ensures consumption-optimized driving at low speeds on the one hand, and sporty, agile driving at high speeds on the other.

![Figure 7: Output and torque characteristic curves of the new Mercedes-Benz OM 651 4-cylinder diesel engines in the three available performance levels](image)

The sound levels shown in Figure 8 (solid-borne sound level recorded in front of the powertrain bearing points; air-borne sound level determined via multiple measurement points around the engine) show yet another major improvement in the new 4-cylinder diesel engine over the preceding OM 640 engine. A significant improvement is evident
across virtually the entire speed range, which the driver and passengers will experience directly in the form of reduced sensitivity to NVH.

It also offers outstanding fuel consumption, already complying with the EU 6 emissions category. The conchoid diagram shows a ‘best point’ of \( be = 196 \, \text{g/kWh} \), along with vast areas of the performance chart with values lower than 230 g/kWh (Figure 9). This means that the product offers not only best-in-class consumption values in the NEDC, but also significant benefits in real-life driving situations.

Compared with its predecessor, the new A-Class offers much better consumption values despite improved emissions and greater output. The new TopType A 220 CDI with the 7-speed DCT transmission offers consumption of 4.3 l/100 km or 114 g/km CO\(_2\) (provisional values).
Figure 8: Sound pressure level: air-borne and solid-borne sound

Figure 9: be consumption performance chart for the new Mercedes-Benz OM 651 DE22
3 Powertrain Integration

The highly compact powertrain package is achieved through short-type engines and transmissions. On the engine side, this is achieved by means of technical measures that were implemented as early as the basic engine design phase, taking the option of transverse installation into account:

- Small cylinder spacing of 94 mm
- Compact gear drive on the rear side of the engine to drive the control unit and other components
- Compact belt drive in a transverse-installation-specific design
- Short type 3-shaft gear set concept

This provides an excellent basis for the package in the compact vehicle. The short gap between the longitudinal members gives the vehicle a small turning circle and was a key development goal for the design team.

During the concept phase of vehicle development, particular attention was paid to good NVH characteristics. For this reason, particular significance is attached to the powertrain’s bearing concept.

Unlike the previous model, the current generation of Mercedes-Benz compact vehicles no longer feature a four-point powertrain bearing. Instead, they feature a torque-roll bearing (Figure 10). This consists of two mounts that support the powertrain at the front of the engine and on the transmission housing and are supported on the vehicle longitudinal members. It also consists of two pendulum supports that absorb the torques around the crankshaft axis. This separates the mounting function from the support function in the bearings. Both mounts have been designed as hydro-mounts with enhanced damping. This ensures a comfortable driving performance.
4 The 7-speed DCT from Mercedes-Benz

The 7-speed DCT replaces the continuously variable automatic transmission (Autotronic) previously used in the B-Class. Thanks to Mercedes-Benz' long-standing experience with automatic and manual transmissions, a product based on the new concept was created within a short space of time. A component featuring an innovative gear set concept and an ultra-compact design was developed within just three years.

Similar to transmissions already on the market, the outer one of the two concentrically arranged clutches is connected to the odd-numbered gears (1, 3, 5 and 7), while the inner clutch operates gears R, 2, 4 and 6.

The new transmission system must have a compact design, short response and shift times and be highly efficient (Figure 11).
Figure 11: Requirements and technical concept of the new Mercedes-Benz 7-speed DCT

The new 7-speed DCT features an oil-cooled multi-disk clutch, which offers considerable advantages compared to the non-lubricated multi-disk clutches normally available on the market:

- **Low moment of inertia:** The required torque capacity of 350 Nm (can be expanded as an option) leads to much higher weights and moments of inertia in non-lubricated clutches than in multi-disk clutches. This, in turn, leads to reduced driving dynamics.

- **Thermal robustness:** The new Mercedes-Benz A- and B-Class vehicles are designed to be highly reliable – given a permissible vehicle/trailer weight of over three tons – even in critical situations, such as maneuvering, stopping and moving off on inclines. Combining two gear set designs with two different final-drive ratios, the transmission can be adapted to meet all requirements of the Mercedes-Benz A- and B-Class. In this way, small petrol engines have a gear ratio spread of 7.16, while the larger petrol and diesel engines achieve optimum power delivery with a gear-ratio spread of almost 8.

To provide drivers with maximum variance in terms of driving performance, the vehicles can be driven in the E-program (economy) if the focus is on low consumption or in the S-program (sport) if the driver is in the mood for a more sporty performance. Drivers can also manually shift to the M-program (manual sport mode) using the shift paddle.

In the E-program, upshifts take place at very low speeds, which gives a subjectively quiet and comfortable driving experience, due in no small part to the diesel engine’s high torque. This also ensures economical driving. In the S-program, however, upshifts take place
much later. Thanks to a lower ratio and hence higher RPMs at the same speed, drivers experience a more direct link between the gas pedal and vehicle response as well as a more spontaneous and stronger power delivery (Figure 12).

The difference between the E- and S-program does not only lie in shift points but in the “modeling” of the gear change sequence itself. The shift operations are longer and softer in the E-program, but shorter and “crisper” in the S-program (Figure 13). If needed, however, the driver can induce a performance-oriented shift response in the E-program by means of a kick-down. All in all, this means that outstanding shift times were achieved, also in comparison with the competition.

In addition to the short response and shift times to give a decidedly sporty driving style, numerous technical measures were taken to create a very high level of efficiency. This responds to the increasing significance that customers attach to vehicle consumption when deciding to purchase a vehicle or not.

The fuel savings of over 8% attributable to the 7-speed DCT are primarily the result of measures to optimize the transmission concept, starting device and oil supply. The change in transmission concept from the old continuously variable automatic transmission to the current dual-clutch transmission concept along with an increase in gear ratio spread have lead to fuel savings of 4%. Changing the starting device from a torque converter with a lockup clutch to an oil-cooled dual clutch resulted in an approximately 3% increase in efficiency. A further 2% fuel saving was achieved in the oil supply and hydraulics by reducing leaks and implementing the innovative two-pump concept. In all applications within the A- and B-Class, the 7-speed DCT is at the same level as the manual transmission.

A further 5% was saved by the first ever use of a start-stop system in a dual-clutch transmission with a wet dual clutch. Before the start-stop system could be implemented, the electrical auxiliary oil pump had to be integrated in the transmission.
Figure 12: Comparison of shift response of the 7-speed DCT in the E- and S-program

Figure 13: Comparison of shift times with modeled gear change sequence in the E- and S-program
5 Application and Drivability

The main focus in adapting the 7-speed DCT in the Mercedes-Benz A- and B-Class is on intensively applying and refining all the functions that can be experienced by customers. In particular, the three available driving programs – E (economy), S (sport) and M (manual sport mode) – achieved clear differentiation in the clutch change, start-up, driving strategy, forming the double-declutching intervention and the other driving functions. This means that gearshifts from comfortable to extremely sporty are possible.

The automatic program recognizes the current driving condition and adapts itself depending on the driving situation algorithms that are applied. For example, it responds to an extremely sporty driving style, and the shift points are moved to even higher rpms or lower pedal values. As is already known from the S-program of the Mercedes-Benz Autotronic, the shift to a lower rpm at a constant cruising speed is being implemented for the first time in a multi-stop automatic transmission.

Under driving conditions with low loads and low speed changes, the upshift point is lowered in a continuously variable manner so that the gearbox can assign the highest gear depending on the driving situation. The purpose of this measure is to further lower real-world consumption in the sporty S-automatic program.

S-mode has the following functions:

- Sporty shift program with a higher speed level, but that can also be lowered again during cruising. The eco-program is also used in cruise-control / distronic mode in the background for consumption reasons.
- Activating the S-program initiates a downshift.
- 30% quicker, more sporty gearshifts than in the E-program
- When drivers take their foot off the accelerator more quickly, a shift to a higher gear is delayed in order to improve the rpm connection (e.g. after hairpin bends).
- Using the engine’s entire speed range up to the speed limit.

With this sporty set-up, the 7-speed DCT is setting new standards for gearshift times. A major prerequisite for quick, precise gearshifts and a harmonious start-up is the quality of the engine torque signal exchanged between the engine and gearbox. This applies in particular for dual-clutch gearboxes. In Mercedes, the dynamic torque accuracy has been systematically enhanced for the current engine generation. Dynamic adjustments are calculated for this purpose in the engine control unit. A precise, dynamic torque signal is sent to the gearbox control unit. This makes it possible to reduce the deviations between the measured and real-world engine torque to a fraction of those deviations found in conventional approaches.

Both in the E- and S-program, drivers can switch to a temporary manual program using the paddle shift fitted, as standard, on the steering wheel. The temporary M-program is automatically terminated after a few seconds (except if the vehicle is decelerating) and switched back to the E- or S-program selected by the driver. The M-program can also be permanently selected using the program selector button.
The electrical parking brake now also offers enhanced comfort features. Now, the driver no longer has to release the electrical parking brake manually. The transmission control automatically asks the driver to release the parking brake when a drive away request is made. Drivers also benefit from the “hold” function, a familiar feature in the Mercedes-Benz luxury class. Simply tapping the brakes causes the brake to remain actuated even when the gear has been engaged or changed. If the driver signals an acceleration request by pressing the accelerator, the break is released after automatic adjustment with the transmission control unit.

When the vehicle is started on an incline, intelligent communication with the ESP system prevents it from inadvertently rolling backward. The brake is not released until the required engine torque exceeds the required propulsion torque. Stop/start operation is a firmly established consumption measure. Some powertrains were offered with this function in the previous A- and B-Class vehicle generation. This feature is standard in all powertrain combinations in the new generation of A- and B Classes.

In addition to a reliable and quick restart, high availability and easy parking are particularly important for customers. Particularly in traffic jams or urban traffic, customers’ are especially grateful for the ease with which the vehicle can be parked. A long run-on and heavy shaking are undesirable. This constitutes a special challenge, particularly for diesel engines. To achieve these comfort goals, the parking functions were enhanced to ensure optimum balance between run-on and vibrations. Figure 14 shows the x-y-z amplitude of acceleration in selected vehicle comfort points in comparison with other vehicles from the compact segment. The A- and B-Class redefine both the start and stop comfort.

In combination with Distronic-Plus, the new A- and B-Class is capable of automatically stopping in stop-and-go traffic, stopping the engine and following the vehicle in front again. With these comfort functions, the new 7-speed DCT is also leading the way over the dual-clutch systems currently available on the market in the compact class.
Overall, the technical solutions described above deliver significant improvements in terms of customer-perceptible powertrain criteria. In addition to high power and torque values as well as excellent driving performance, the new Mercedes-Benz A- and B-Class vehicles achieve consumption values that are at the peak of efficiency in the reference segment. This goes hand in hand with a clear increase in agility and enhanced driving comfort – the cultivated sportiness typical of the Mercedes brand. Thanks to clearly differentiated driving programs, customers have even more ways to adapt the vehicle’s character to their needs.

6 Customer-relevant Characteristics of Diesel Powertrains

Figure 14: NVH characteristics when the engine starts and stops in stop/start mode
7 Summary

In addition to the 1.8 l 4-cylinder diesel engines with outputs of 80 kW and 100 kW featured with the new Mercedes-Benz B-Class, the new top engine version with the 2.2 l 4-cylinder powertrain with an output of 125 kW and a torque of 340 Nm is being used in conjunction with the new dual-clutch transmission for the first time in the diesel engine powertrains in the new A- and B-Class.

Certification for this was granted in accordance with the EU 6 limit values in force from 2014 onward.

The powertrain shown in the A 220 CDI offers comfort-oriented drivability that does justice to the high standards that Mercedes-Benz customers expect. In addition, the optional S-program achieves whole new performance-oriented driving characteristics that offer maximum driving fun.

In addition to outstanding driving performance, the dual clutch transmission achieves gearshift times that consolidate the vehicle’s sporty character and set benchmarks in its class.

With consumption levels of less than 115 g/km CO\(_2\) on the basis of EU 6 emission certification, the 170 HP compact vehicles are thus setting new standards in a competitive environment.
Literature
