



CDI Diesel Direct Injection for OM 651

System Description

Mercedes-Benz



CDI Diesel Direct Injection for OM 651 System Description

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Dear Reader,

This brochure presents the new CDI system from Mercedes-Benz.

This system description is not specific to any particular vehicle and is based on the Common Rail Direct Injection (CDI) system of the second generation from Delphi by way of example.

This system description provides you with an overview of the new system on the occasion of its market launch. The main purpose of this brochure is to provide technicians and fitters in the service outlets with a link between the Introduction into Service Manuals and the more detailed information in the Workshop Information System (WIS) and the Diagnosis Assistance System (DAS).

In terms of content, the emphasis is on presenting the operating principles and the functional relationships irrespective of the vehicle model. The following aspects are covered:

- Design and function with subsystems
- Relationships between the components in the system
- Interaction between the system and its components

The system description is not intended as a basis for repair work or for the diagnosis of technical problems. For such needs, the Workshop Information System (WIS) and the Diagnosis Assistance System (DAS) are available as usual.

We will publicize modifications and new features in the relevant WIS documents only. The information presented in this system description may therefore differ from the information published in the WIS.

All of the technical data and details in this brochure are valid as of the copy deadline in August 2008 and may therefore differ from the current production configuration.

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Introduction

History of CDI diesel engines

The first common rail diesel direct injection system, which was introduced in the Mercedes-Benz C 220 CDI (OM 611) in 1998, finally allowed the diesel engine to establish itself in the luxury class. The common rail system installed at the time achieved a maximum injection pressure of 1,350 bar.

On vehicles with Common Rail Direct Injection (CDI), the fuel is injected directly into the combustion chamber under high pressure. The quantity of fuel that is injected is set based on performance maps stored in the engine control unit. Mixture formation with the intake air starts in the combustion chamber during the compression stroke on vehicles with CDI. Fuel may be injected several times per stroke depending on the load condition of the engine.

The performance of the engines improved continuously in subsequent years. The direct injection and turbocharging technologies were optimized, resulting in a boom in diesel vehicles which was previously unimaginable.

With the introduction of the 125 kW variant of engine 646, the system was able to achieve a maximum injection pressure of 1,600 bar and generated a maximum engine torque of 400 Nm.

The new engine 651 has a maximum injection pressure of 2,000 bar and generates a maximum engine torque of 500 Nm. In addition, the system uses directly actuated piezo injectors which operate up to five times more quickly than the solenoid injectors used previously. The injection process is divided into preinjection, main injection and post injection phases to improve combustion and reduce exhaust emissions.



Engine 611

With 2.2 l displacement and 60 kW to 95 kW used from 1998 to 2003 in C-Class, CLK-Class and E-Class.



Engine 646

With 2.2 l displacement and 100 kW to 125 kW used as of 2003 in C-Class, CLK-Class and E-Class.



Engine 651

With 2.2 l displacement and 150 kW used as of October 2008 in C-Class.

Engine 651

Engine 651 incorporates a set of innovative technologies. These include a number of new developments which cannot be found in this combination in any other series-produced passenger car diesel engine. Of particular importance are the piezo injectors, the dual-stage turbocharging and the gear drive in combination with a chain drive on the output side.

The system fully complies with the Euro 5 exhaust emissions standard using the familiar exhaust after-treatment system consisting of an oxidation catalytic converter and diesel particulate filter (DPF). At the same time, the engine output has even been increased by 20% to 150 kW with a smaller displacement and the maximum engine torque has been increased by 25% to 500 Nm.

Engine 651 is characterized primarily by the following innovations:

- Common Rail Direct Injection (CDI) system of the second generation from Delphi
- Gear drive in combination with a chain drive on the output side
- Two Lanchester balance shafts integrated into one housing together with the crankshaft (main bearing bridge)
- Piezo injectors without leak oil line
- Exhaust gas recirculation with a pre-cooler integrated in the coolant circuit and an exhaust gas recirculation cooler with switchable bypass duct
- Extended thermal management system with coolant pump and oil spray nozzles controlled according to need
- Oil pump volume-controlled at clean oil side

In-engine measures

The in-engine measures and extended control functions of the CDI control unit have allowed nitrogen (NO_x) emissions, carbon dioxide (CO_2) emissions and fuel consumption levels to be further reduced from those of the (already economical) predecessor engine.

The following measures contribute to the improvement:

- Optimized combustion chamber
- Lower compression ratio
- Higher ignition pressure
- Lower friction due to roller bearings on Lanchester balancer
- Reduced inner friction

i Note

A detailed description of the new engine 651 can be found in the Introduction into Service Manual.

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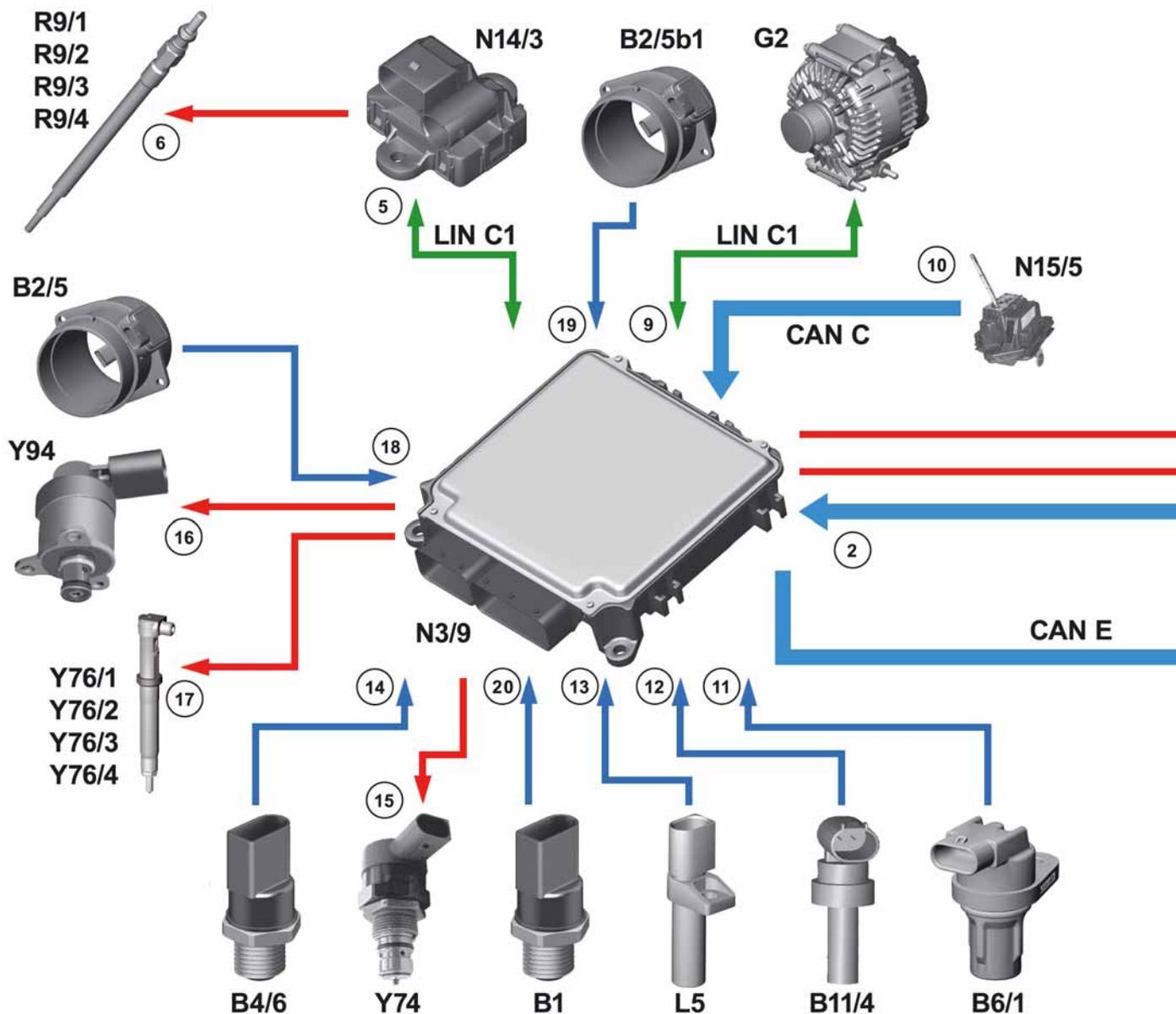
System comparison

| | Engine 646.821 EVO | Engine 651.911 |
|--------------------------------|--|--|
| Injection pressure (max.) | 1,600 bar | 2,000 bar |
| High pressure regulation | Via quantity control valve and pressure regulating valve | |
| Fuel supply | Uncontrolled electric fuel pump in fuel tank | |
| Fuel filter heater | Standard as of 09 / 08 | Standard |
| High pressure pump | 3-piston | 2-piston |
| High pressure pump drive | Chain | Gear wheel |
| Quantity control valve | X | X |
| Pressure regulating valve | X | X |
| Fuel temperature sensor | X | X |
| Fuel injector type | Solenoid injectors | Piezo injectors |
| Actuation | Indirectly hydraulically actuated by voltage increase | Directly electrically actuated by voltage drop |
| Fuel injector | 7-hole nozzle | 7-hole nozzle |
| Quantity adjustment / I2C code | 18-digit | 24-digit |
| Turbocharger type | 1-stage turbocharging with variable turbine geometry | 2-stage turbocharging with fixed geometry |
| Boost pressure control | Electric | Pneumatic |
| Intake port shutoff | X | X |



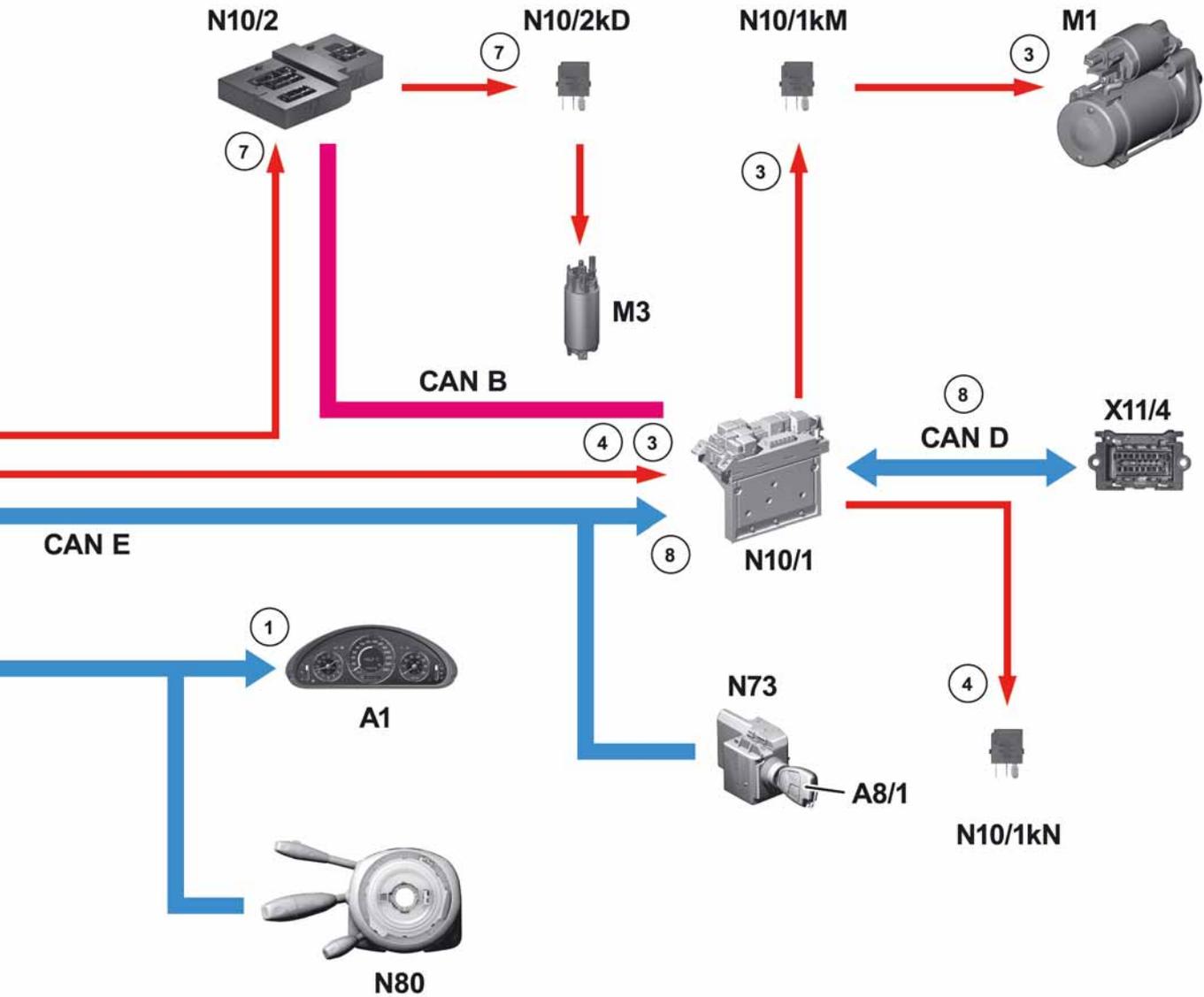
| | Engine 646.821 EVO | Engine 651.911 |
|---|-------------------------|------------------------------|
| Exhaust gas recirculation pre-cooler | X | X |
| Regulation of exhaust gas recirculation (EGR) | Electric | |
| EGR valve type | Poppet valve | Flap |
| EGR bypass | Pneumatically switched | |
| Coolant pump | Uncontrolled | With pneumatic shutoff |
| Oil pump | Uncontrolled | Controlled at clean oil side |
| Oil spray nozzles (piston cooling) | X Cannot be shut off | X Can be shut off |
| Emergency operation via camshaft sensor | — | X |
| Knock sensors | 1 | 2 |
| Chain | Dual | Single |
| Crankshaft sensor | Inductive sensor | |

CDI function schematic



Function schematic of Common Rail Direct Injection (CDI), starting/starter control

- | | | | |
|----|---|--------|---------------------------------------|
| 1 | Instrument cluster, message | 17 | Fuel injectors, actuation |
| 2 | Circuit 50, status | 18 | Hot film mass air flow sensor, signal |
| 3 | Starter, actuation | 19 | Intake air temperature sensor, signal |
| 4 | Combustion engine circuit 87 relay, actuation | 20 | Oil temperature sensor, signal |
| 5 | Preheat, request | A1 | Instrument cluster |
| 6 | Glow plugs, actuation | A8/1 | Transmitter key |
| 7 | Fuel pump relay, actuation | B1 | Oil temperature sensor |
| 8 | Engine control diagnosis, communication | B2/5 | Hot film mass air flow sensor |
| 9 | Circuit 61, status | B2/5b1 | Intake air temperature sensor |
| 10 | Electronic selector lever module control unit, status | B4/6 | Rail pressure sensor |
| 11 | Camshaft Hall sensor, signal | B6/1 | Camshaft Hall sensor |
| 12 | Coolant temperature sensor, signal | B11/4 | Coolant temperature sensor |
| 13 | Crankshaft position sensor, signal | G2 | Alternator |
| 14 | Rail pressure sensor, signal | | |
| 15 | Pressure regulating valve, actuation | | |
| 16 | Quantity control valve, actuation | | |



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- | | | | |
|---------|---|--------|--------------------------|
| L5 | Crankshaft position sensor | R9/2 | Cylinder 2 glow plug |
| M1 | Starter | R9/3 | Cylinder 3 glow plug |
| M3 | Fuel pump | R9/4 | Cylinder 4 glow plug |
| N3/9 | CDI control unit | X11/4 | Diagnostic connector |
| N10/1 | Front SAM control unit with fuse and relay module | Y74 | Pressure regulator valve |
| N10/1kM | Circuit 50 relay, starter | Y76/1 | Cylinder 1 fuel injector |
| N10/1kN | Circuit 87 relay, engine | Y76/2 | Cylinder 2 fuel injector |
| N10/2 | Rear SAM control unit with fuse and relay module | Y76/3 | Cylinder 3 fuel injector |
| N10/2kD | Fuel pump relay | Y76/4 | Cylinder 4 fuel injector |
| N14/3 | Glow output stage | Y94 | Quantity control valve |
| N15/5 | Electronic selector lever module control unit | CAN B | Interior CAN |
| N73 | Electronic ignition lock control unit | CAN C | Drivetrain CAN |
| N80 | Steering column module control unit | CAN D | Diagnostic CAN |
| R9/1 | Cylinder 1 glow plug | CAN E | Chassis CAN |
| | | LIN C1 | Drive LIN |

Fuel system

The fuel supply system ensures that the injection system is continuously supplied with fuel. During driving operation, the fuel pump pumps the fuel to the high-pressure pump. From there, it is directed to the piezo injectors at the required pressure.

The fuel supply system is divided into the "low-pressure system" and the "high-pressure system".

Low-pressure system

The electric fuel pump pumps the fuel via the fuel filter and quantity control valve to the high-pressure pump and from there on to the fuel pressure relief valve. The quantity control valve controls the fuel volume delivered to the two pump elements of the high-pressure pump via the annular passage.

When the quantity control valve is closed (deceleration mode), fuel from the fuel feed line is sent directly into the annular passage via the zero delivery throttle to lubricate the pump elements. The fuel pressure present at the quantity control valve is limited to 4.0 – 4.5 bar by the fuel pressure relief valve. If this value is exceeded, the fuel pressure relief valve opens and directs the surplus fuel back to the fuel tank via the return line.

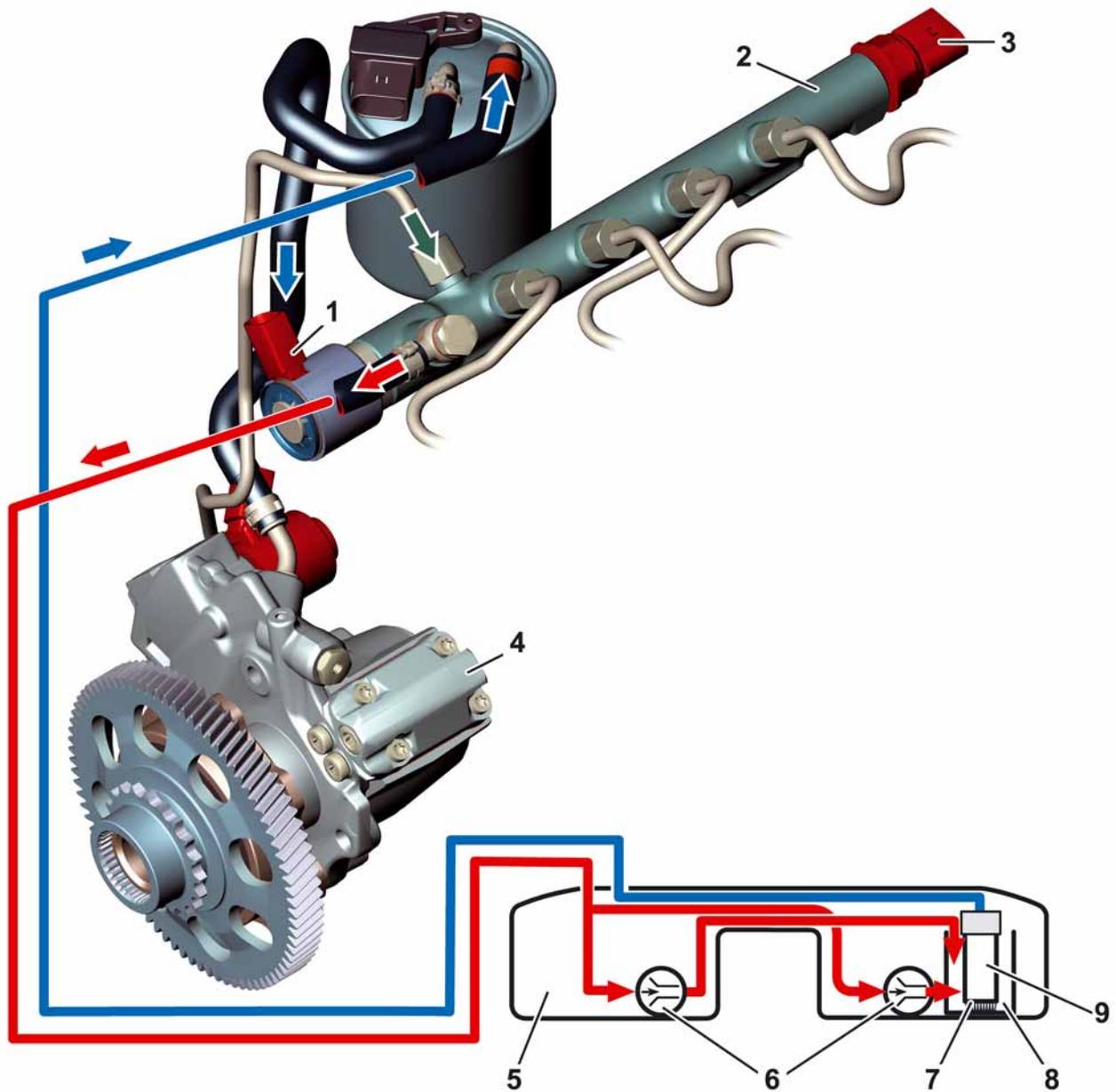
The fuel pressure relief valve also redirects a portion of the fuel to the eccentric shaft for lubrication purposes. If there is air in the fuel, the air is directed to the return line of the high-pressure pump via the fuel pressure relief valve, thus bleeding the low-pressure system.

To improve the efficiency of the engine and to keep the temperature of the fuel low, the quantity control valve regulates the flow of fuel to the high-pressure pump.

There is a heating element in the fuel filter to ensure that the fuel can flow through the lines even when the outside temperature is very low. The heating element is supplied with power by the front signal acquisition and actuation module (SAM).

Note

If the supplemental restraint system control unit transmits a "crash signal" to the CDI control unit, actuation of the fuel pump is immediately interrupted and the system is depressurized.



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Low-pressure system

- 1 Pressure regulating valve
- 2 Rail
- 3 Rail pressure sensor
- 4 High-pressure pump
- 5 Fuel tank

- 6 Suction jet pump
- 7 Fuel strainer
- 8 Swirl pot
- 9 Fuel pump

Fuel system

High-pressure system

The high-pressure system generates and stores the fuel pressure required for injection. The fuel is supplied to the rail by the high-pressure pump in a controlled manner. The fuel reaches the individual piezo injectors at a maximum injection pressure of up to 2,000 bar via the high-pressure lines. In addition, the high-pressure system operates without a leak oil line.

The injection quantity depends on the fuel pressure in the rail and the duration of the actuation of the piezo injectors. The rail pressure is regulated by the CDI control unit via the quantity control valve and / or pressure regulating valve.

The injection quantity is individually computed for each cylinder by the CDI control unit based on performance maps.

High pressure regulation

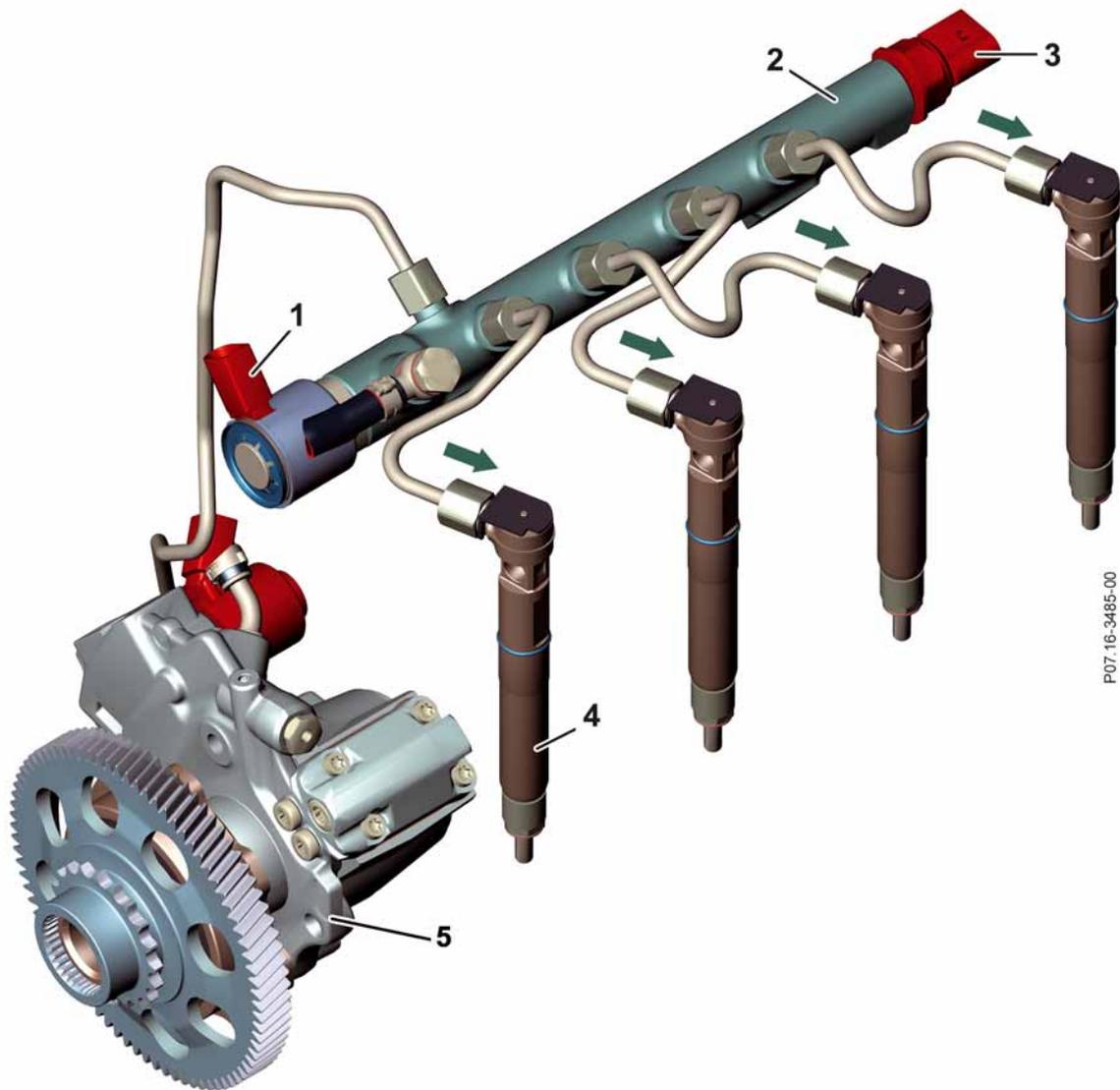
The high-pressure pump compresses a certain quantity of fuel depending on the signal from the accelerator pedal sensor and the engine speed. The actual fuel pressure and fuel temperature in the rail are recorded by the rail pressure sensor and fuel temperature sensor and continuously forwarded to the CDI control unit.

Component damage

When working on the high-pressure system (e.g. rail, pressure lines, high-pressure pump, fuel injectors) it is important to pay particular attention to quality and cleanliness. Even the slightest contamination can very quickly lead to engine running problems and engine damage.

Safety

When the engine is switched off, a residual pressure of 50 to 80 bar remains in the system. For safety reasons, the injection system may only be opened after the pressure has been released. More detailed information on this can be found in the Workshop Information System (WIS).



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High-pressure system

- 1 Pressure regulating valve
- 2 Rail
- 3 Rail pressure sensor

- 4 Piezo injector
- 5 High-pressure pump

Fuel system

Rail pressure regulation

The CDI control unit regulates the rail pressure via the pressure regulating valve or the quantity control valve based on performance maps. Regulation via the pressure regulating valve and regulation via the quantity control valve are distinct processes.

Regulation via pressure regulating valve

After each engine start, the pressure regulating valve is actuated first whereas the quantity control valve is not actuated and remains fully open. This allows the maximum quantity of fuel to be supplied to the high-pressure pump.

Regulation via the pressure regulating valve takes place under the following conditions:

- After every engine start with the engine idling up to a fuel temperature of 10 °C, with the fuel temperature rising.
- After every engine start with the engine idling as of a fuel temperature of 5 °C, with the fuel temperature dropping.

One of the functions of regulation via the pressure regulating valve is to rapidly warm up cold fuel. Pressing the fuel through the narrow gap in the pressure regulating valve can heat up the fuel to over 150 °C in certain conditions.

Regulation via quantity control valve

The advantage of regulation via the quantity control valve is that the high-pressure pump only has to compress as much fuel as the quantity control valve lets through to the high-pressure pump based on performance maps. This reduces fuel consumption and relieves the load on the high-pressure pump.

Regulation via the quantity control valve takes place under the following conditions:

- The fuel temperature is above 10 °C.
- During one-off rail pressure requests greater than 310 bar (e.g. when starting off).

When the engine is switched off, the quantity control valve interrupts the fuel supply to the pump elements.

Injection control

The injection control system defines the injection timing point and the injection period. The injection quantity depends on the rail pressure and injection period.

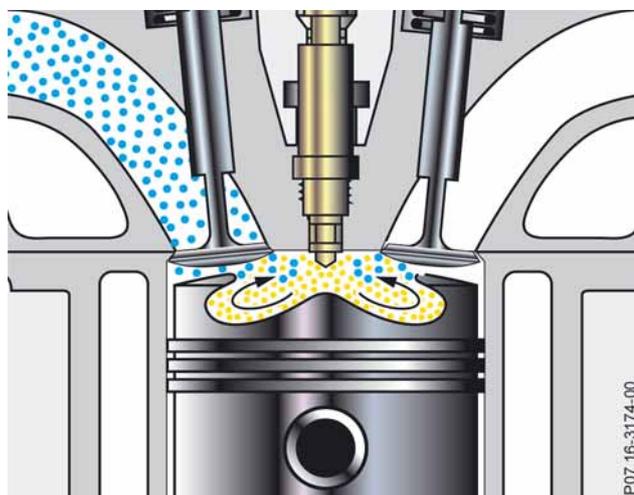
The piezo injectors, which are directly actuated by the CDI control unit, allow the fuel injection process to be more precisely adapted to the respective situation in terms of load and rpm. Depending on the injection timing point, the injection phase is referred to as preinjection, main injection or post injection.

Preinjection

With preinjection, a small quantity of fuel is injected into the cylinder before the actual main injection phase starts. This procedure takes place up to two times. This improves the efficiency of combustion and produces a smoother combustion cycle due to the heating of the combustion chamber. This results in lower exhaust emissions and less combustion noise.

The CDI control unit calculates the preinjection quantity and the start of piezo injector actuation depending on the following factors:

- Load condition of the engine
- Start of actuation of last main injection



Schematic illustration of CDI process

Mixture formation

Main injection

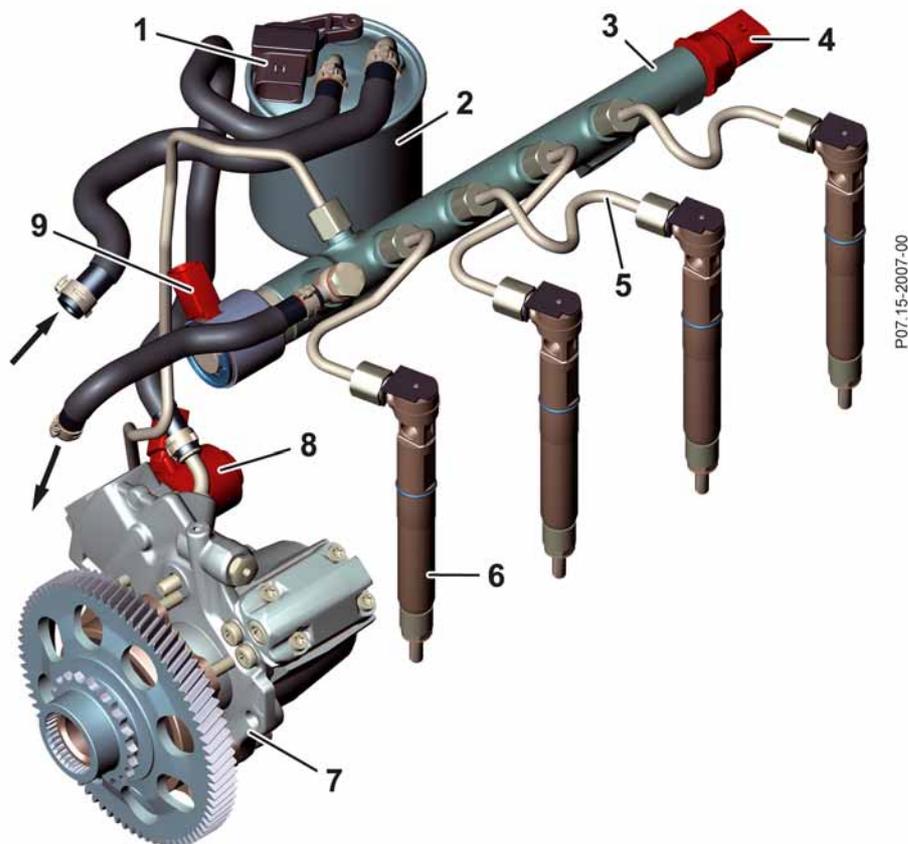
The main injection phase regulates the engine torque and output.

Main injection is performed shortly after preinjection. The injection pressure of up to 2,000 bar causes the fuel to be atomized very finely. The resulting fuel droplets have a large surface area in relation to their volume. This both accelerates the combustion process and reduces the size of particle emissions.

Post injection

The CDI control unit initiates up to two post injections following on from the main injection.

The first post injection serves to increase the exhaust temperature, which supports the conversion process for exhaust components in the oxidation catalytic converter. The second post injection is performed depending on the load condition of the diesel particulate filter (DPF). This further increases the exhaust temperature and triggers the regeneration process in the DPF. The particles in the exhaust are subsequently burnt.



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CDI injection system

- | | | |
|------------------------|------------------------|----------------------------|
| 1 Fuel heating element | 4 Rail pressure sensor | 7 High-pressure pump |
| 2 Fuel filter | 5 Pressure line | 8 Quantity control valve |
| 3 Rail | 6 Piezo injector | 9 Pressure regulator valve |

Injection quantity correction

The friction produced during opening and closing of the piezo injectors causes wear on the nozzle seat of the nozzle needle. This changes the injection quantity over the service life, which is compensated for by correcting the actuation duration.

Injection quantity correction comprises the following:

- Zero quantity calibration
- Main injection quantity correction

The following function requirements are required for this:

- Engine speed between 1,000 and 2,600 rpm
- Deceleration mode or driving operation greater than zero
- Engine oil temperature greater than 80 °C

Zero quantity calibration

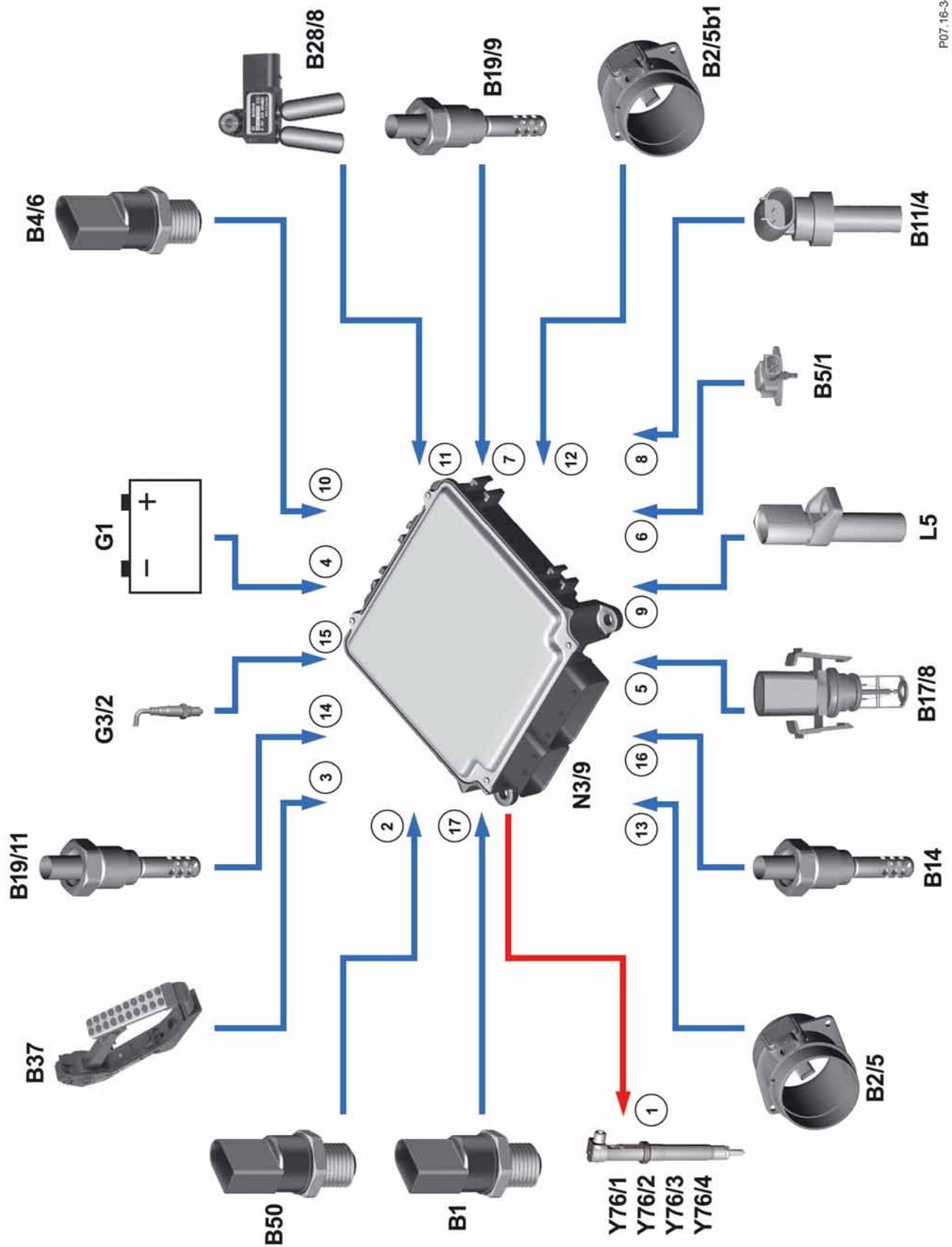
In order to counteract the change in the injection quantity, the actuation duration of the fuel injectors can be corrected via zero quantity calibration. On engine 651 with the Delphi injection system, correction is performed with the help of two knock sensors.

At defined intervals during engine operation or in deceleration mode, a preinjection quantity is calibrated for each cylinder individually. Based on the shortest possible actuation duration, the actuation duration is increased until the CDI control unit receives a signal from both knock sensors. The difference between the determined and the nominal actuation duration is used for injection quantity correction.

Main injection quantity correction

This function corrects the main injection quantity using the oxygen sensors upstream of the catalytic converter. The injection quantity is changed until the specified lambda value stored in the CDI control unit is reached.

Mixture formation



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Function schematic of Common Rail Direct Injection (CDI), injection control

| | | | |
|------|---|--------|--|
| 1 | Fuel injectors, actuation | B2/5b1 | Intake air temperature sensor |
| 2 | Fuel temperature sensor, signal | B4/6 | Rail pressure sensor |
| 3 | Accelerator pedal sensor, signal | B5/1 | Boost pressure sensor |
| 4 | Battery voltage, signal | B11/4 | Coolant temperature sensor |
| 5 | Charge air temperature sensor, signal | B14 | Outside temperature sensor |
| 6 | Boost pressure sensor, signal | B17/8 | Charge air temperature sensor |
| 7 | Temperature sensor upstream of DPF, signal | B19/9 | Temperature sensor upstream of diesel particulate filter |
| 8 | Coolant temperature sensor, signal | B19/11 | Temperature sensor upstream of turbocharger |
| 9 | Crankshaft position sensor, signal | B28/8 | Differential pressure sensor (DPF) |
| 10 | Rail pressure sensor, signal | B37 | Accelerator pedal sensor |
| 11 | Differential pressure sensor (DPF), signal | B50 | Fuel temperature sensor |
| 12 | Intake air temperature sensor, signal | G1 | On-board electrical system battery |
| 13 | Hot film mass air flow sensor, signal | G3/2 | Oxygen sensor upstream of catalytic converter |
| 14 | Temperature sensor upstream of turbocharger, signal | L5 | Crankshaft position sensor |
| 15 | Oxygen sensor, signal | N3/9 | CDI control unit |
| 16 | Outside temperature sensor, signal | Y76/1 | Cylinder 1 fuel injector |
| 17 | Oil temperature sensor, signal | Y76/2 | Cylinder 2 fuel injector |
| | | Y76/3 | Cylinder 3 fuel injector |
| | | Y76/4 | Cylinder 4 fuel injector |
| B1 | Oil temperature sensor | | |
| B2/5 | Hot film mass air flow sensor | | |

Glow system

Instant Start System

The electronically controlled Instant Start System consists of a glow output stage and four ceramic glow plugs. The Instant Start System allows the engine to be started immediately without preglowing at high coolant temperatures. In order to improve the cold start and warm-up characteristics of the engine, afterglowing is performed in steps via the controllable glow temperature. The CDI control unit regulates the voltage at the glow plugs via the glow output stage depending on time and temperature.

This has the following advantages:

- Short preglow time
- Stable idling
- Low exhaust gas emissions
- Good response behavior
- Controllable glow temperature

Preglowing

Preglowing warms up the combustion chambers of the engine so that the required ignition temperature of the fuel/air mixture is reached. The CDI control unit first evaluates the engine oil temperature and then actuates the glow output stage via the drive LIN (LIN C1) depending on the coolant temperature.

A prerequisite for the preglow is a coolant temperature below 30 °C.

Start-ready glowing

The start-ready glow function provides a sufficiently high temperature after preglowing until the engine is finally started. To achieve this, the glow output stage actuates the glow plugs. The preglow indicator lamp goes out once a start-ready temperature of 1,250 °C is reached in the glow plug.

Start-up glowing

Start-up glowing stabilizes the starting speed of the engine. When the CDI control unit receives the information "Circuit 50 ON" from the electronic ignition lock control unit, the glow output stage actuates the glow plugs via the drive LIN, thus supporting the first firing strokes and engine start-up.

Afterglowing

Afterglowing improves engine running after a cold start and the warm-up characteristics of the engine. The CDI control unit evaluates the engine oil temperature and actuates the glow plugs via the glow output stage after the engine is started. Afterglowing is terminated once the coolant temperature reaches a specified value.

Note

If a fault occurs in the preglow system, glow plugs or lines, this is indicated by the preglow indicator lamp and the fault is also stored in the fault memory of the CDI control unit.

Diagnostic glowing

This function is used for diagnosis of the individual glow circuits. The glow plugs are actuated at a low temperature level so that system faults can be detected and stored in the fault memory of the CDI control unit. Diagnostic glowing is used for troubleshooting and allows a system test to be performed irrespective of the engine oil temperature. Diagnostic glowing is also performed automatically by the system when the preglow system has not been active for an extended period of time (e.g. no glowing procedure activated due to high coolant temperatures).

Diesel particulate filter glowing

Diesel particulate filter (DPF) glowing is only performed during DPF regeneration to increase the load and stabilize combustion.

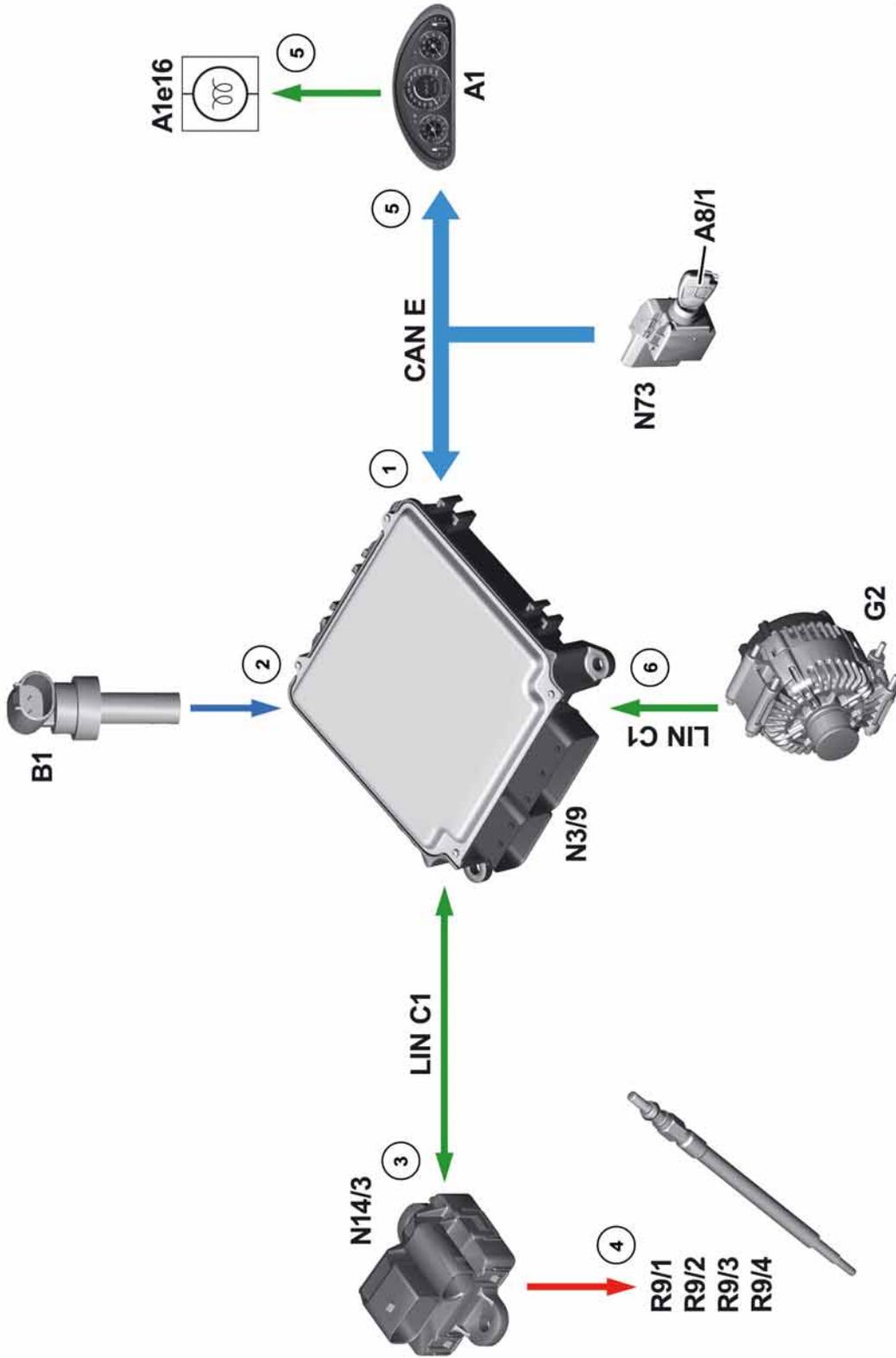
Emergency glowing

The emergency glowing function is activated for 180 s if a problem occurs with communication via the Local Interconnect Network (LIN) bus (e.g. in the event of open circuit or short circuit). The emergency glowing function is also activated for 180 s if communication fails during the glow procedure for longer than 250 ms. The glow duration and glow voltage are then based on substitute values.

Preglow indicator lamp

The preglow indicator lamp in the instrument cluster lights up during the glow procedure and indicates faults in the glow system.

Glow system



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Function schematic of Common Rail Direct Injection (CDI), glowing

| | | | | | | | |
|---|-----------------------------------|-------|------------------------|-------|---------------------------------------|--------|----------------------|
| 1 | Circuit 50, status | A1 | Instrument cluster | N14/3 | Glow output stage | R9/4 | Cylinder 4 glow plug |
| 2 | Oil temperature sensor, signal | A1e16 | Preglow indicator lamp | N73 | Electronic ignition lock control unit | CAN E | Chassis CAN |
| 3 | Glow, request | A8/1 | Transmitter key | R9/1 | Cylinder 1 glow plug | LIN C1 | Drive LIN |
| 4 | Glow plugs, actuation | B1 | Oil temperature sensor | R9/2 | Cylinder 2 glow plug | | |
| 5 | Preglow indicator lamp, actuation | G2 | Alternator | R9/3 | Cylinder 3 glow plug | | |
| 6 | Circuit 61, status | N3/9 | CDI control unit | | | | |

Intake port shutoff

The intake port shutoff (EKAS) function uses the charge air manifold to ensure the best possible ratio between air mixing and air mass in all engine load conditions and thus an optimal fill level. This optimizes the exhaust characteristics and engine output.

Functional principle

In the charge air manifold, there is a permanently open tangential intake port and a flap-controlled spiral intake port for each cylinder. The flaps are connected to each other by a shaft. The CDI control unit controls the position of the flaps based on performance maps.

The spiral intake ports are closed by the flaps in the lower engine speed and engine load range and the open tangential intake ports create a high level of air mixing.

When the engine switches from the partial load range to the full load range, the flaps in the spiral intake ports are opened according to performance maps.

The larger volume of air flow increases the flow rate and ensures optimal mixing of the air mixture. This improves combustion and reduces the amount of particles in the exhaust in the upper load and engine speed range.

In the event of a fault or if the supply voltage is interrupted, the flaps in the spiral intake ports are mechanically opened by the return springs.

Charging

General

On engine 651, charging is performed via a dual stage turbocharging process. Depending on the operating phase, the engine is provided with the required boost pressure through the interaction of a high-pressure turbocharger (HD-Lader) and a low-pressure turbocharger (ND-Lader). This increases the cylinder charge and thus the engine output and engine torque. With exhaust gas turbocharging, the flow energy of the exhaust gases is used to drive the two charge air turbines.

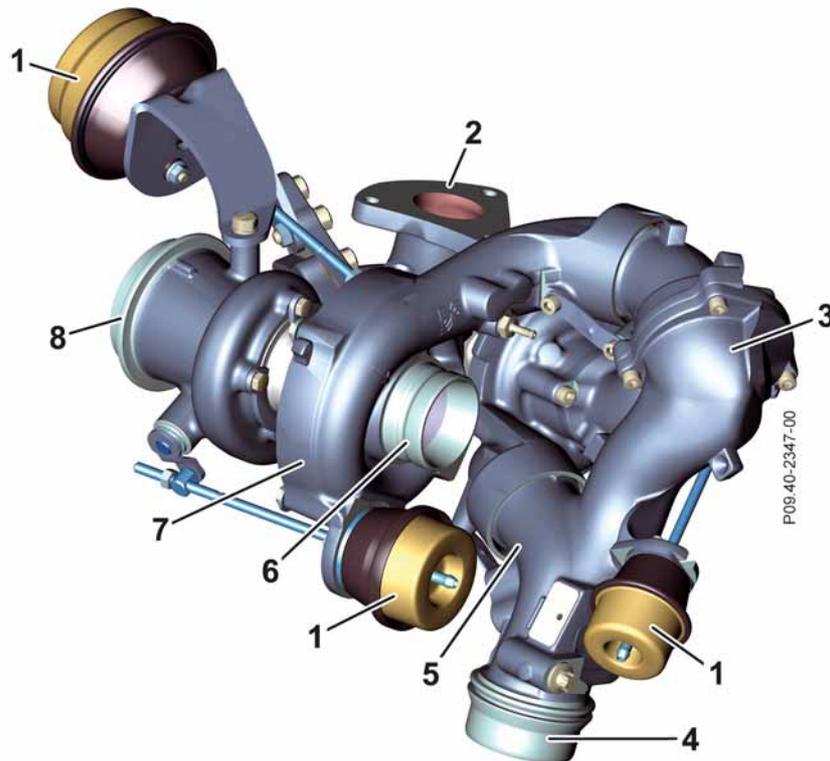
The boost pressure is regulated via the boost pressure control flap (LRK), the wastegate and the charge air bypass flap. The control operations take into account the respective engine torque request based on performance maps.

Function sequence of boost pressure control

For a better overview of how dual stage turbocharging works, three different states of wide open throttle operation have been selected. These states will be used to explain and illustrate the exact process.

The following boost pressure control states are described:

- Wide open throttle operation up to 1,200 rpm
- Wide open throttle operation between 1,200 and 2,800 rpm
- Wide open throttle operation as of 2,800 rpm



Turbocharger

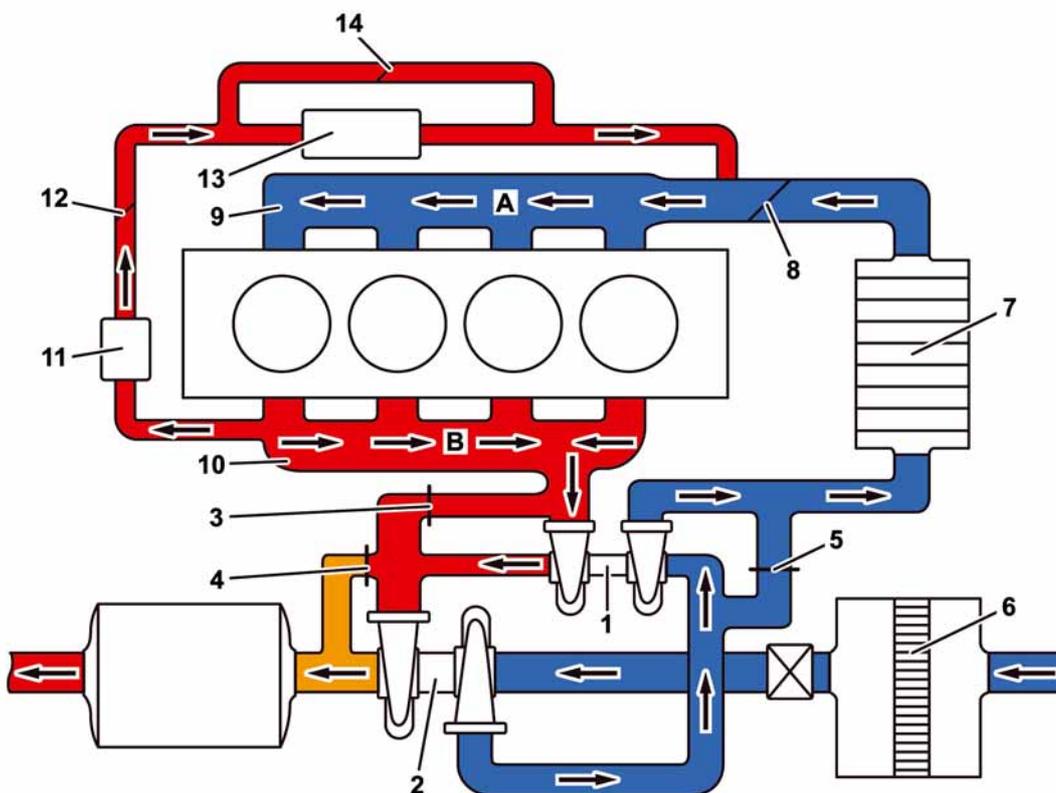
- | | |
|------------------------------|--------------------|
| 1 Vacuum unit | 5 HD-Lader |
| 2 Exhaust inlet | 6 Charge air inlet |
| 3 Bypass | 7 ND-Lader |
| 4 Charge air hose connection | 8 Exhaust outlet |

Boost pressure control during wide open throttle operation up to 1,200 rpm

The boost pressure control flap (LRK) is almost closed up to an engine speed of 1,200 rpm during wide open throttle operation. In this state, the entire exhaust flow flows over the turbine wheel of the high-pressure turbocharger (HD-Lader) to the turbine wheel of the low-pressure turbocharger (ND-Lader) and then to the exhaust system.

The majority of the exhaust energy acts on the turbine wheel of the HD-Lader, which generates the main part of the required boost pressure. Despite the low exhaust flow, this produces a high boost pressure which builds up very quickly.

The remaining exhaust energy acts on the turbine wheel of the ND-Lader, which drives the compressor impeller via the supercharger shaft. The ND-Lader thus does not act as a hydrodynamic retarder. The wastegate and charge air bypass flap are closed in this operating condition.



P09.40-2348-00

Schematic illustration of boost pressure control during wide open throttle operation up to 1200 rpm

- | | | |
|-------------------------------------|---------------------------|---|
| A Intake air | 4 Wastegate | 10 Exhaust manifold |
| B Exhaust flow | 5 Charge air bypass flap | 11 Exhaust gas recirculation (EGR) pre-cooler |
| 1 High-pressure turbocharger | 6 Air filter | 12 EGR actuator |
| 2 Low-pressure turbocharger | 7 Charge air cooler | 13 EGR cooler |
| 3 Boost pressure control flap (LRK) | 8 Throttle valve actuator | 14 EGR bypass flap |
| | 9 Intake manifold | |

Charging

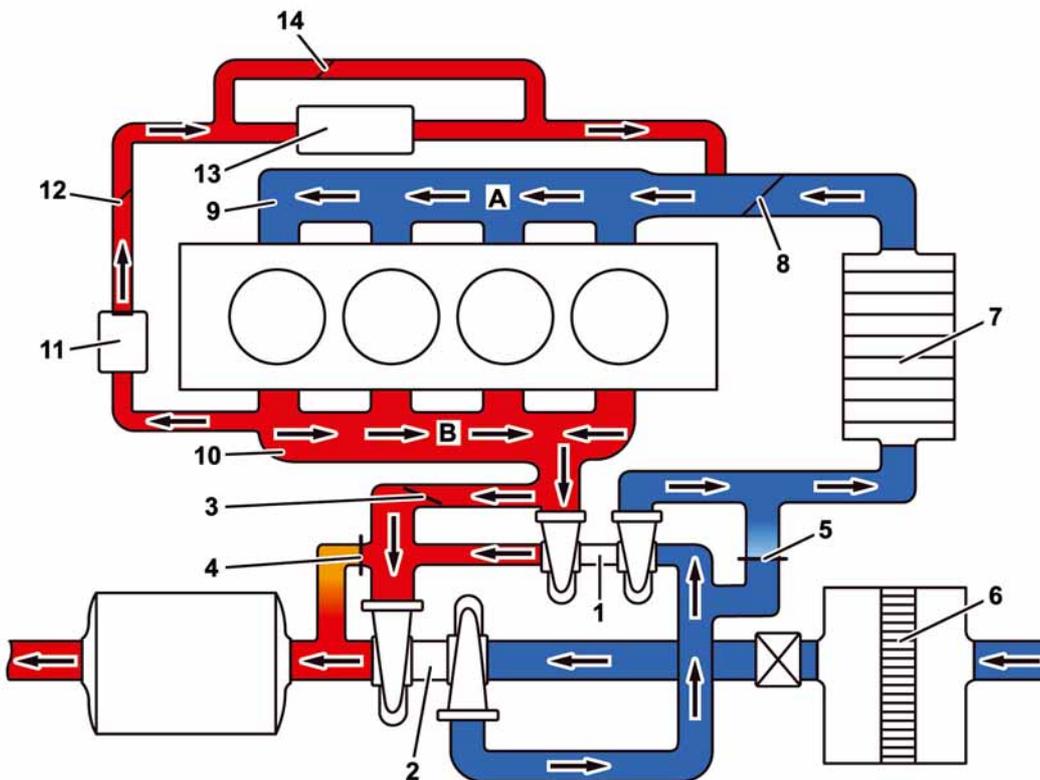
Boost pressure control during wide open throttle operation between 1,200 and 2,800 rpm

As of an engine speed of 1,200 rpm during wide open throttle operation, the boost pressure control flap (LRK) is opened in the working range (cross-section of opening) of 5% to 95% depending on the boost pressure required.

As the cross-section of the LRK opening increases, the ND-Lader is continuously engaged and a greater exhaust volume flows through it. The intake of clean air is further pre-compressed.

In this state, the two turbochargers work together and provide the required boost pressure jointly.

The wastegate and charge air bypass flap are closed in this operating condition.



P09.40-2349-00

Schematic illustration of boost pressure control during wide open throttle operation between 1200 and 2800 rpm

- | | | |
|-------------------------------------|---------------------------|---|
| A Intake air | 4 Wastegate | 10 Exhaust manifold |
| B Exhaust flow | 5 Charge air bypass flap | 11 Exhaust gas recirculation (EGR) pre-cooler |
| 1 High-pressure turbocharger | 6 Air filter | 12 EGR actuator |
| 2 Low-pressure turbocharger | 7 Charge air cooler | 13 EGR cooler |
| 3 Boost pressure control flap (LRK) | 8 Throttle valve actuator | 14 EGR bypass flap |
| | 9 Intake manifold | |

Boost pressure control during wide open throttle operation as of 2,800 rpm

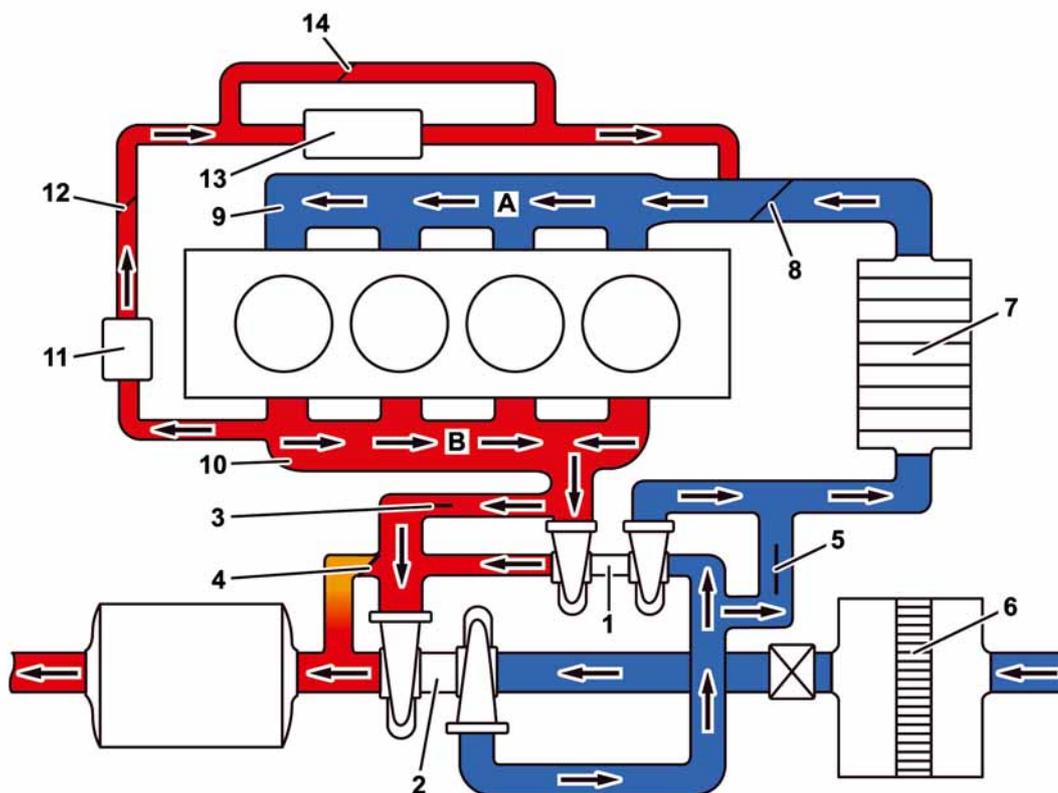
The LRK is fully open as of an engine speed of 2,800 rpm. This causes almost the entire flow of exhaust gas to be fed nearly without loss to the low-pressure turbine via the bypass duct and limits the level of exhaust back pressure.

This procedure means that the HD-Lader no longer makes any contribution to increasing the boost pressure. The HD-Lader has reached its choking limit. This means that it can no longer generate boost pressure and, in the event of further loading, the turbine speed would drop off significantly.

In order to prevent pressure loss and additional warming of the charge air as it flows through the high-pressure compressor, the charge air bypass flap is opened so that the main part of the air flow is guided to the charge air cooler along a direct, low-loss path.

The wastegate is used to regulate the turbine output of the low-pressure turbine in the engine performance map as required and depending on the load condition.

Depending on the load condition, the HD-Lader can build up a high level of boost pressure at low engine speeds and prevent overload of the ND-Lader at high engine speeds.



P09.40-2350-00

Schematic illustration of boost pressure control during wide open throttle operation as of 2800 rpm

- | | | |
|-------------------------------------|---------------------------|---|
| A Intake air | 4 Wastegate | 10 Exhaust manifold |
| B Exhaust flow | 5 Charge air bypass flap | 11 Exhaust gas recirculation (EGR) pre-cooler |
| 1 High-pressure turbocharger | 6 Air filter | 12 EGR actuator |
| 2 Low-pressure turbocharger | 7 Charge air cooler | 13 EGR cooler |
| 3 Boost pressure control flap (LRK) | 8 Throttle valve actuator | 14 EGR bypass flap |

Exhaust gas recirculation

General

The exhaust system ensures that the legally required exhaust emission limits are met.

The exhaust system of engine 651 combines two technologies for emission reduction. Exhaust gas recirculation (EGR) reduces emissions of nitrogen oxide (NO_x) and exhaust treatment reduces the emission of hydrocarbons (HC) and soot particles.

Exhaust gas recirculation

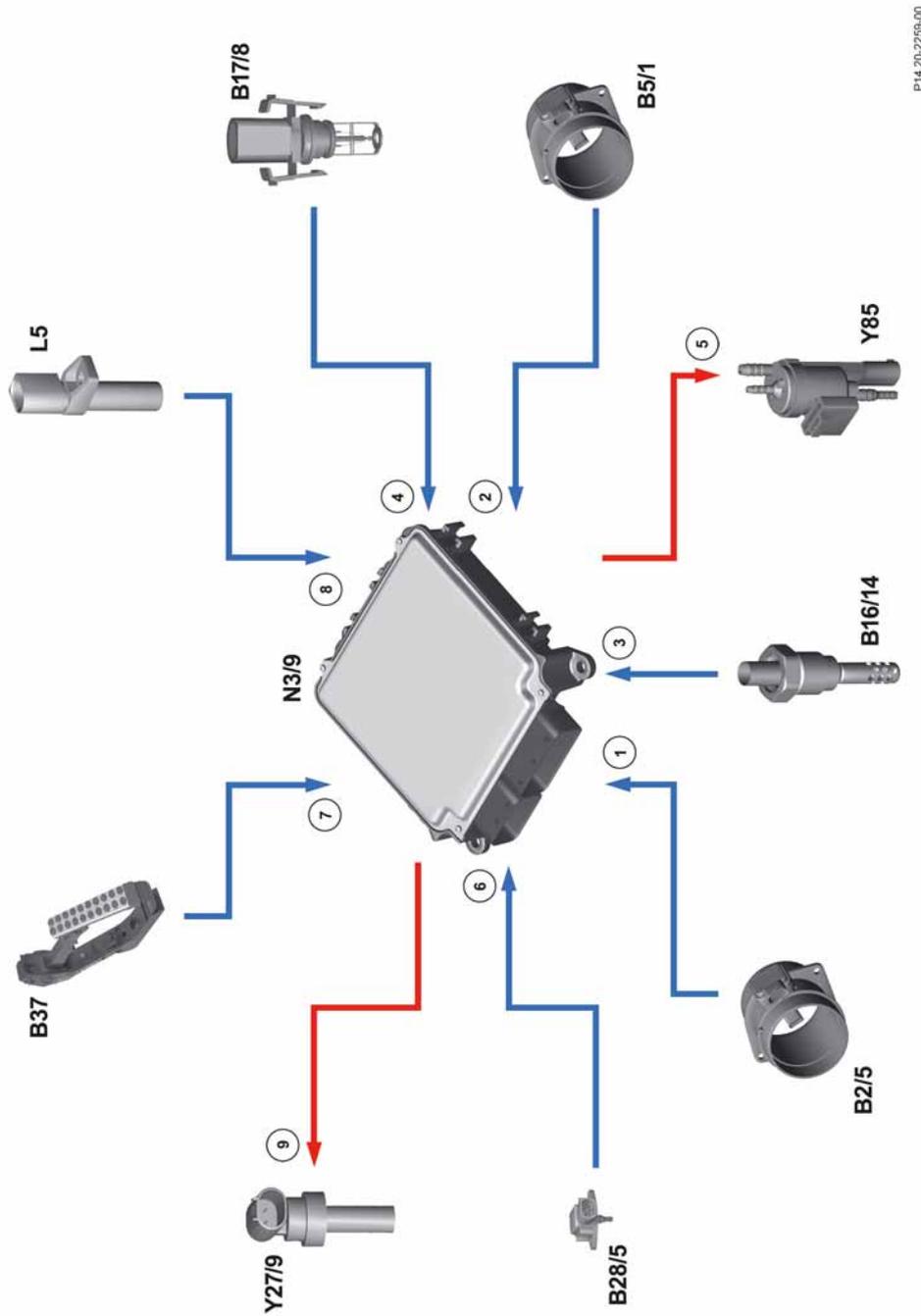
With exhaust gas recirculation (EGR), part of the exhaust flow is guided through the EGR path to the charge air. Exhaust gas recirculation lowers the combustion temperature and the proportion of excess oxygen (O_2) is reduced. This measure reduces the production of NO_x during combustion. In addition, the lack of oxygen reduces the combustion velocity and the exhaust flow to the oxidation catalytic converter is reduced.

The recirculated exhaust gas first enters the actual EGR path via a pre-cooler. The recirculated exhaust gas quantity is controlled via the EGR actuator.

In order to further improve the efficiency, the exhaust gas is directed via the EGR cooler and cooled further depending on the performance map. If the temperature of the incoming exhaust gas is too low, the path to the EGR cooler is closed via a bypass flap and the exhaust gas is guided directly to the charge air manifold. The EGR bypass flap is actuated by the CDI control unit via a vacuum unit.

If some of the exhaust gas is directed past the EGR cooler, the combustion chambers are warmed up more rapidly in the lower load range. This means that there is less carbon monoxide (CO) and hydrocarbons (HC) in the exhaust.

In the upper load range, the exhaust gas is directed via the EGR cooler and thus cooled. This lowers the concentration of nitrogen oxides (NO_x) in the exhaust.



P14.20.2259-00

Function schematic of Common Rail Diesel Injection (CDI), exhaust gas recirculation

| | | | |
|--------|---|-------|--|
| 1 | Hot film mass air flow sensor, signal | B37 | Accelerator pedal sensor |
| 2 | Boost pressure sensor, signal | L5 | Crankshaft position sensor |
| 3 | Exhaust gas recirculation temperature sensor, signal | N3/9 | CDI control unit |
| 4 | Charge air temperature sensor, signal | Y27/9 | Exhaust gas recirculation actuator |
| 5 | Exhaust gas recirculation cooler bypass switchover valve, actuation | Y85 | Exhaust gas recirculation cooler bypass switchover valve |
| 6 | Pressure sensor downstream of air filter, signal | | |
| 7 | Accelerator pedal sensor, signal | | |
| 8 | Crankshaft position sensor, signal | | |
| 9 | Exhaust gas recirculation actuator, actuation | | |
| B2/5 | Hot film mass air flow sensor | | |
| B5/1 | Boost pressure sensor | | |
| B16/14 | Exhaust gas recirculation temperature sensor | | |
| B17/8 | Charge air temperature sensor | | |
| B28/5 | Pressure sensor downstream of air filter | | |

Exhaust system

Exhaust treatment

The exhaust treatment system filters a large part of the remaining pollutants still present in the exhaust gas. The system consists of the familiar combination of oxidation catalytic converter and diesel particulate filter (DPF). The exhaust treatment system supplements exhaust gas recirculation to intercept the following pollutants and reduce them through after-treatment:

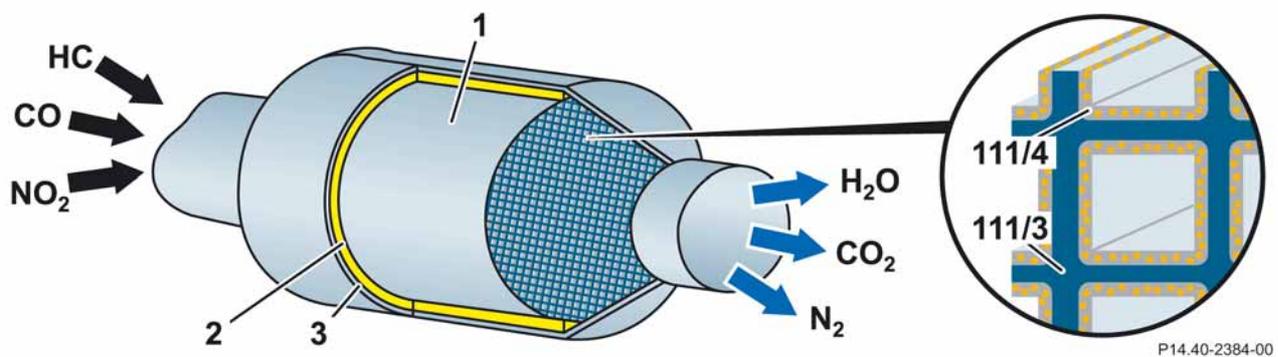
- Nitrogen oxides (NO_x)
- Hydrocarbons (HC)
- Carbon monoxide (CO)
- Pollutant and soot particles

Function sequence of exhaust treatment

The exhaust gases emitted by the engine are cleaned in an oxidation catalytic converter and a diesel particulate filter (DPF).

The oxidation catalytic converter reduces the concentration of hydrocarbons (HC) and carbon monoxide (CO) and generates the required thermal energy for the DPF regeneration phase through afterburning. The DPF comprises a ceramic honeycomb filter element made of silicon carbide and coated with platinum.

The exhaust gas which is precleaned in the oxidation catalytic converter flows into the channels of the DPF which open out towards the front and reaches the channels which open out to the rear through the porous filter walls of the honeycomb filter body. The soot particles are held in the honeycomb filter of the DPF. The cleaned and filtered exhaust is then dissipated through the exhaust system.



P14.40-2384-00

Operation of oxidation catalytic converter (schematic)

| | | | | | |
|-------|------------------|---------------|-------------------------------|----------------------|------------------|
| 1 | Catalyst support | 113/4 | Intermediate layer (washcoat) | HC | Hydrocarbon |
| 2 | Insulating mat | CO | Carbon monoxide | H_2O | Water |
| 3 | Housing | CO_2 | Carbon dioxide | N_2 | Nitrogen |
| 111/4 | Ceramic monolith | | | NO_2 | Nitrogen dioxide |

DPF regeneration

The DPF differential pressure sensor reports the load condition of the DPF to the CDI control unit. If the load of soot particles is too great and exceeds a limit value stored in a performance map, the CDI control unit initiates the regeneration phase when the load condition is suitable. Regeneration takes place by periodically increasing the exhaust gas temperature.

The soot particles stored in the DPF are largely burnt off to produce carbon dioxide (CO₂). Approximately 99% of soot particles are reduced. The residual ash which is produced remains in the DPF.

The regeneration times are dependent on temperature and decrease significantly as the exhaust gas temperature rises. The following measures are used to increase the exhaust temperature:

- Post injection
- Exhaust gas recirculation with intake air throttling
- DPF glow function

During regeneration, the exhaust temperature is monitored by the temperature sensor upstream of the turbocharger and the temperature sensor upstream of the DPF.

i Note

If DPF regeneration is interrupted as a result of short-distance trips, the process is spread out over several driving cycles. Until the specified regeneration temperature is reached several heating-up phases are required.

Regeneration occurs unnoticed by the customer.

i Note

If the DPF is overloaded with ash, the engine diagnosis indicator lamp on the instrument cluster indicates that the DPF requires maintenance.

Following the regeneration phase, the CDI control unit registers the calculated difference in pressure via the DPF differential pressure sensor and compares this value with a reference value. From this the CDI control unit determines the residual ash load of the diesel particulate filter.

CDI control unit

CDI control unit (N3 / 9)

The CDI control unit is located on the air filter housing. The CDI control unit is equipped with cooling fins at the bottom which project inside the air filter housing and are cooled by the intake air.

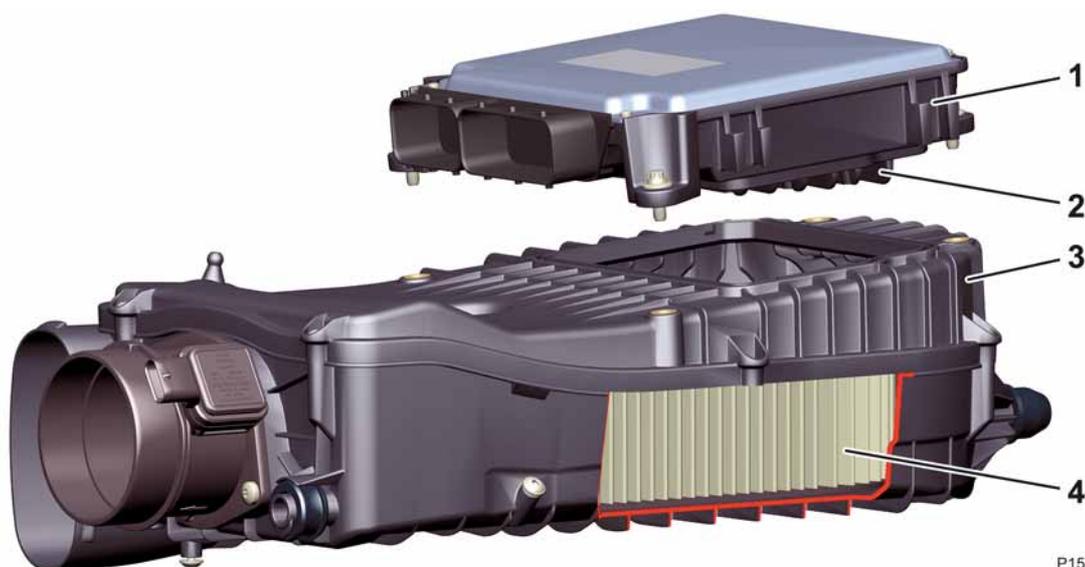
The task of the CDI control unit is divided into the following subtasks:

- Engine torque control
- Injection control
- Charging
- Deceleration fuel shutoff
- Thermal management
- Exhaust gas recirculation (EGR)
- Exhaust treatment

The CDI control unit serves as an interface between the drive train CAN (CAN C) and the chassis CAN (CAN E).

The engine control system is equipped with a fault memory and powerful diagnostic functions for monitoring all system components and functions. This incorporates the following aspects:

- Fault memory checking
- Engine control diagnosis
- European On-Board Diagnosis (EOBD)
- Diagnosis via CAN bus
- Diagnosis via K-line



P15.00-2190-00

CDI control unit

- 1 CDI control unit
2 Cooling fins

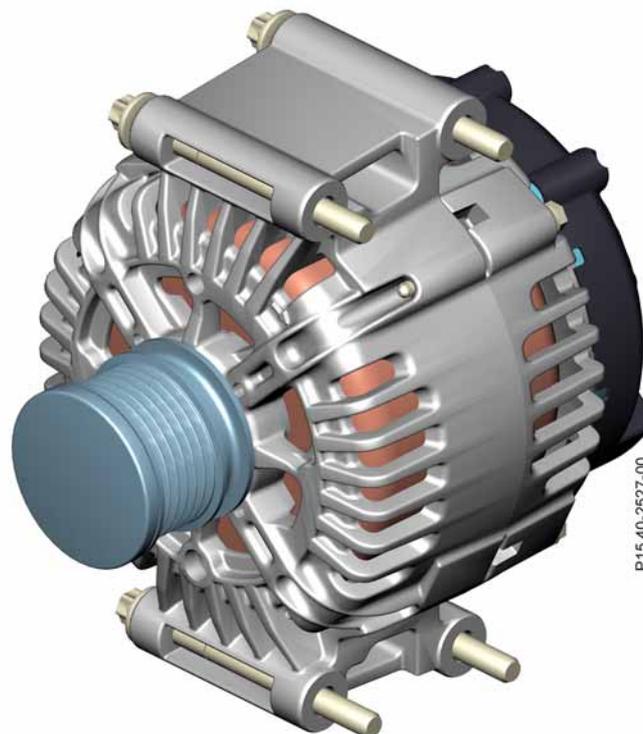
- 3 Air filter housing
4 Air filter

Alternator (G2)

The alternator regulates the charging voltage depending on electrical consumption and the battery charge level. The CDI control unit regulates the alternator output via an alternator interface. This has the effect of, for example, reducing the engine idle speed and exhaust emissions.

The alternator detects various faults and reports them in turn to the CDI control unit.

Communication between the CDI control unit and the alternator takes place over the Local Interconnect Network (LIN) bus.



Alternator

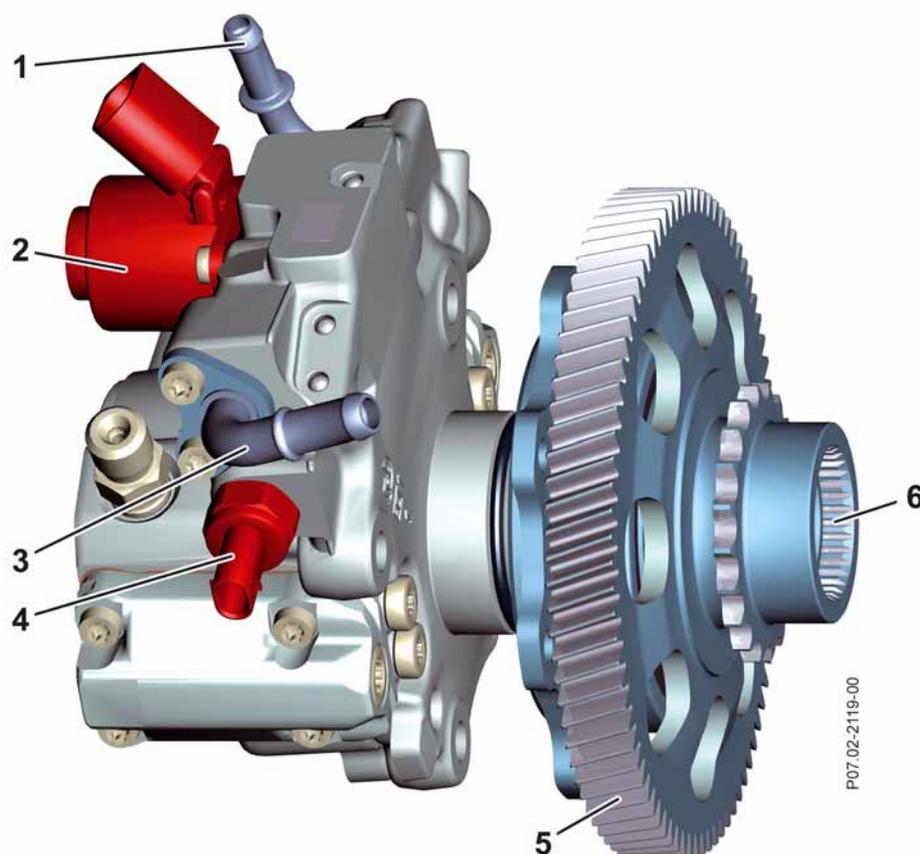
i Note

When testing the regulation voltage, the on-board electrical system battery must be placed under load by a battery tester.

High-pressure pump

The 2-piston high-pressure pump is located on the left-hand side of the crankcase at the output side. The high-pressure pump compresses the fuel and generates the required rail pressure.

The gear wheel of the high-pressure pump is driven by the gear drive at half of the crankshaft rpm. The torque is transferred to the shaft of the high-pressure pump via a multi-gear driver.



High pressure pump

- | | | | |
|---|------------------------|---|-------------------------|
| 1 | Return flow | 4 | Fuel temperature sensor |
| 2 | Quantity control valve | 5 | Gear wheel |
| 3 | Feed | 6 | Multi-gear driver |

i Note

The high-pressure lines between the high-pressure pump, the rail and the piezo injectors may only be used once.

High-pressure side

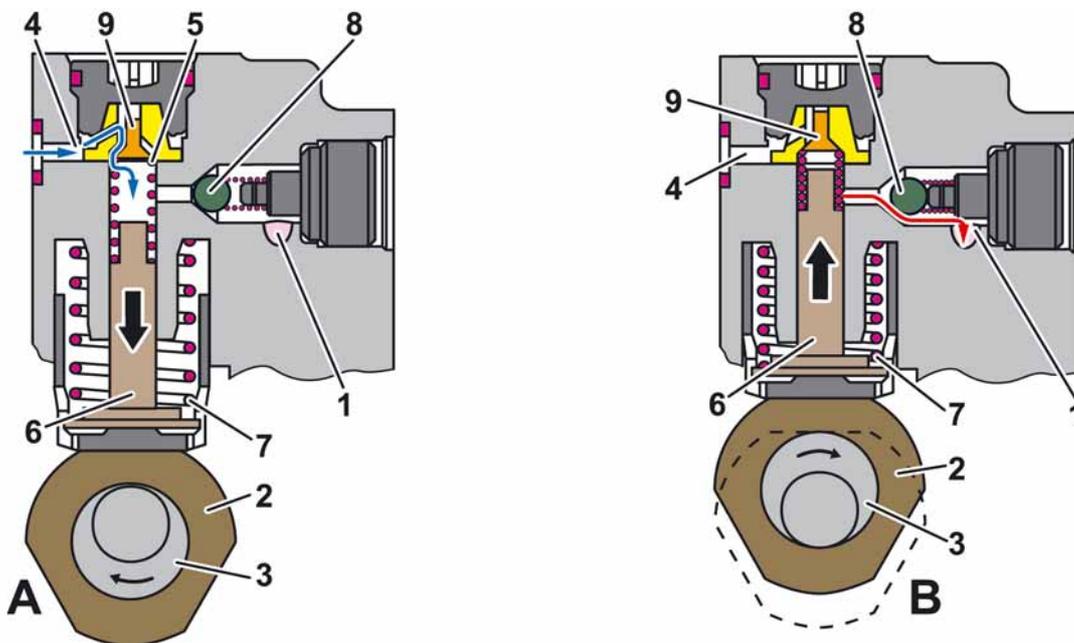
The eccentric shaft (3) with its crank disk (2) moves the pistons (6) up and down against the respective piston springs (7). This fills the piston (picture A) and enables the fuel to be compressed.

Piston filling

The piston is pressed downwards by the tensioned piston spring (7). The fuel supplied enters the annular passage and then the cylinder via a valve (9). A defined force must be applied to the valve spring (5) in the process. The ball valve (8) prevents the fuel from flowing back from the high-pressure channel (1) into the pump elements.

High pressure generation

The leading edge of the eccentric shaft causes the piston to move upwards. This compresses the fuel (picture B). The valve separates the fuel being compressed from the fuel feed. If the fuel pressure in the cylinder rises above the pressure inside the high-pressure system, the ball valve opens and the fuel is directed into the high-pressure system.



P07.02-2120-00

Schematic diagram

- 1 High-pressure channel
- 2 Crank disk
- 3 Eccentric shaft
- 4 Fuel feed to high-pressure elements
- 5 Valve spring
- 6 Piston
- 7 Piston spring

- 8 Ball valve
- 9 Valve
- A Piston filling
- B High-pressure generation

Rail pressure control valves

Pressure regulating valve (Y74)

The pressure regulating valve is screwed into the rail on the output side.

If the pressure regulating valve is not actuated, it is hydraulically opened so that pressure compensation can take place between the high-pressure side and low-pressure side.

The CDI control unit regulates the coil current via a pulse width modulated signal to produce a magnetic force. This process causes the valve pin to press against the balls, thus creating an equilibrium of force against the high-pressure side. The diverted fuel flows back into the fuel tank via the fuel return connection on the rail.

Quantity control valve (Y94)

The quantity control valve is located directly on the high-pressure pump.

Based on the signal from the CDI control unit, the quantity control valve regulates the fuel quantity supplied to the pump elements via the annular passage.

The quantity control valve has the following tasks:

- Regulation of the fuel flow to the pump elements of the high-pressure pump.
- Interrupt fuel feed to pump elements of high-pressure pump when engine is switched off.



P07.05-2065-00

Pressure regulator valve



P07.05-2064-00

Quantity control valve

Piezo injector

The piezo injectors (Y76) inject the highly pressurized fuel into the respective cylinders. The injection quantity depends on the duration of actuation, the pressure present and the opening / closing speed of the injector.

In contrast to previous fuel injectors, the new piezo injectors do not inject upon a voltage increase, but upon a voltage drop.

Function

A discharge of voltage causes the piezo element to shorten. This movement is transferred to the nozzle needle of the nozzle module via a travel transmission device (coupler module). This raises the nozzle needle to free up the injection holes. Injection is stopped when the piezo element is recharged by the CDI control unit. The piezo element re-extends when charged. The nozzle needle is lowered and the injection holes are resealed. With "Circuit 16 OFF" and with CDI control unit run-on over, the nozzle needle is returned to its starting position by a spring so that the injection nozzles are again sealed.

I2C coding

On engine 651 with the new CDI system, the coding has been extended to a 24-digit I2C code.

The I2C coding permits even more accurate tuning (injection quantity and injection period) of the individual piezo injectors when new.

If a piezo injector is replaced, the CDI control unit must be supplied with this coding via Star Diagnosis.

It must be ensured that the correct I2C codes are entered after replacing the injectors.

If the I2C codes are entered incorrectly or not at all, the following problems may arise:

- Smoke formation
- Rough or vibrating engine
- Power loss
- Generation of noises



Piezo injector

P07.03-2242-00

Actuation of piezo injectors

Engine OFF: Ignition ON

The pressure in the low-pressure fuel system is built up. A spring holds the nozzle needle in the nozzle seat until the piezo element is charged and has expanded.

Engine running: No injection

The rail pressure generated is applied to the nozzle needle. The piezo element of the fuel injector is charged in this state. A spring holds the nozzle needle in the nozzle seat. The nozzle is closed.

Engine running: Injection

Voltage discharge from the piezo element causes it to shorten. A travel transmission device transfers this movement to the nozzle needle. The nozzle needle raises to free up the injection holes in the nozzle. Injection takes place until the piezo element is recharged by the CDI control unit.

Engine running: End of injection

Voltage is applied to the piezo element to move it back to its starting position. The travel transmission device transfers this movement to the nozzle needle. The nozzle needle is thus pressed into the nozzle seat and seals the injection holes.

Engine OFF: Control unit run-on finished

The injection system is full of fuel, but is unpressurized (atmospheric pressure). A spring holds the nozzle needle in the nozzle seat. The nozzle is closed and no injection takes place.

Warning! Risk of death!

During operation, a high voltage of up to 250 V is applied to the piezo injectors.

Warning

No voltage measurements may be performed on injectors.

Due to the risk of engine damage, no connections on the injection system may be disconnected while the engine is running.

Glow output stage

Glow output stage (N14 / 3)

The glow output stage is located on the end of face of the cylinder head at the front. It consists of a plastic housing reinforced by an aluminum plate on the underside.

The CDI control unit reads in the following parameters about the engine operating condition to control the glow output stage:

- Engine speed
- Load
- Coolant temperature

The glow output stage is actuated by the CDI control unit via Local Interconnect Network (LIN).

Diagnostic communication between the glow output stage and the CDI control unit takes place over the same LIN connection.

A distinction is made between the following glowing types:

- Preglowing: For reaching the start temperature of the glow plugs more quickly
- Start-ready glowing: Ensures that the temperature is high enough after preglowing and until the engine is started
- Start-up glowing: Stabilizes the starting speed of the engine
- Afterglowing: Improves engine running after a cold start and the warm-up characteristics of the engine
- Diagnostic glowing: For system diagnosis
- Diesel particulate filter (DPF) glowing: Supports regeneration
- Emergency glowing: Initiated in the event of problems with communication over the Local Interconnect Network (LIN) bus



P07.07-2075-00

Glow output stage

Ceramic glow plugs (R9)

Engine 651 features glow plugs with a ceramic glow pin.

Ceramic glow plugs reach a glow temperature of approx. 1,300 °C, which is approx. 200 °C higher than that of conventional glow plugs, and they are also less acceptable to drops in glow temperature over their service life.

Properties of ceramic glow plugs:

- Lower energy consumption
- Outstanding starting characteristics
- Rapid temperature increase
- High conductivity
- High glow temperature
- Long service life

Risk of engine damage

Safety information for handling ceramic glow plugs:

- Only use glow plugs from unopened original packaging
- If a glow plug is dropped on the floor, it must not be used
- Important: Engine damage can occur because glow plugs are very sensitive to shock! Hairline cracks may develop in the ceramic element. As a consequence, parts may become detached and drop into the combustion chamber while the engine is running. Always handle glow plugs with the utmost care!
- The glow plugs must be removed before removing the cylinder head, and must not be reinstalled until the cylinder head has been installed.



P15.20-2181-00

Ceramic glow plug

Hall sensor

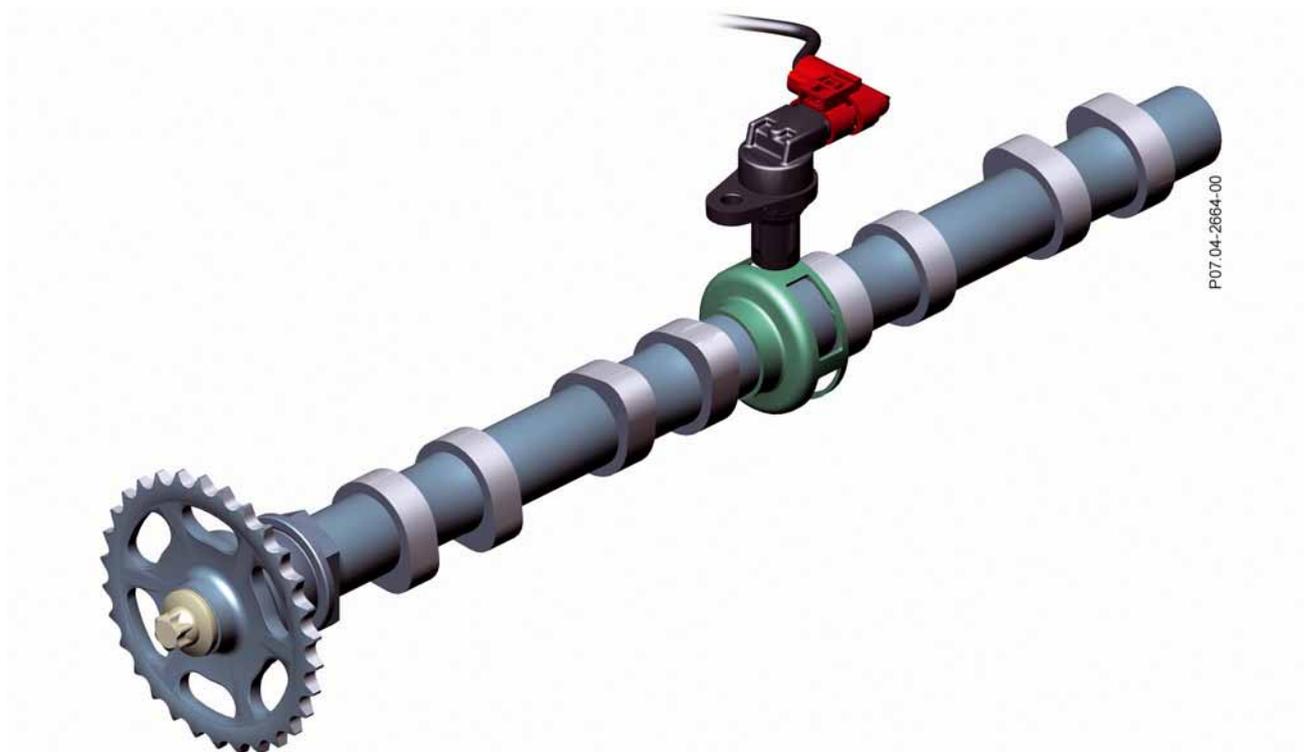
Hall sensor for camshaft (B6 / 1)

The Hall sensor is located at the center of the cylinder head cover over the exhaust camshaft.

A permanent magnet installed in the Hall sensor creates a magnetic field. The magnetic field is periodically interrupted by an orifice plate positioned on the exhaust camshaft. Due to the electronics installed in the Hall sensor, a voltage signal is created by the magnetic field. The electronics convert the signal into a square wave signal which is evaluated by the CDI control unit.

Together with the signal from the crankshaft position sensor, the signal from the camshaft Hall sensor is used by the CDI control unit for cylinder 1 recognition.

If the signal from the crankshaft position sensor is not available to the CDI control unit, the engine can still be started because the CDI control unit uses the signal from the camshaft Hall sensor as a substitute value (emergency operation).



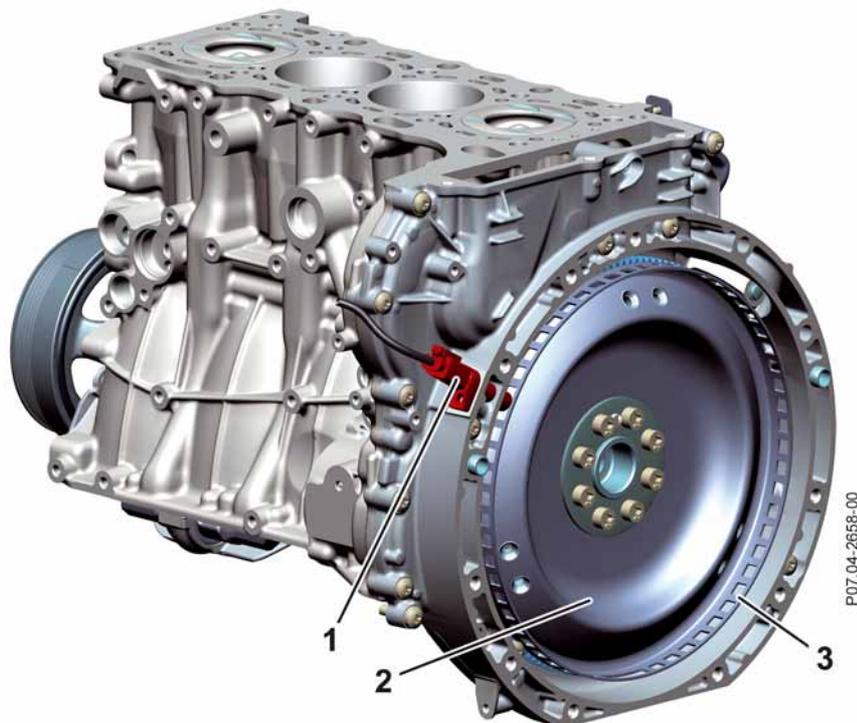
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Hall sensor with camshaft

Position sensor for crankshaft (L5)

The position sensor is located on the transmission flange at the left on the output side.

The position sensor for the crankshaft is supplied with voltage by the CDI control unit. A permanent magnet is installed in the crankshaft position sensor. The magnetic field it generates is periodically interrupted by the orifice plate. The interruptions in the magnetic field create a voltage pulse in the built-in electronics. The Hall electronics convert this signal into a square wave signal which is forwarded to the CDI control unit.



Position sensor for crankshaft

1 Crankshaft position sensor

2 Flywheel

3 Orifice plate

Temperature sensors

Low-temperature sensors

Low-temperature sensors consist of Negative Temperature Coefficient (NTC) resistors. They are made of current-conducting material (silicon). The resistance of the low-temperature sensors reduces as the temperature increases. The voltage changes are forwarded to the CDI control unit where they are evaluated.

Coolant temperature sensor (B11 / 4)

The coolant temperature sensor is installed in the thermostat housing.

Charge air temperature sensor (B17 / 8)

The temperature sensor for charge air is located in a plastic housing in front of the throttle valve actuator.

Fuel temperature sensor (B50)

This temperature sensor records the temperature of the fuel flowing through the high-pressure pump and is located next to the fuel feed line of the high-pressure pump. Injection quantity and rail pressure are automatically reduced as soon as the temperature of the supplied fuel exceeds 90 °C.

Oil temperature sensor (B1)

The oil temperature sensor records the engine oil temperature and is located above the vacuum pump in the oil duct on the crankcase.

Intake air temperature sensor (B2 / 5b1)

The intake air temperature sensor is located in the housing of the hot film mass air flow sensor.

High-temperature sensors

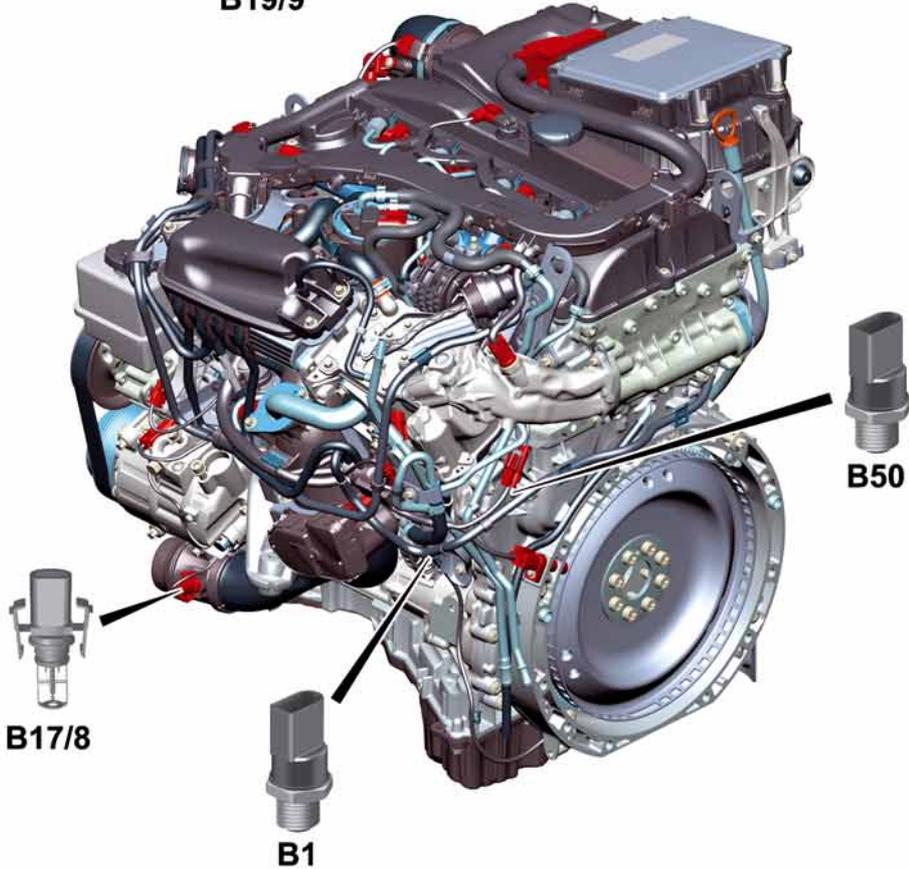
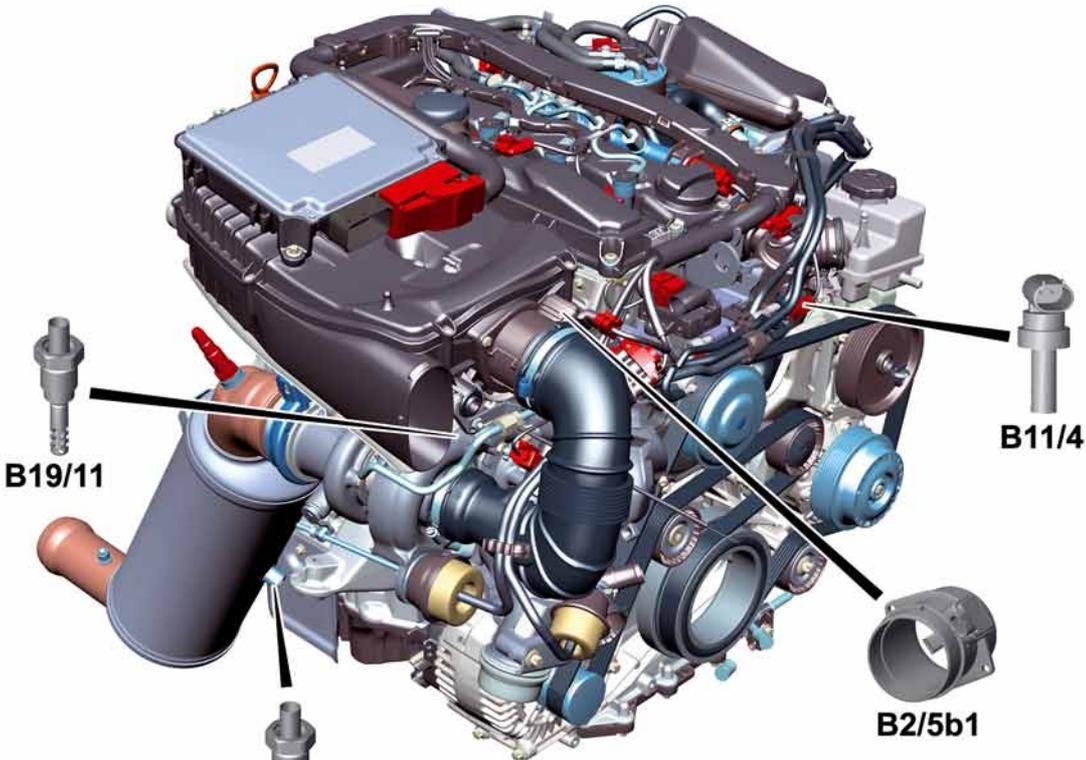
High-temperature sensors consist of Positive Temperature Coefficient (PTC) resistors. They are made of metal. The resistance of the high-temperature sensors increases as the temperature increases. The voltage changes are forwarded to the CDI control unit where they are evaluated.

Temperature sensor upstream of turbocharger (B19 / 11)

The temperature sensor is located on the exhaust manifold flange upstream of the turbocharger where it determines the exhaust temperature. This allows the thermal load on the engine and the turbocharger to be monitored.

Temperature sensor upstream of diesel particulate filter (B19 / 9)

The temperature sensor is located in the assembly upstream of the diesel particulate filter (DPF). The sensor measures the temperature of the exhaust gas as well as the thermal load on the oxidation catalytic converter.



P01.00-3116-00

Engine 651 with temperature sensors

Oil spray nozzle shutoff valve

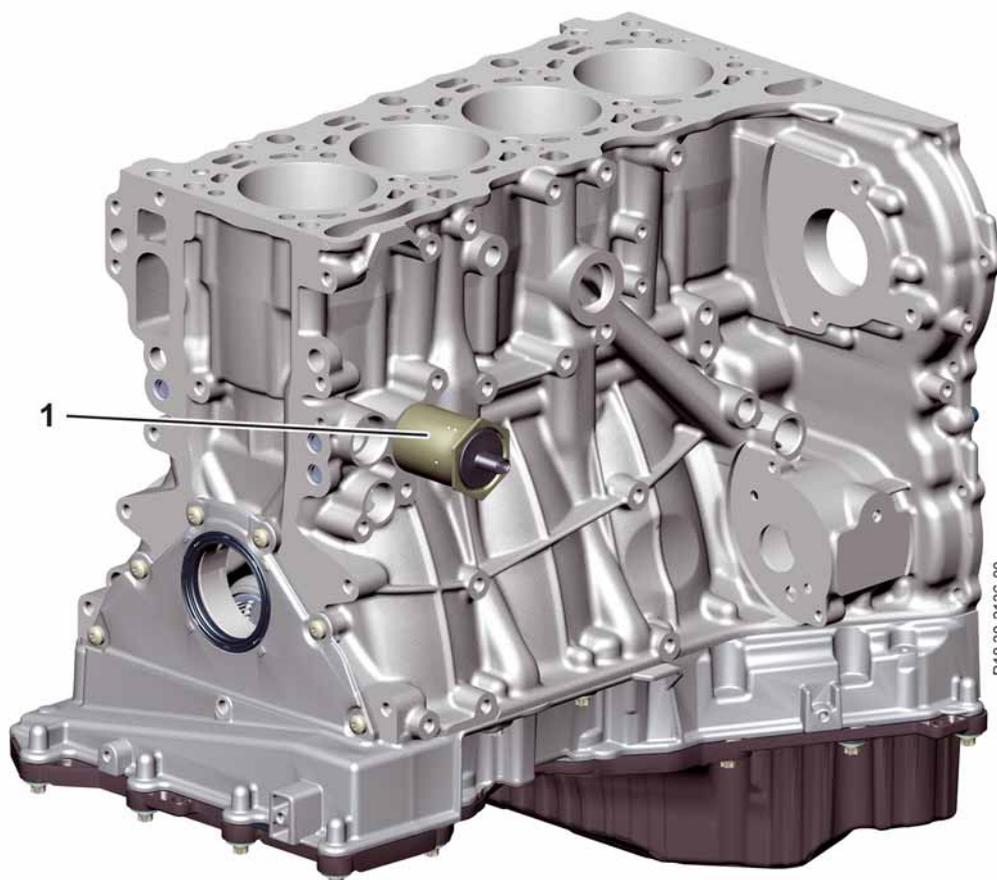
Shutoff valve for oil spray nozzles (Y131)

The shutoff valve for oil spray nozzles is located on the crankcase on the left in the direction of travel.

The shutoff valve shuts off the oil feed to the oil spray nozzles for piston crown cooling. If it is not actuated, the shutoff valve is open.

The oil spray nozzles are shut off in the post-start phase as long as one of the following conditions is fulfilled:

- Engine oil temperature greater than $-10\text{ }^{\circ}\text{C}$
- And:
- The max. shutoff duration (depending on intake air and engine oil temperature) has not yet been reached
- Or:
- The engine speed or the injection quantity has not yet reached a specified limit value



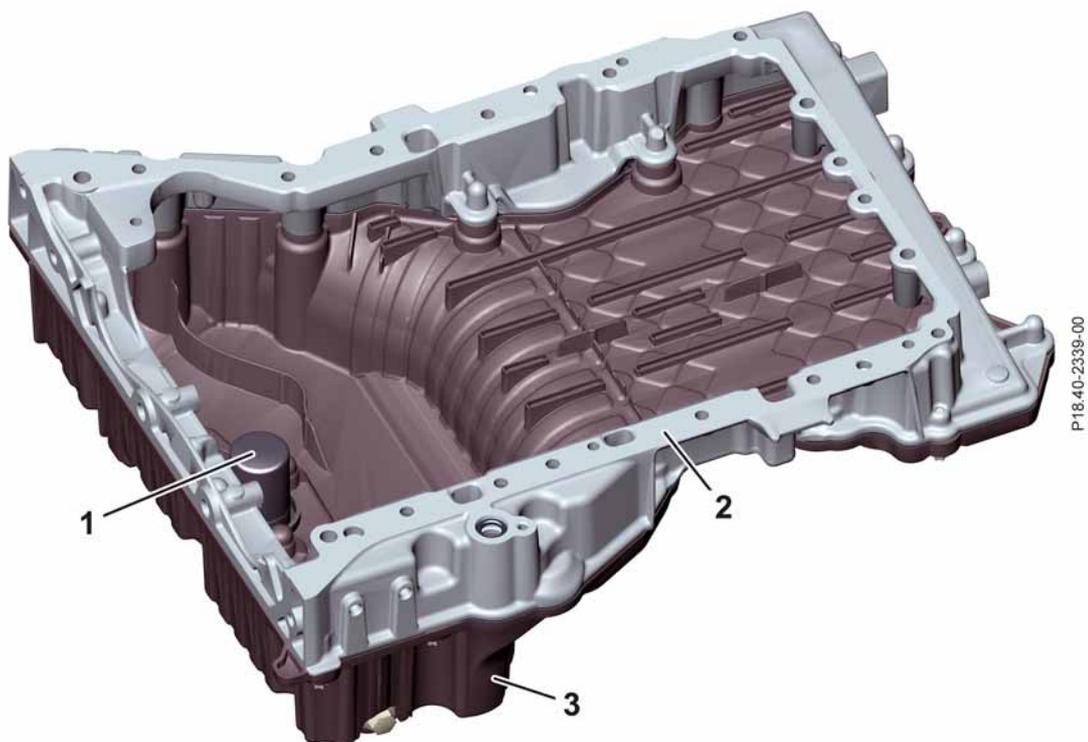
Crankcase with shutoff valve

1 Shutoff valve for oil spray nozzles

Switch for oil level check (S43)

The switch for oil level checking is screwed on to the lower section of the oil pan on the outside.

The oil level in the float chamber of the switch equalizes with the oil level in the oil pan via a feed and drain bore in the oil level check switch and in the oil pan. If enough engine oil is present, the reed contact is closed by the magnetic field of the ring magnet. The reed contact opens if the minimum level is dropped below. The connection to the ground contact is interrupted and a warning message is displayed on the instrument cluster.



Oil level check

1 Oil level check switch

2 Upper section of oil pan

3 Lower section of oil pan

i Note

Temporary level fluctuations are balanced out by the volume of the housing and the size of the drain bores of the oil level check switch. This prevents unnecessary warning messages from occurring e.g. when cornering.

Air mass and intake air

Hot film mass air flow sensor (B2 / 5)

The hot film mass air flow sensor (HFM) is located in the intake manifold behind the air filter. The HFM records the actual air mass flow rate very precisely.

The heated sensor element in the HFM is cooled more rapidly as more air flows past. The heating current required to maintain the temperature of the sensor element is used as an indicator for the air mass flowing past.

Integrated electronics evaluate this measurement data, making it possible to precisely determine the air volume flow rate. Only a part of the air mass flow is recorded by the sensor element. The overall air mass flowing through the measurement pipe is determined based on a data model.

Intake air temperature sensor (B2 / 5b1)

The temperature sensor is located in the same housing as the HFM and is a NTC resistor.

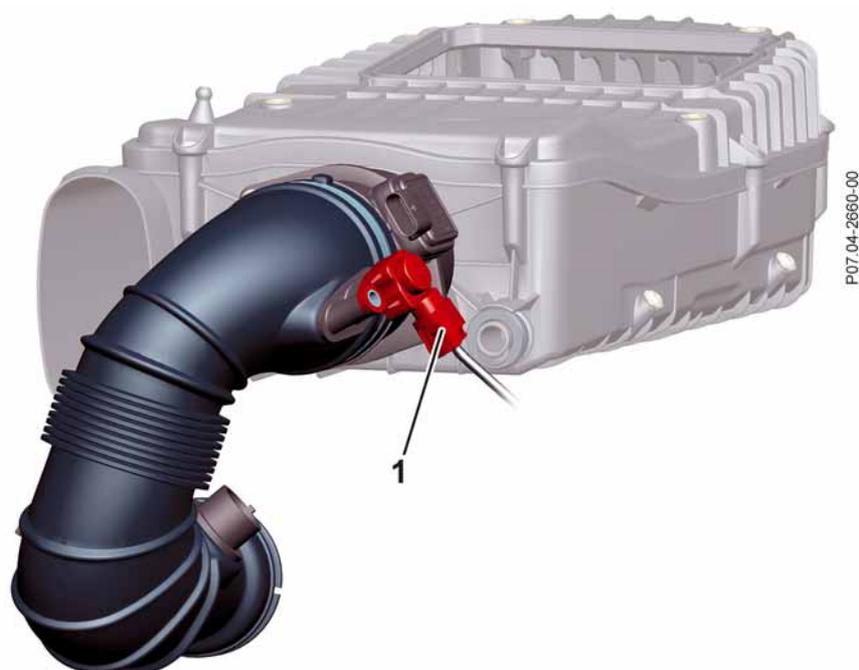


Air filter housing

1 Hot film mass air flow sensor

The pressure sensor (B28 / 5) is located on the clean air line downstream of the air filter housing and is tasked with recording the vacuum in the intake tract.

When the air pressure is built up, a measuring diaphragm with strain resistors is deformed. The resulting changes in resistance cause changes in voltage. These are evaluated by the CDI control unit.



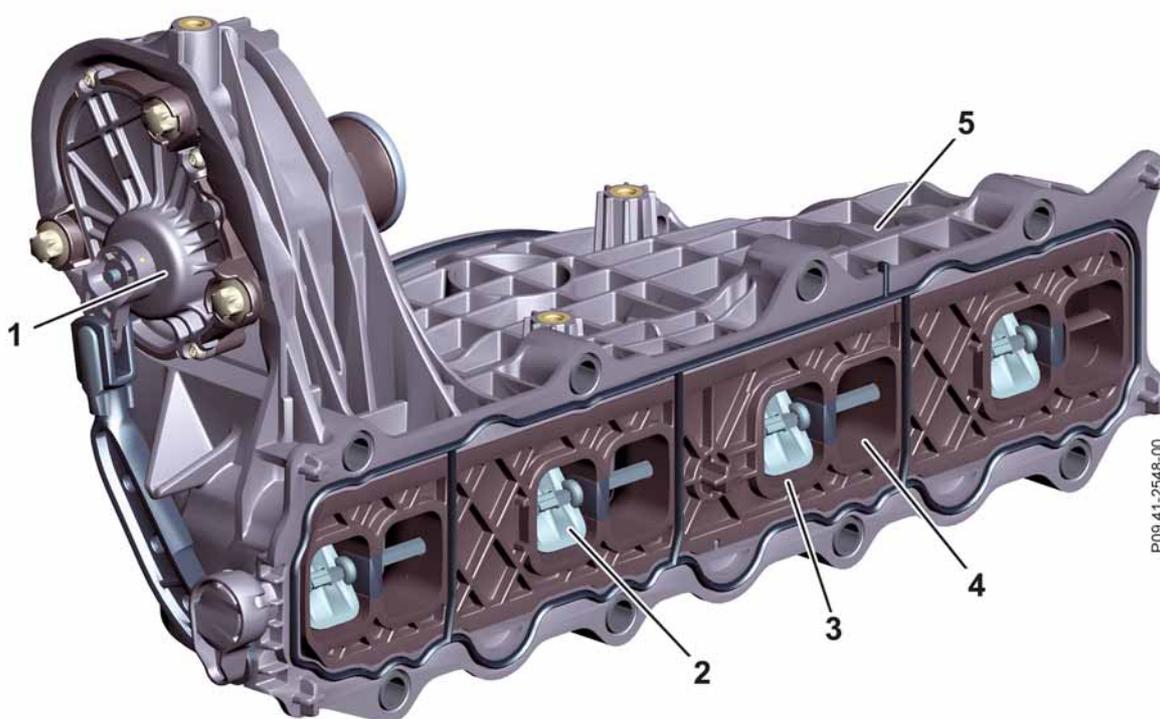
Clean air line on air filter

- 1 Pressure sensor downstream of air filter

Intake port shutoff actuator motor

The actuator motor for intake port shutoff (EKAS / M55) is located above the charge air manifold at the output side on the left. Depending on how it is actuated by the CDI control unit, the actuator motor for EKAS changes the position of the flaps in the spiral intake ports of the charge air manifold via an adjustment lever. A potentiometer serves as an angle sensor allowing comparison of specified / actual values for the position of the adjustment lever.

In the event of a fault or if the supply voltage is interrupted, the flaps in the spiral intake ports are mechanically opened by the return springs.



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Intake port shutoff

- | | |
|----------------------|--------------------------|
| 1 Actuator motor | 4 Tangential intake port |
| 2 Adjustment flap | 5 Charge air manifold |
| 3 Spiral intake port | |

Throttle valve actuator (M16 / 6)

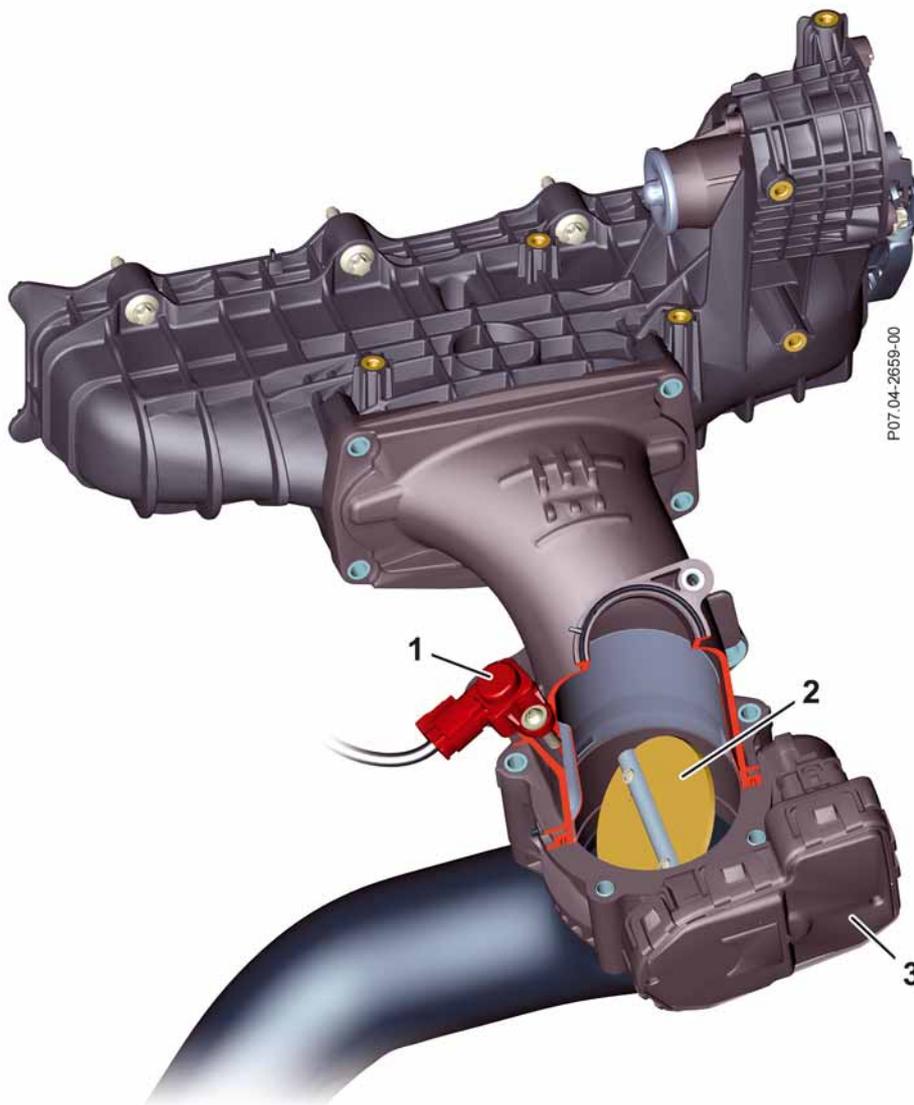
The throttle valve actuator is located on the left of the engine underneath the charge air manifold.

The throttle valve actuator is actuated by the CDI control unit via a pulse width modulated signal. The throttle valve actuator influences the air volume fed to the engine and the mixing ratio of charge air and recirculated exhaust gas mixed in downstream of the throttle valve. The throttle valve is closed when the engine is switched off.

Boost pressure sensor (B5 / 1)

The boost pressure sensor is located on the left of the engine downstream of the throttle valve actuator.

When the charge air pressure is built up, a measuring diaphragm deforms by a defined value, which is processed by the CDI control unit as a change in resistance.



Throttle valve

1 Boost pressure sensor

2 Throttle valve

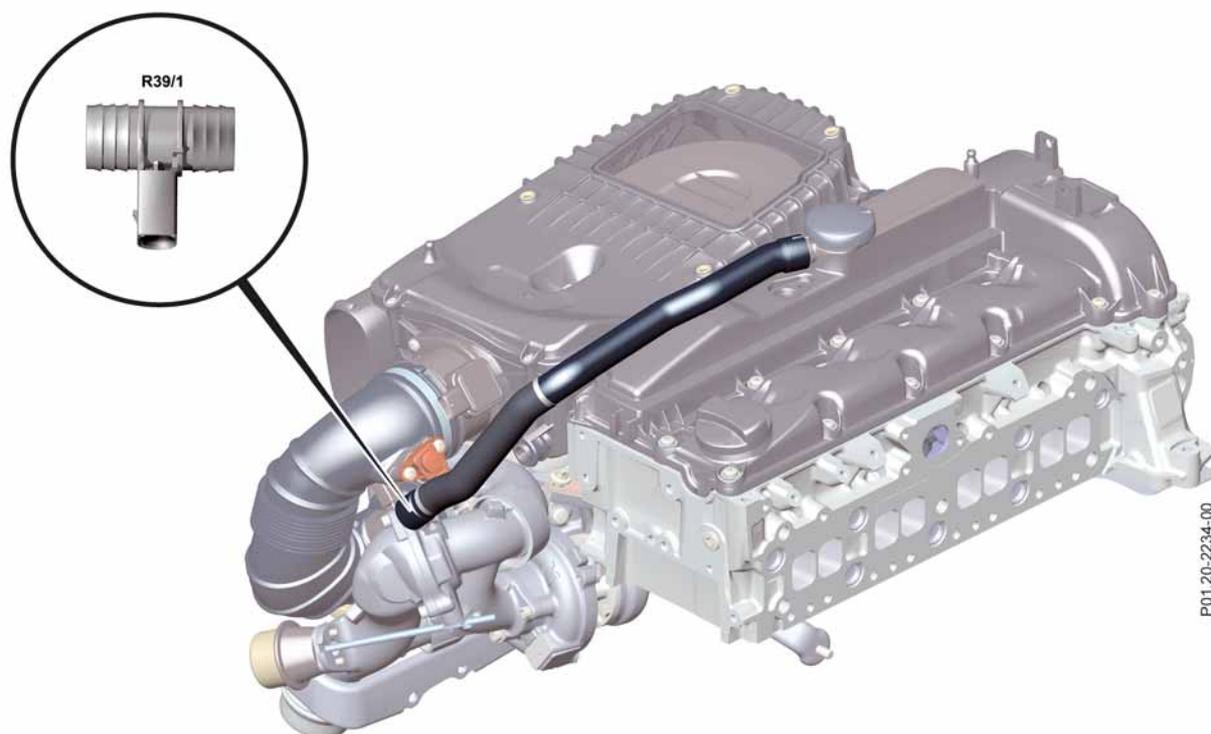
3 Throttle valve actuator

Heater element

Heating element for vent line (R39 / 1)

The heating element is located at the end of the vent line which is installed on the clean air line to the low-pressure turbocharger. This heating element prevents the crankcase ventilation system from freezing up.

The heating element consists of a plastic housing with an integrated heating resistor. The CDI control unit switches the heating element on or off depending on the outside temperature.



Heating element for vent line

Fuel preheating system heating element (R54)

The fuel preheating system heating element is located in the fuel filter housing.

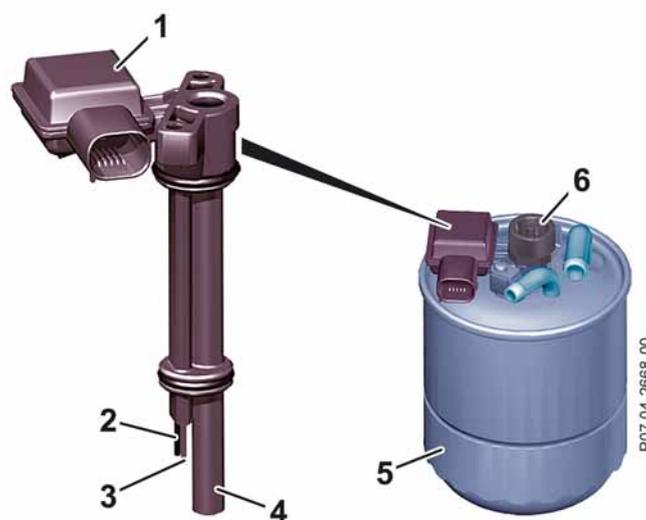
There is a heating element in the fuel filter to ensure that the fuel can flow through the lines even when the outside temperature is very low. The heating element is supplied with power by the signal acquisition and actuation module (SAM).

Fuel filter condensation sensor with heating element (B76 / 1)

The condensation sensor is only present in vehicles with code U41 (fuel / water separator and lubrication package). It is inserted in the fuel filter from above where it measures the water level.

The sensor determines the electrical resistance between the electrodes in the water level sensor. If fuel lies between the electrodes, the sensor does not send an output signal. If the water level in the fuel filter rises up to the electrodes, the electrical resistance decreases. This voltage change is recorded and forwarded to the CDI control unit.

When there is an increased level of water in the fuel filter, the CDI control unit sends a message to the instrument cluster via the chassis CAN (CAN E).



Fuel filter condensation sensor with heating element (code U41)

- 1 Integral electronics
- 2 Electrode 1
- 3 Electrode 2

- 4 Heating element
- 5 Fuel filter housing
- 6 Cap (for water extraction)

Turbocharger

Dual stage turbocharger

The two turbochargers are located on the right of the crankcase underneath the exhaust manifold. The dual stage turbocharging system incorporates two turbochargers of different size with a bypass control system.

The dual stage turbocharger enables continuous power output without the familiar problem of "turbo lag".

An overview of the most important advantages:

- A pronounced and high torque curve
- Increase in rated output combined with lowering of rated speed
- Improved boost pressure curve
- Reduced fuel consumption
- Reduction in nitrogen oxide (NO_x) emissions
- Long service life and high reliability

Operating principle

The exhaust gas flowing from the cylinders first flows into the exhaust manifold. From here, the exhaust flow can either be directed via the high-pressure turbocharger (HD-Lader) or it can be diverted via the bypass line to the low-pressure turbocharger (ND-Lader).

The exhaust flow is directed to the HD-Lader or ND-Lader depending on the position of the boost pressure control flap (LRK). The position of the LRK is regulated by the CDI control unit based on performance maps.

The initial boost pressure buildup is mainly generated by the HD-Lader but afterwards the boost pressure is increasingly built up by the ND-Lader.

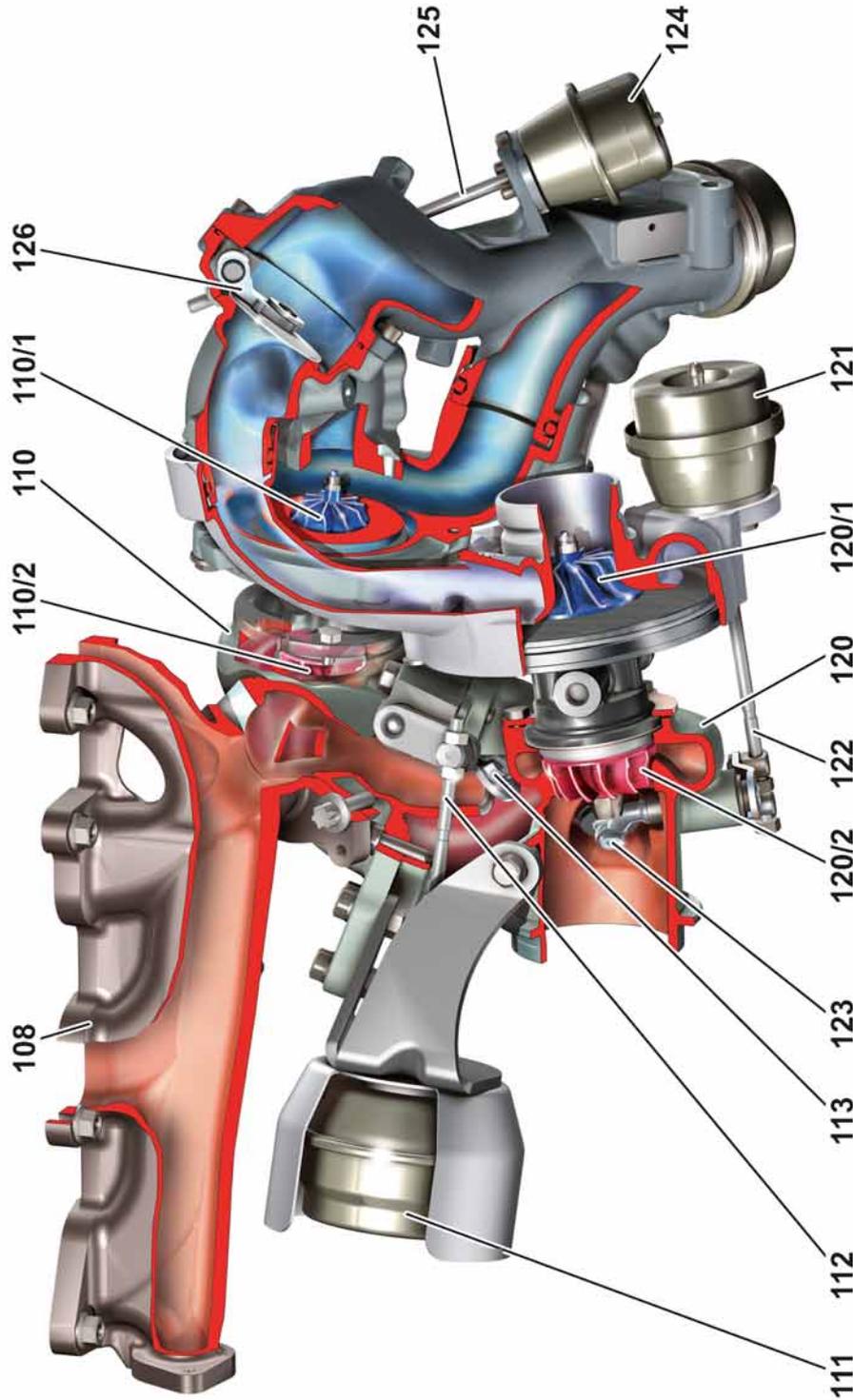
If the HD-Lader reaches its output limit, boost pressure buildup is performed by the ND-Lader alone. In this case, the charge air bypass flap opens and the compressed charge air from the ND-Lader is directed past the compressor housing of the HD-Lader. The boost pressure is limited by the wastegate.

i Note

The vacuum units and adjustment rods of the respective flaps and of the wastegate can be replaced.

When installing vacuum lines, always pay attention to the respective color coding of the vacuum line and vacuum unit.

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Dual stage turbocharging

| | | | | | |
|-------|--|-------|--------------------------------------|-----|---------------------------------------|
| 108 | Exhaust manifold | 113 | Boost pressure control flap | 123 | Wastegate |
| 110 | High-pressure turbocharger (HD-Lader) | 120 | Low-pressure turbocharger (ND-Lader) | 124 | Charge air bypass flap vacuum unit |
| 110/1 | HD-Lader compressor impeller | 120/1 | ND-Lader compressor impeller | 125 | Charge air bypass flap adjustment rod |
| 110/2 | HD-Lader turbine wheel | 120/2 | ND-Lader turbine wheel | 126 | Charge air bypass flap |
| 111 | Vacuum unit (boost pressure control flap) | 121 | Wastegate vacuum unit | | |
| 112 | Adjustment rod (boost pressure control flap) | 122 | Wastegate adjustment rod | | |

Turbocharger

Pressure transducer for boost pressure control flap (Y93)

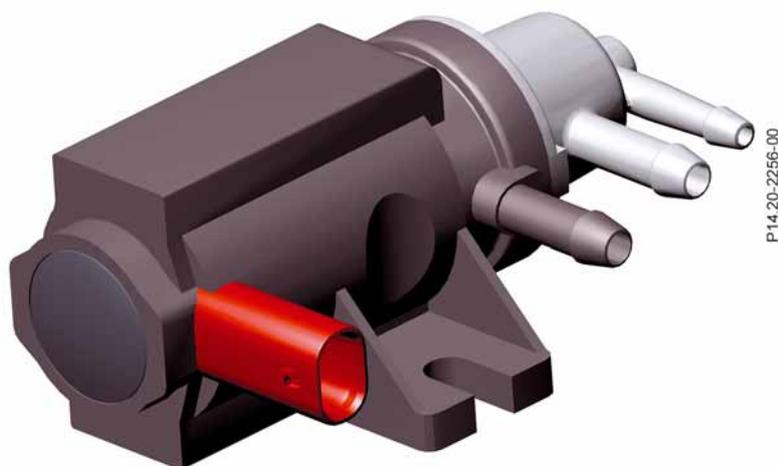
The pressure transducer for the boost pressure control flap is located at the rear on the left above the throttle valve actuator.

Wastegate control pressure transducer (Y31 / 4)

The pressure transducer for wastegate control is located at the right front on the cylinder head.

i Note

The CDI control unit transmits a pulse width modulated signal to the pressure transducer. The respective pressure transducer regulates the flap positions via the vacuum units (cross-section of opening 5% to 95%).



Pressure transducer

Charge air bypass flap switchover valve (Y132)

The charge air bypass flap switchover valve is located at the front on the cylinder head.

The flap position (cross-section of opening 5% to 95%) is controlled by means of vacuum.

If the bypass flap is not actuated, air is admitted between the vent connection (atmosphere) and the vacuum unit. The charge air bypass flap thus seals the bypass duct.

Low-pressure turbocharger boost pressure sensor (B5 / 4)

The low-pressure turbocharger (ND-Lader) boost pressure sensor is located on the left next to the hot film mass air flow sensor on the cylinder head.

The boost pressure sensor records the boost pressure generated by the ND-Lader. The boost pressure causes a measuring diaphragm with strain resistors to deform. The resulting changes in resistance cause changes in voltage. These are evaluated by the CDI control unit.

Exhaust gas recirculation

EGR actuator (Y27 / 9)

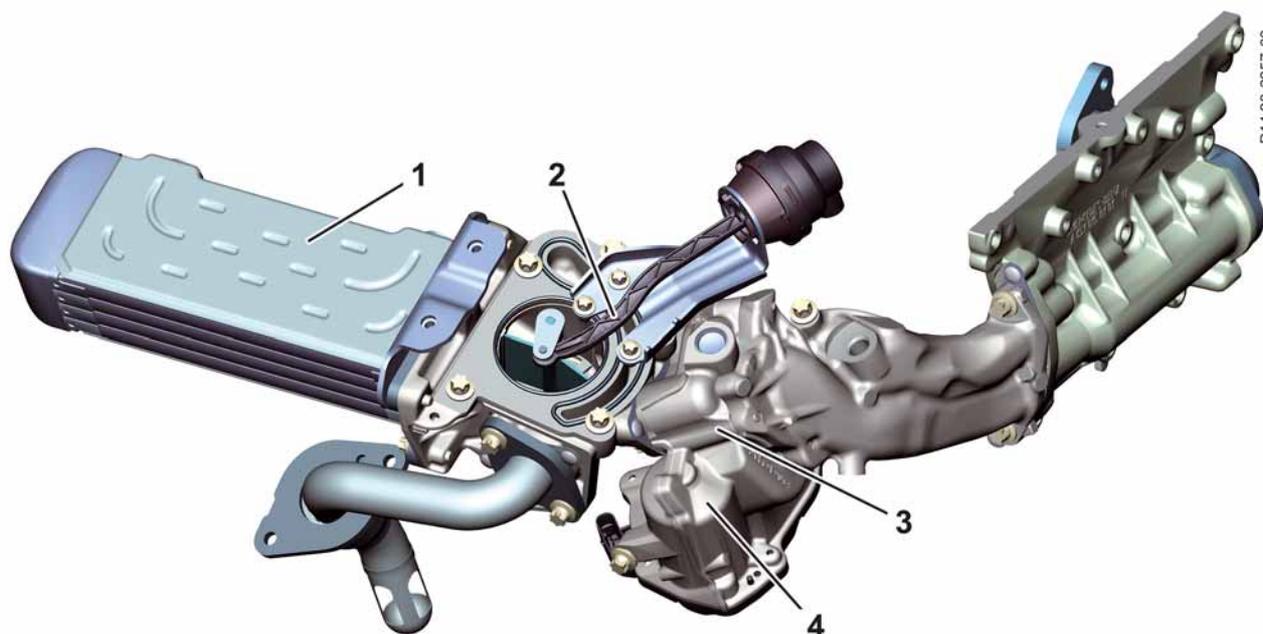
The EGR actuator is integrated on the left between the EGR bypass flap and the EGR pipe.

The EGR actuator regulates the exhaust gas flow in order to reduce nitrogen oxide (NO_x) emissions. The CDI control unit actuates the actuator motor for EGR directly. The cross-section of the valve opening determines the exhaust volume which is recirculated into the engine intake tract via the charge air manifold. The EGR actuator is integrated into the cooling circuit of the engine, which protects it from thermal overload.

EGR cooler

The EGR cooler is located on the left in the direction of travel downstream of the EGR bypass flap. The housing is made of stainless steel and coolant flows through it.

This reduction in temperature increases the density of the exhaust gas without increasing the number of soot particles. This in turn increases the exhaust gas recirculation rate as well as lowering NO_x missions.



EGR path

- | | | | |
|---|----------------------------|---|---------------------------------|
| 1 | EGR cooler | 3 | EGR actuator |
| 2 | Bypass flap for EGR cooler | 4 | Actuator motor for EGR actuator |

Switchover valve for EGR cooler bypass (Y85)

The switchover valve is located on the left of the crankcase.

The position of the EGR cooler bypass flap (open or closed) is controlled by means of vacuum depending on the exhaust temperature. When the bypass flap is open, recirculated exhaust gas flows via the EGR cooler.

In the rest position, air is admitted between the vent connection (atmosphere) and the vacuum unit and the bypass flap closes the bypass duct.

Switchover valve for coolant pump (Y133)

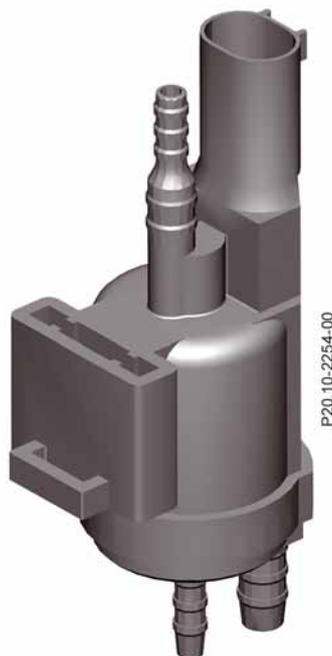
The switchover valve is located at the front of the engine, on the left of the throttle valve actuator.

The position of the regulating valve (open or closed) in the coolant pump is controlled by the switchover valve of the coolant pump. When the regulating valve is open, the coolant can circulate in the coolant circuit.

In the rest position, the regulating valve is open.

The coolant pump is switched off during a cold start for max. 500 s if the following conditions are fulfilled:

- The limit values stored in the control unit for intake air and coolant temperature and for the total fuel injection quantity have not yet been reached.
- The engine speed or injection quantity has not exceeded the specified limit value.
- "Heat" has not been requested by the automatic air conditioning control and operating unit.



Switchover valve

Oxygen sensor

The wideband oxygen sensor (G3 / 2) is a planar (multi-layer) two-cell limit current sensor with oxygen pump cell. It integrates several functions based on its modular design.

The planar wideband oxygen sensor contains two voltage jump sensors made of zirconium dioxide (ZrO_2): one as a sensor cell and one as an oxygen pump cell.

The two cells are arranged so that there is a minimal diffusion gap (approx. 10 to 50 μm) between them. The diffusion gap acts as a measuring chamber and is connected to the exhaust gas via an intake opening. The measuring cell has a reference air duct which is connected to the atmosphere.

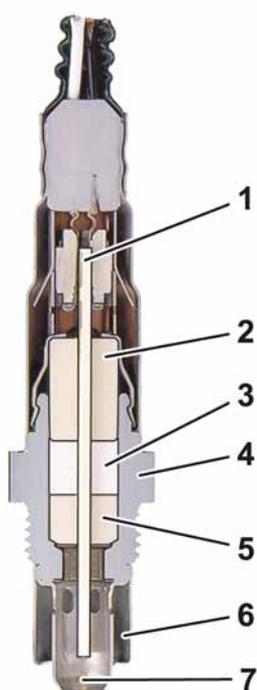
Since the conductivity of the ceramic sensor body is temperature-dependent, the optimal operating temperature of the wideband oxygen sensor is approx. 700 °C to 800 °C. The temperature of the ceramic sensor body is constantly kept at approx. 780 °C by a heating element.

Mode of operation of pump cell:

Oxygen ions can be caused to move by applying a voltage to the solid electrolytes of the voltage sensor (pump current). The direction of the ion movement depends on the polarity (+/-) of the voltage applied.

Mode of operation of sensor cell:

The sensor cell operates on the principle of a voltage jump sensor. It determines the residual oxygen content (O_2) in the exhaust gas.



Design of wideband oxygen sensor

- 1 Sensor element
- 2 Upper isolator bushing
- 3 Sealing package
- 4 Sensor housing
- 5 Lower isolator bushing
- 6 Outer protective tube
- 7 Inner protective tube

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Differential pressure sensor on DPF (B28 / 8)

The differential pressure sensor of the DPF is located on the right of the cylinder head on the rear bracket for the air filter.

The sensor consists of the following components:

- Pressure sensor element
- Electronics for signal amplification

The differential pressure sensor records the exhaust pressure upstream of and downstream of the DPF via the exhaust pressure lines and thus determines the pressure differential. This pressure differential acts on the pressure sensor element, which produces a voltage which is forwarded to the CDI control unit.

Exhaust back pressure sensor (B60)

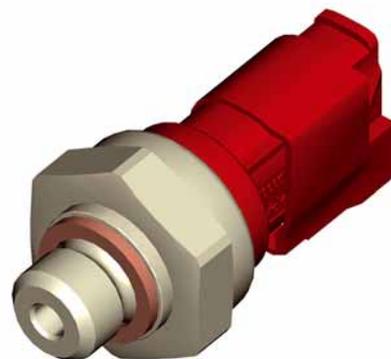
The sensor is located at the left rear on the EGR pipe.

A metallic separating diaphragm with plunger acts on the sensor membrane when pressure is applied. The pressure-dependent resistors on the sensor membrane cause the resistance to change when the membrane is deflected. This value is forwarded to the CDI control unit as a voltage signal, which uses it to calculate the exhaust back pressure. This pressure information is used by the CDI control unit to protect the turbocharger and the engine.



P07.04-2667-00

Differential pressure sensor



P14.20-2261-00

Exhaust back pressure sensor

Abbreviations

AGR

Exhaust Gas Recirculation (EGR)

CAN

Controller Area Network

CDI

Common Rail Direct Injection

CO

Carbon monoxide

CO₂

Carbon dioxide

DAS

Diagnosis Assistance System

DPF

Diesel Particulate Filter (DPF)

EKAS

Intake port shutoff

EOBD

European On-Board-Diagnosis

HC

Hydrocarbons

HD-Lader

High-pressure turbocharger

HFM

Hot film mass air flow sensor

H₂O

Water

I2C

Improved Individual Injection Correction

LIN

Local Interconnect Network

LRK

Boost pressure control valve

N₂

Nitrogen

ND-Lader

Low-pressure turbocharger

NO₂

Nitrogen dioxide

NO_x

Nitrogen oxide

NTC

Negative Temperature Coefficient

O₂

Oxygen

PTC

Positive Temperature Coefficient

SAM

Signal aquisition and actuation module

WIS

Workshop Information System

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