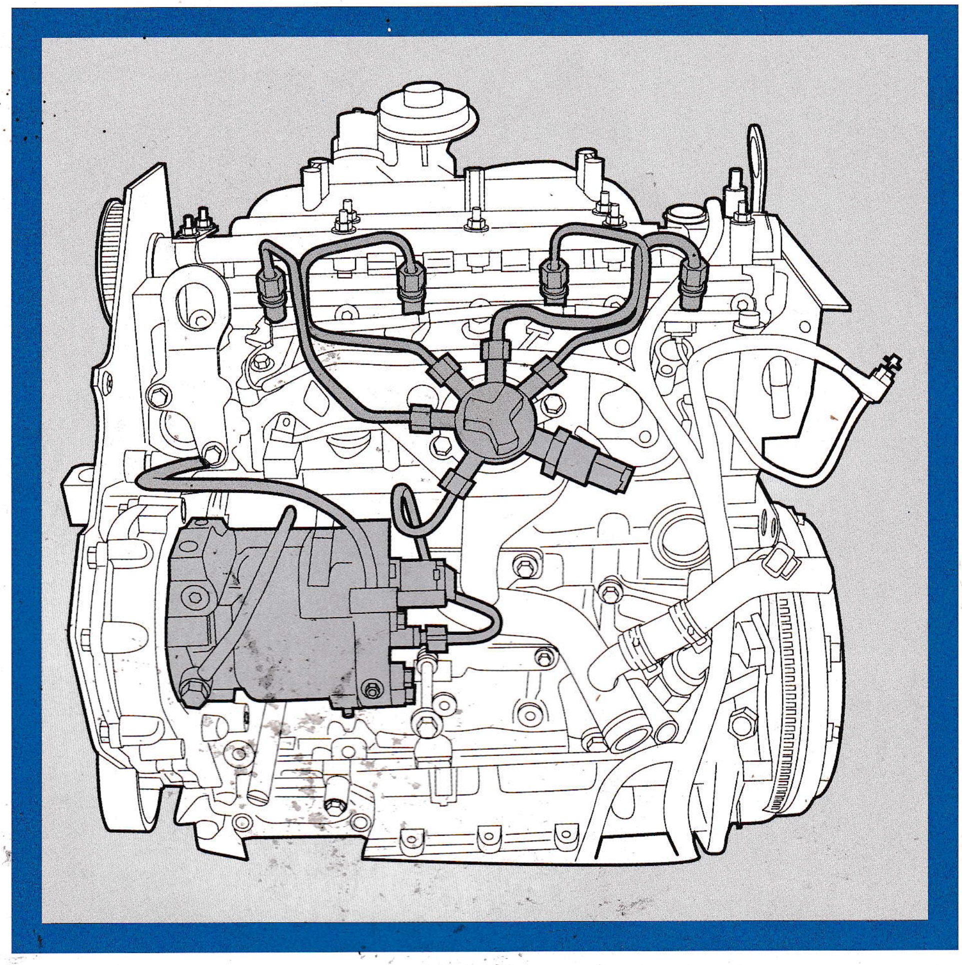
T6

Technical Service Training

2001.5 Focus

New Product Introduction TN7002116S

1.8L DuraTorq-TDCi-Diesel Engine



Student Information

CG 7901/S en 02/2001

The demands on modern diesel engines as regards power output, fuel consumption, exhaust and noise emissions are rising all the time and can only be satisfied by continuous improvements in mixture formation.

The mechanical distributor-type fuel injection pump has limits as regards precision of control of the start of fuel injection and the quantity of fuel injected.

The 1.8L DuraTorq-TDCi-Diesel Engine with the common rail fuel injection system is being introduced with the 2001.5 Focus.

The common rail fuel injection system separates pressure generation and fuel injection. This allows the fuel injection pressure to be generated independently of the engine speed and quantity of fuel injected. Combustion noise is reduced considerably again by the precisely controlled pilot injection. In addition, optimum spray preparation allows almost ideal combustion to take place throughout the entire combustion chamber, resulting in enhanced emission characteristics. A special control module monitors the fuel injection and combustion processes during the pilot and main injection phases over the entire engine speed range.

This New Product Introduction publication provides detailed descriptions of all the components of the common rail fuel injection system and their operation and the changes made to the basic engine.

This Student Information publication is arranged and designed as a self-learning medium in lessons in line with the new Ford global training concept.

Each lesson begins with a list of the objectives to be achieved in the course of the lesson and ends with test questions to check learning progress. The answers to these are to be found at the end of the Student Information publication.

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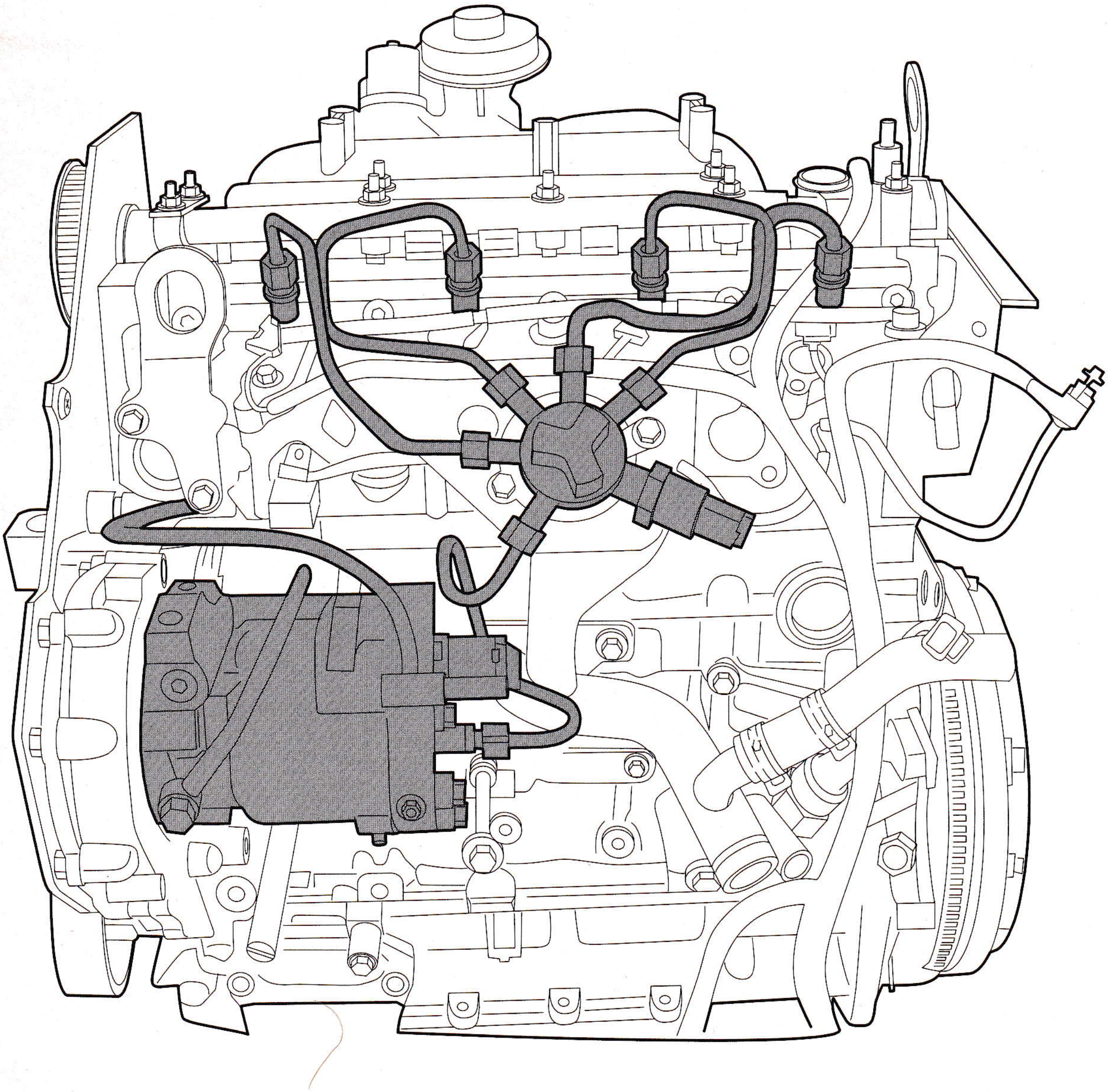
Objectives

On completing this lesson, you will:

- be able to describe the technical differences in relation to the 1.8L Endura-DI turbocharged diesel engine
- know the technical data of the Focus 1.8L DuraTorq-TDCi-Engine with the common rail fuel injection system
- be familiar with the external features of the 1.8L DuraTorq-TDCi-Engine



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- The 1.8L DuraTorq-TDCi-Engine with the common rail fuel injection system is based on the 1.8L Endura-DI turbocharged intercooled diesel engine with the distributor-type fuel injection pump developing 66 kW (90PS).

- The power output has been increased to 85 kW (115PS) and the torque to 250 Nm through the introduction of a variable turbocharger and the common rail fuel injection system.

- The cylinder block and the crank gear have been modified and changed in some details to cope with the increased power.

- The exhaust manifold has also been modified to accommodate the variable turbocharger. This modification also affects the intake manifold which has additionally been equipped with a vaccum diaphragm unit.

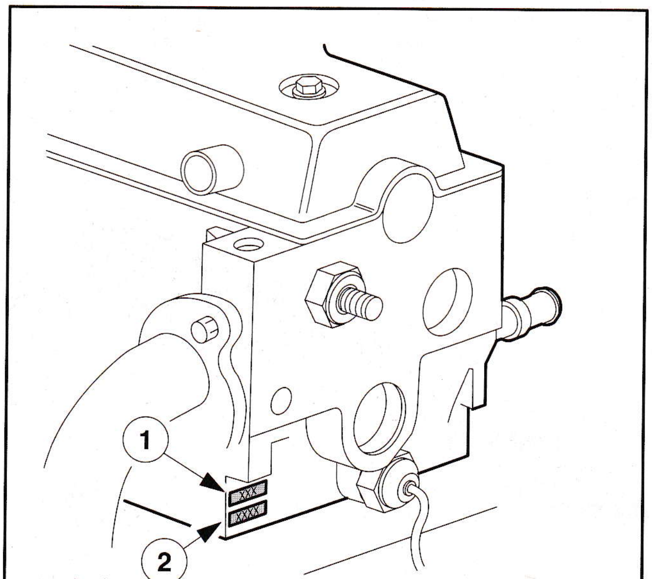
- The engine is controlled by the EEC V engine management system with an integral strategy for the variable turbocharger and the common rail fuel injection system. In addition, an injector driver module (IDM) has been introduced to control the common rail fuel injection system.

- The common rail fuel injection system also requires cylinder identification which is carried out by a camshaft position (CMP) sensor.

- The engine management system diagnostics are carried out with the worldwide diagnostic system (WDS) through the data link connector (DLC).

Engine identification

- The engine code and serial number are stamped on the cylinder head.



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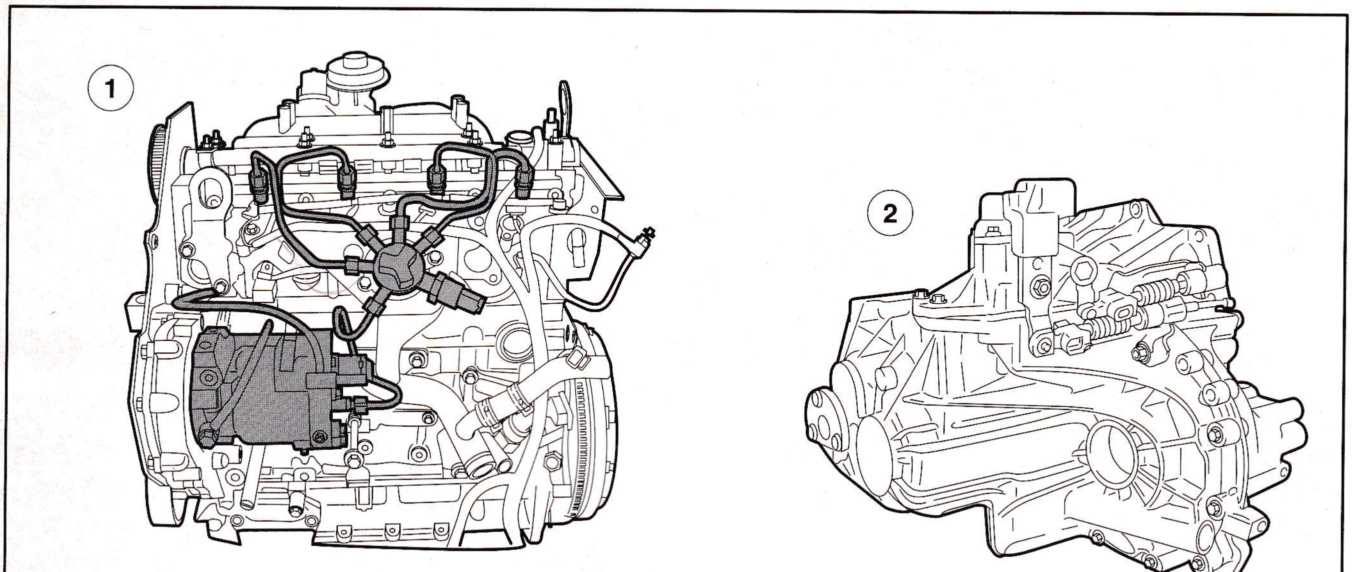
1 Engine code F9DA

2 Serial number

Engine and transmission combination



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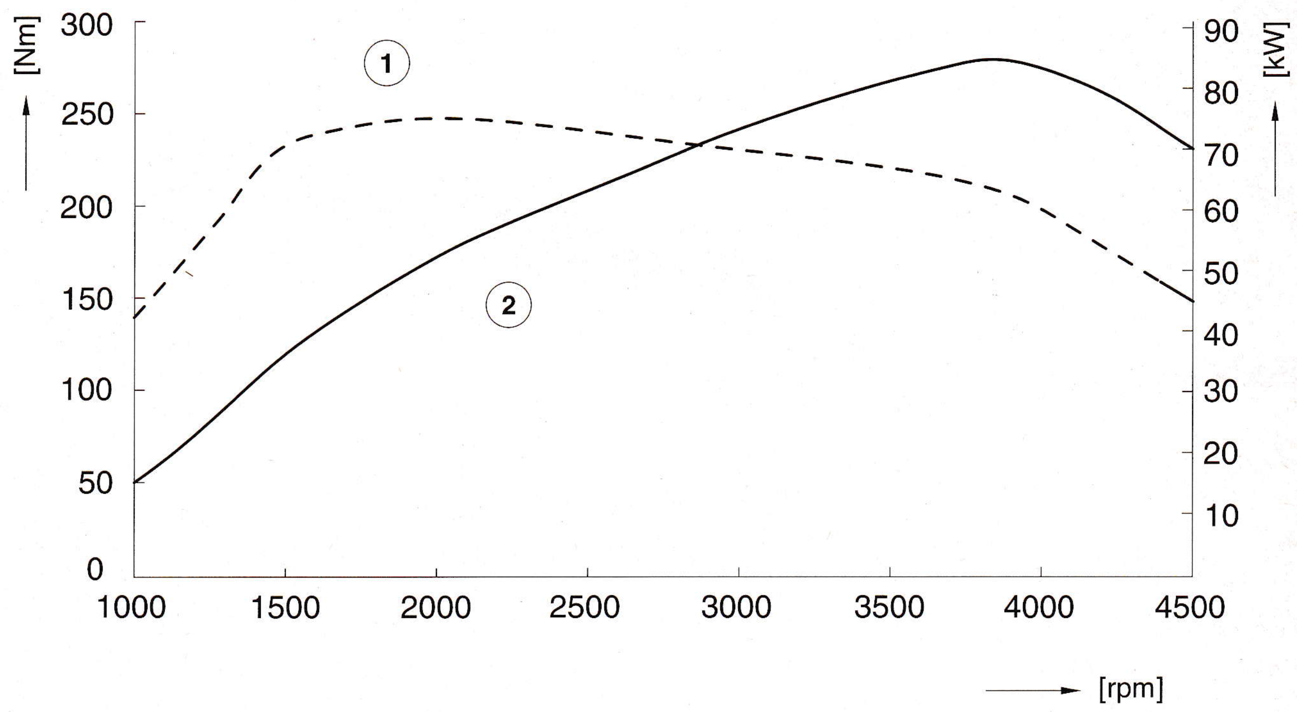
1 1.8L DuraTorq-TDCi-Engine

2 MTX-75 manual transaxle

Engine power output and torque



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1 Torque curve

2 Power output curve

Technical data

Engine data	Dimensions
Cubic capacity	1753 cc
Stroke	82 mm
Bore	82.5 mm
Maximum power output (DIN/EEC)	85 kW (115 PS) at 3800 rpm
Maximum torque (DIN/EEC)	250 Nm at 1850 rpm
Compression ratio	18.5 : 1

Find the correct answer.

1. Which statement about the 1.8L DuraTorq-TDCi-Engine is correct?

- ☐ a) The 1.8L DuraTorq-TDCi-Engine has a unit-injector fuel injection system.
- ☐ b) The 1.8L DuraTorq-TDCi-Engine is equipped with a common-rail fuel injection system.
- ☐ c) The 1.8L DuraTorq-TDCi-Engine works with a distributor-type fuel injection pump.
- ☐ d) The diesel fuel injection system of the 1.8L DuraTorq-TDCi-Engine is the same as that of the 1.8L Endura-DI engine.

2. What decisive advantage is offered by the fuel injection system of the 1.8L DuraTorq-TDCi-Engine?

- ☐ a) Generation of pressure and fuel injection are independent of one another (separated).
- ☐ b) The fuel injection pressure depends on the engine speed.
- ☐ c) The fuel injection timing cannot be selected freely.
- ☐ d) The fuel injection takes place continuously.

3. Which statement about the pilot injection is incorrect?

- ☐ a) The pilot injection reduces the load on the crankgear.
- ☐ b) The pilot injection makes it possible to achieve much higher fuel injection pressures.
- ☐ c) The pilot injection reduces combustion noise.
- ☐ d) The associated increase in fuel injection pressure reduces exhaust emissions.

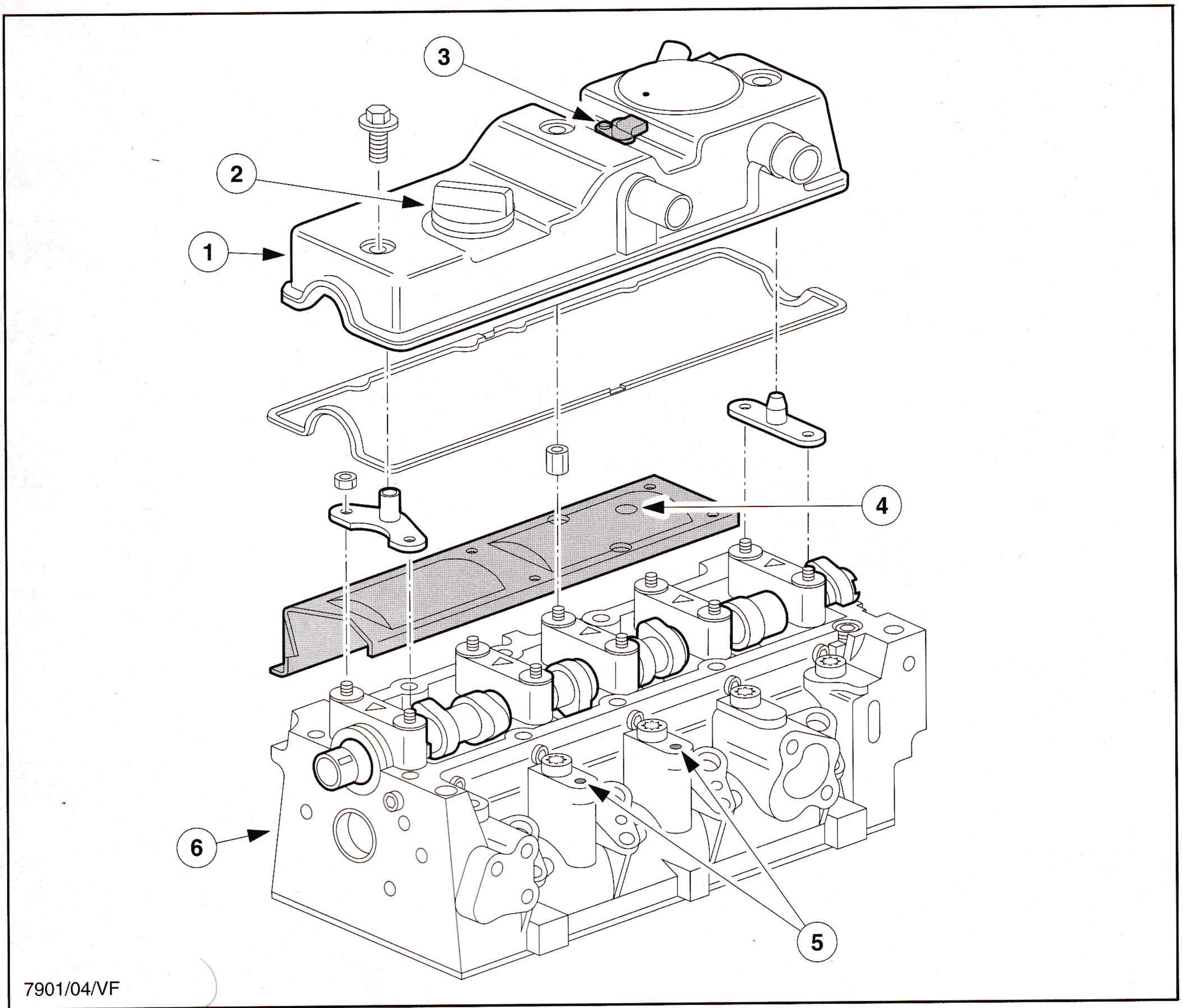
Objectives

On completing this lesson, you will:

- be familiar with the changes to the cylinder head of the 1.8L DuraTorq-TDCi-Engine and the accessories mounted on it compared with the 1.8L Endura-DI engine
- know the identification markings of the cylinder block, connecting rods and pistons and the modifications made to them for use in the 1.8L DuraTorq-TDCi-Engine
- be familiar with the measures taken to compensate for crankshaft vibration on the 1.8L DuraTorq-TDCi-Engine
- know the modifications made to the camshaft drive, lubrication and cooling systems

Cylinder head and valve cover

- The cylinder head is unchanged except for two additional holes for fixture of the mounting bracket for the fuel injection supply manifold.
- The camshaft position (CMP) sensor has been incorporated into the valve cover.
- A groove is milled in the cylinder head on the right next to the exhaust port of cylinder No. 1 as an additional means of distinguishing the cylinder heads.
- The oil baffle has an additional hole for the CMP sensor.

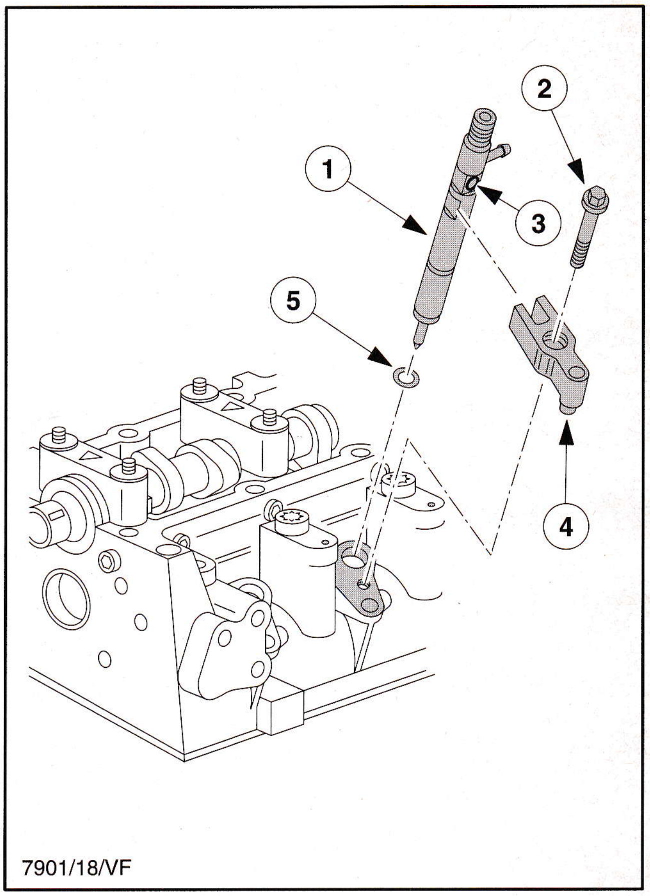


1 Valve cover
2 Oil filler cap
3 CMP sensor
4 Hole for CMP sensor in oil baffle
5 Holes for fuel injection supply manifold mounting bracket
6 Cylinder head identification

Cylinder head

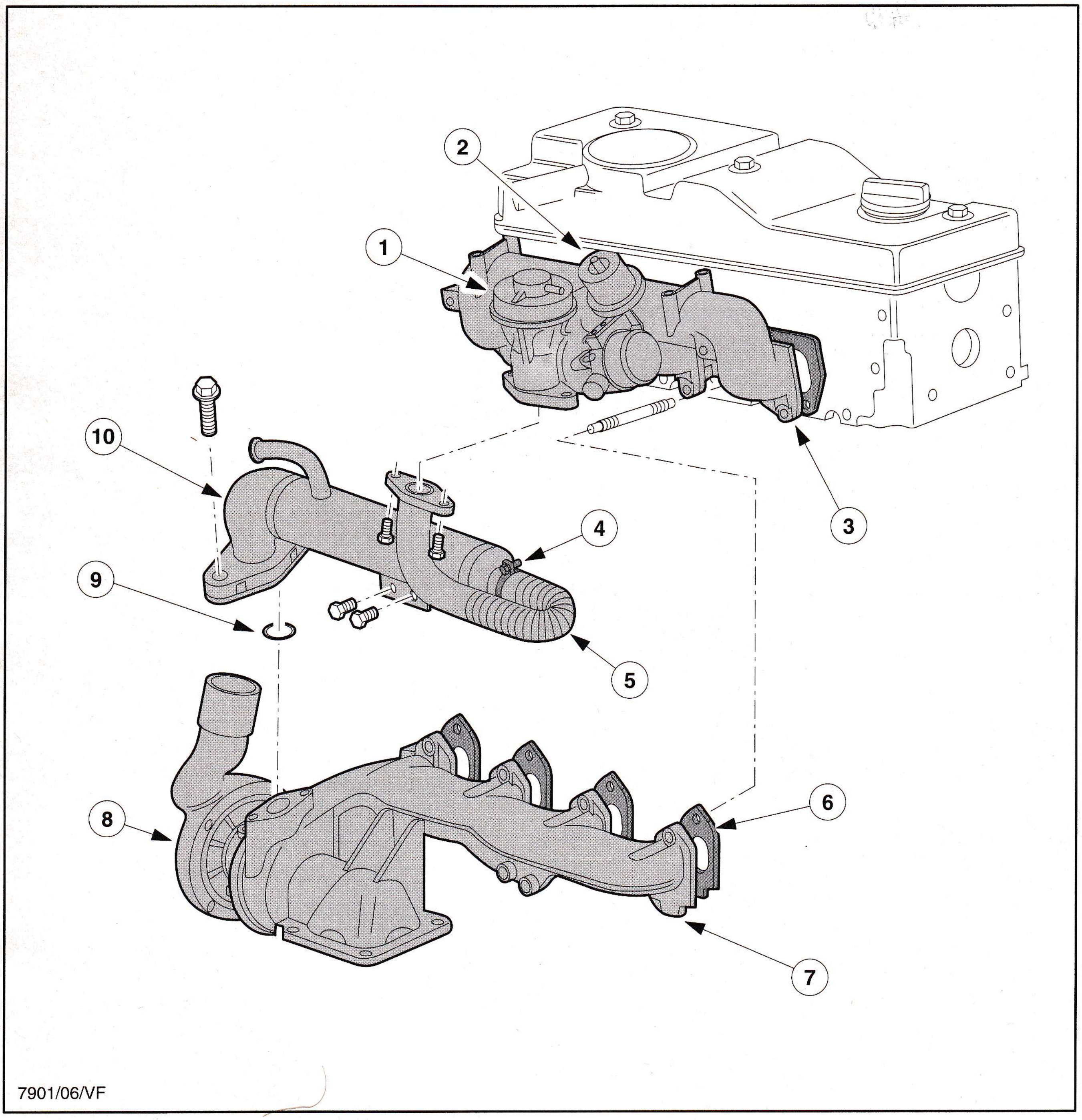
- The cast iron cylinder head is based on the head of the Endura-DI engine.
- The locations of the glow plugs and fuel injectors are the same.
- The fuel injectors are a push fit and held in place individually by a modified retainer.

NOTE: The retaining bolts of the retainers must be tightened to the specified torque. The retaining bolts and the copper seals must not be reused. Refer to the current service literature.



1 Fuel injector
2 Retaining bolt
3 Electrical connection
4 Retainer for fuel injector
5 Copper sealing ring

Cylinder head accessories



1 EGR valve
2 Vaccum diaphragm unit
3 Intake manifold
4 Connecting pipe clip
5 Connecting pipe
6 Exhaust manifold gasket
7 Exhaust manifold
8 Variable turbocharger
9 EGR cooler gasket
10 EGR cooler

Intake manifold with EGR valve

- The intake manifold has been modified for use on the 1.8L DuraTorq-TDCi-Engine.
- The EGR valve no longer has an EGR valve position sensor.
- A vaccum diaphragm unit has been added. Its function is to prevent the vehicle shaking when the engine is switched off.
- The vaccum diaphragm unit is operated by means of a solenoid valve which is actuated by the EEC V.

NOTE: The intake manifold gasket must not be reused.

Exhaust manifold

- The exhaust manifold has been modified to accommodate a larger variable turbocharger.

EGR cooler

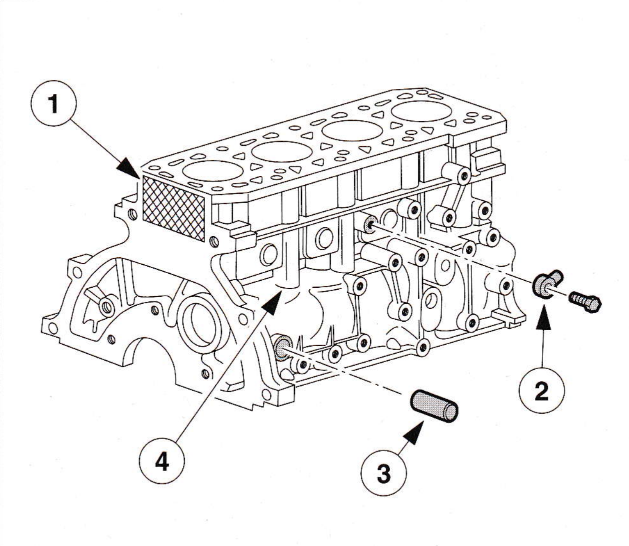
- The modified EGR cooler is no longer secured with a clip. On the engine it is bolted to a flange on the exhaust manifold. This produces better sealing.

Turbocharger

- A variable turbocharger has been introduced for the 1.8L DuraTorq-TDCi-Engine.
- The turbocharger forms a unit with the exhaust manifold.
- The increase in the power output has been achieved mainly through the introduction of the variable turbocharger.
- As a result, the boost pressure has been increased compared with that of the 1.8L Endura-DI engine from 1.0 bar at 2200 rpm to 1.2 bar at 2500 rpm.

Cylinder block

- The cylinder block is also based on the block of the Endura-DI engine, but has been strengthened with additional stiffening ribs.
- Two different bore diameters are used in production to guarantee the correct play between the cylinders and pistons.
- The different bores are identified by letters (A or B) on the block.
- The turbocharger return has been modified to obtain a better oil seal.
- To monitor combustion noise a knock sensor (KS) has been introduced. It is located on the rear of the cylinder block.



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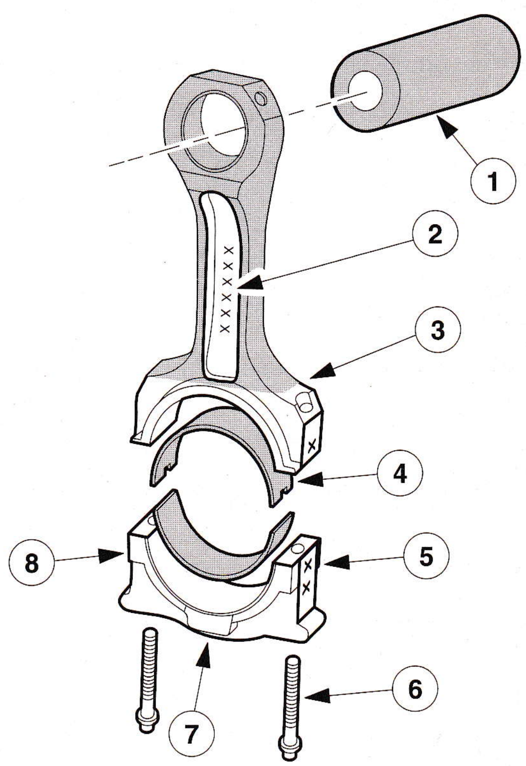
1 Engine identification
2 Knock sensor (KS)
3 Turbocharger oil return
4 Stiffening ribs

Connecting rods

- Because of the increased engine torque compared with the 1.8L Endura-DI engine, the combustion pressures have also increased. This has led to the following changes:
  - reinforced bearing shells with retaining lugs
  - reinforced connecting rod shanks with larger small end bore diameter
  - increased outside diameter of the piston pin
- The division and marking of the connecting rods in length and weight classes has been retained.
- The lug on the bearing cap and the part number on the connecting rod must face towards the front of the engine when they are in place.

NOTE: If retaining bolts are slackened, new bolts must be installed.



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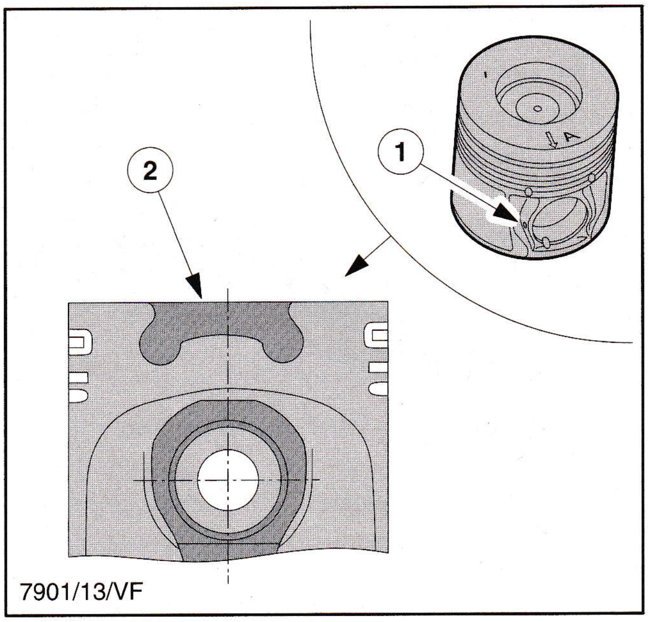
1 Piston pin
2 Part number
3 Connecting rod
4 Bearing shell
5 Connecting rod length marking
6 Bearing cap retaining bolt
7 Position marking
8 Weight class marking

Pistons

- The recess in the piston crown has been enlarged and modified to produce optimum swirl.
- The arrow on the piston crown or mark on the piston skirt must point towards the front of the engine when the piston is installed.
- The pistons installed must have the correct classifications according to diameter (A and B) and weight (+ and –).

NOTE: Only install pistons of the same weight class.

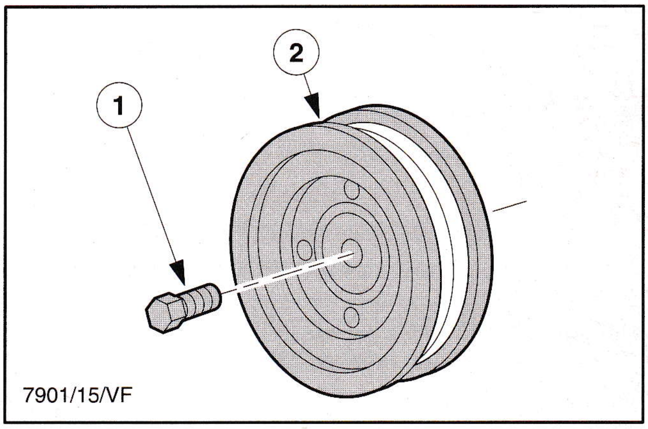


1 Marking
2 Piston recess

Vibration damper

- The vibration damper has been made 6 mm thicker in the outer region for use in conjunction with a dual-mass flywheel.
- The retaining bolt has been shortened by 3 mm to 86 mm.

NOTE: Refer to the current service literature for the changed tightening torque.



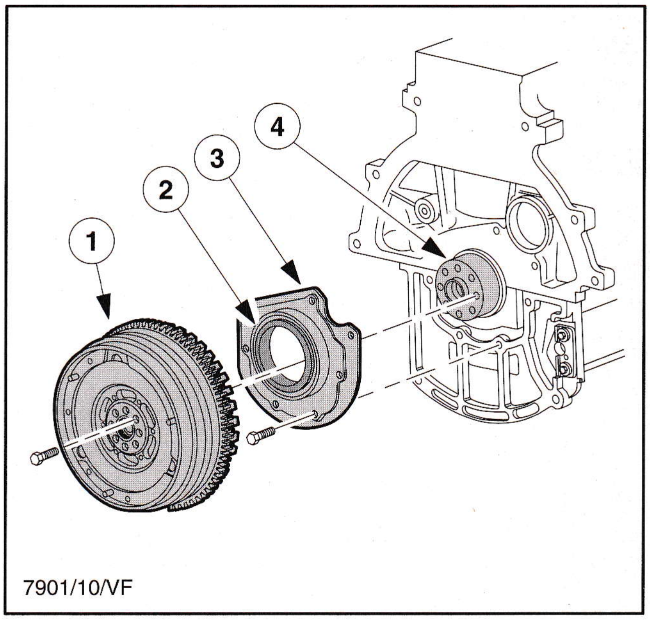
1 Vibration damper retaining bolt
2 Vibration damper

Dual-mass flywheel

- For the 2001.5 Focus a dual-mass-flywheel has been fitted.
- The periodic combustion cycles produce torsional vibrations in the powertrain. This would lead to transmission rattle and body boom due to the higher combustion pressures.
- However, the dual-mass flywheel absorbs these sources of noise so that the smooth operation known from the 1.8L Endura-DI engine is improved even more.
- The retaining bolts have been changed. They are now flanged hexagon head bolts.

NOTE: Refer to the current service literature for the changed tightening torque.

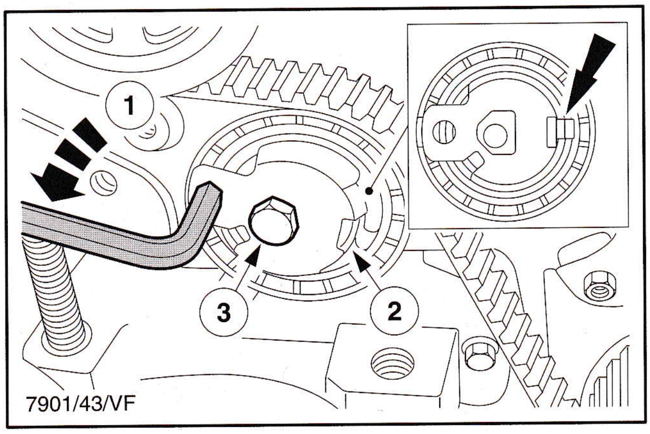
NOTE: The dual-mass flywheel must not be dismantled.



1 Flywheel
2 Locating sleeve
3 Crankshaft oil seal housing
4 Crankshaft

Automatic timing belt tensioner

- As before on the 1.8L Endura-DI-Engine, the 1.8L DuraTorq-TDCi-Engine is equipped with an automatic timing belt tensioner which has been modified slightly.
- After the timing belt is installed, the automatic timing belt tensioner must be turned in a counter clockwise direction until the projection (indicated by the arrow) lines up with the recess (2).
- The tensioner should be held on the Allen key until the retaining bolt has been tightened to the specified torque.

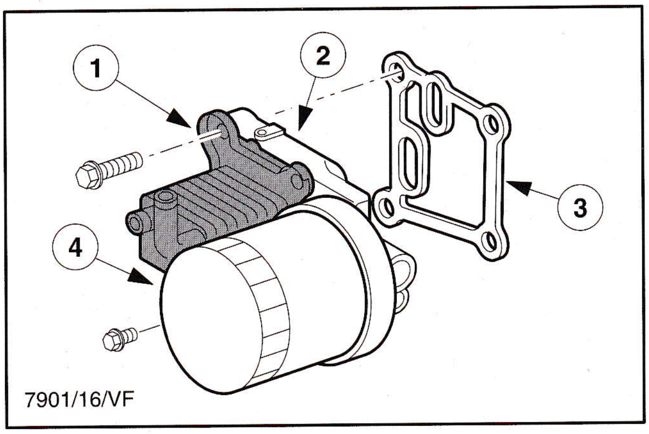


1 Direction of rotation of tool
2 Recess
3 Retaining bolt

NOTE: The timing belt must be changed following the procedure described in the service literature.

Oil cooler and filter

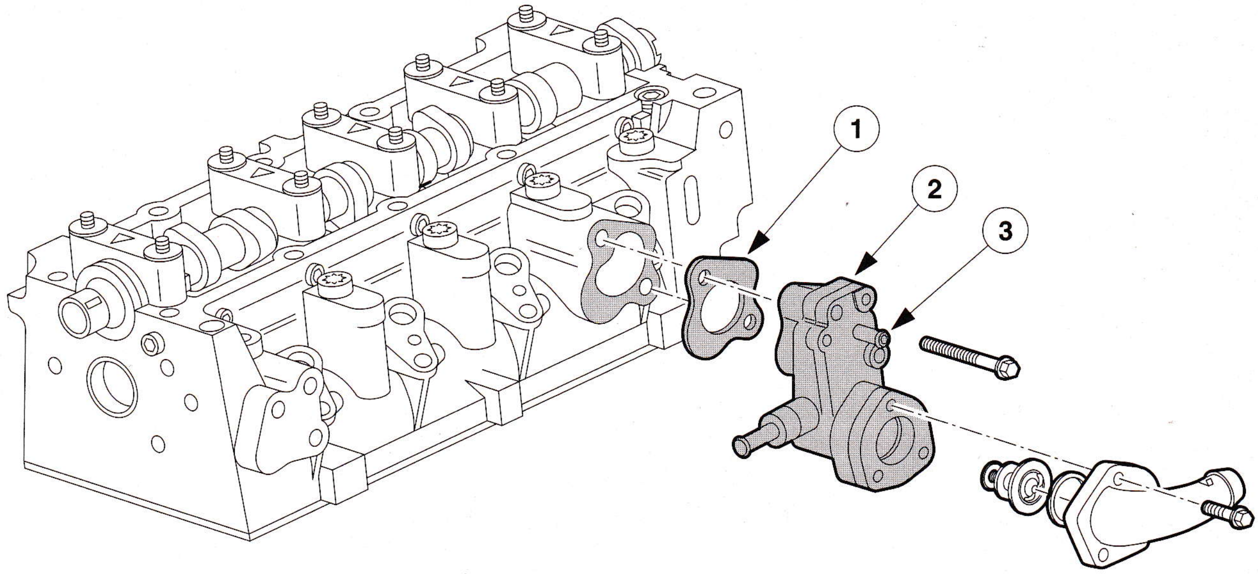
- The oil cooler has two additional cooling segments due to the increased thermal load produced by the increase in power.
- However, the oil fill capacity remains the same as for the Endura-DI engine at 5.6 liters.



1 Oil cooler
2 Adapter
3 Steel gasket
4 Oil filter

Thermostat

- The thermostat housing sits on the side of the cylinder head and is sealed with a steel gasket which cannot be reused.
- The thermostat housing has been changed to accommodate the fuel injection supply manifold of the common rail fuel injection system.
- The connector for the hose to the expansion tank has been moved to the front of the thermostat housing.



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1 Steel gasket
2 Thermostat housing
3 Changed hose connector

Find the correct answer.

1. **How can the cylinder head of the 1.8L DuraTorq-TDCi-Engine be distinguished from the head of the 1.8L Endura-DI engine?**

- ☐ a) The cylinder heads are distinguished by major design features.
- ☐ b) The camshafts are different.
- ☐ c) There is a milled groove on the rear of the cylinder head of the 1.8L DuraTorq-TDCi-Engine.
- ☐ d) The exhaust ports of the 1.8L DuraTorq-TDCi-Engine have been changed.

2. **Which of the following statements about the changes in the 1.8L DuraTorq-TDCi-Engine compared with the 1.8L Endura-DI engine is correct?**

- ☐ a) The retaining bolts of the large-end bearing caps have been changed.
- ☐ b) The valve springs have been uprated.
- ☐ c) The piston rings have been modified.
- ☐ d) The shanks of the connecting rods are thicker.

3. **Which statement about the 1.8L DuraTorq-TDCi-Engine is incorrect?**

- ☐ a) The CMP sensor is incorporated in the valve cover.
- ☐ b) The turbocharger has been carried over from the 1.8L Endura-DI engine.
- ☐ c) The tightening torque of the cylinder head bolts is the same as on the 1.8L Endura-DI engine.
- ☐ d) When the fuel injectors were changed, the retainers were also modified.

Objectives

On completing this lesson, you will be:

- familiar with the reasons for the introduction of the common rail fuel injection system
- familiar with the system as a whole and the components of the high-pressure and low-pressure parts of the common rail fuel injection system
- familiar with the design and operation of the fuel injectors

- The common rail fuel injection system is introduced for the Focus 2001.5.
- In comparison with the distributor-type fuel injection system it provides the following advantages:
  - lower combustion noise,
  - cleaner exhaust emissions,
  - lower fuel consumption,
  - increased torque.
- These advantages are achieved by separating the pressure generation and fuel injection.
- This means that the fuel injection pressure and the quantity of fuel injected can be determined independently of one another for every engine operating point.
- The fuel system comprises a low-pressure side for low-pressure fuel delivery and a high-pressure side for high-pressure fuel delivery.
- The low-pressure system provides fuel to the high-pressure chamber of the high-pressure pump and, additionally, assures sufficient lubrication and cooling of the high-pressure pump.
- Within the high-pressure pump the fuel pressure is raised up to 1600 bar and is fed to the fuel injection supply manifold.
- The fuel injection supply manifold is not designed like a stretched fuel pressure reservoir but, due to space availability, it is spherically shaped.
- The fuel in the fuel injection supply manifold is available for injection at high pressure.
- The common rail fuel injection system has its own control module, the injector driver module (IDM), which calculates the fuel injection pressure and quantity of fuel injected with the aid of the sensors.
- According to the fuel pressure inside the rail the solenoid of the injector is actuated and opened for a certain period of time.
- Optimum spray preparation can be achieved through the use of suitably small injector nozzle openings and the high fuel injection pressure. This results in almost ideal fuel injection throughout the combustion chamber and leads to optimum combustion.
- Combustion is started with the pilot injection. Here it is important that the quantity of fuel injected during the pilot injection phase remains relatively small.
- Injecting a small amount of fuel into the combustion chamber during the pilot injection phase initiates pre-combustion. This produces a slight increase in the compression pressure which shortens the delay in ignition of the main fuel charge.
- In addition, the rise in combustion pressure and the combustion pressure peaks are reduced. This also improves combustion efficiency.
- These effects reduce the combustion noise, fuel consumption and emissions.
- One more advantage of the common rail fuel injection system is, that the fuel injection pressure remains largely unchanged throughout the fuel injection process. In this way the strain on the crank mechanism is reduced.

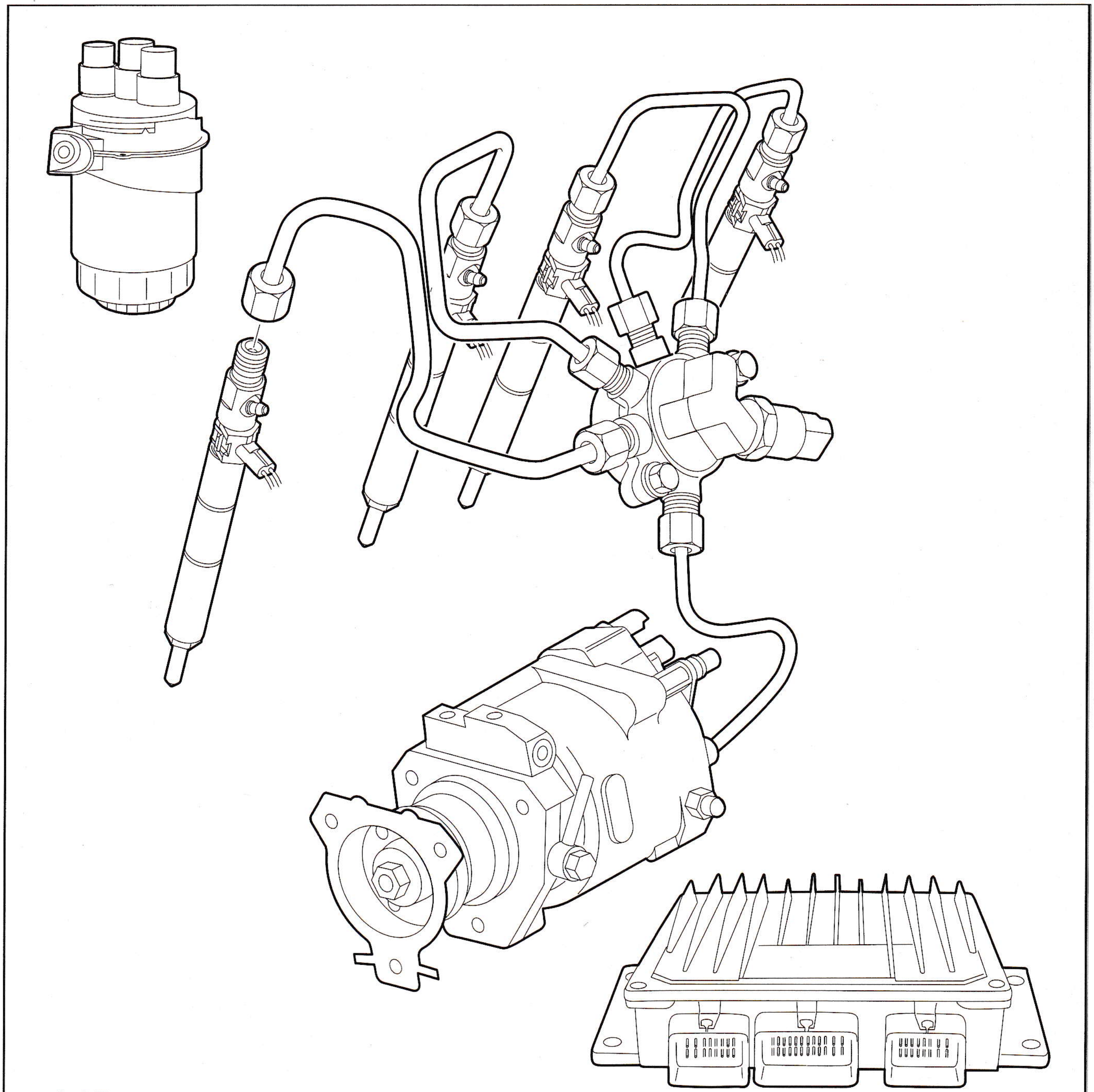
Service-Hints

Cleanliness

- The common rail diesel injection system of the 1.8L DuraTorq Engine consits of high precise components which are produced with sophistical manufacturing techniques adhering to the most rigorous tolerance regulations.
- Because of the extremly tight alignment of the moving parts and the very narrow fuel channels and nozzle orifices, even smallest contaminations in the fuel injection system can lead to failure of single components or to a system breakdown.
- It is therefore essential to ensure **absolute cleanliness** during all interventions on a common rail diesel injection system. This applies as well to storage and handling of spare parts.

⚠ **CAUTION:** Make sure to consult the current service literature before conducting any service work or repairs on the common rail fuel injection system.

System overview



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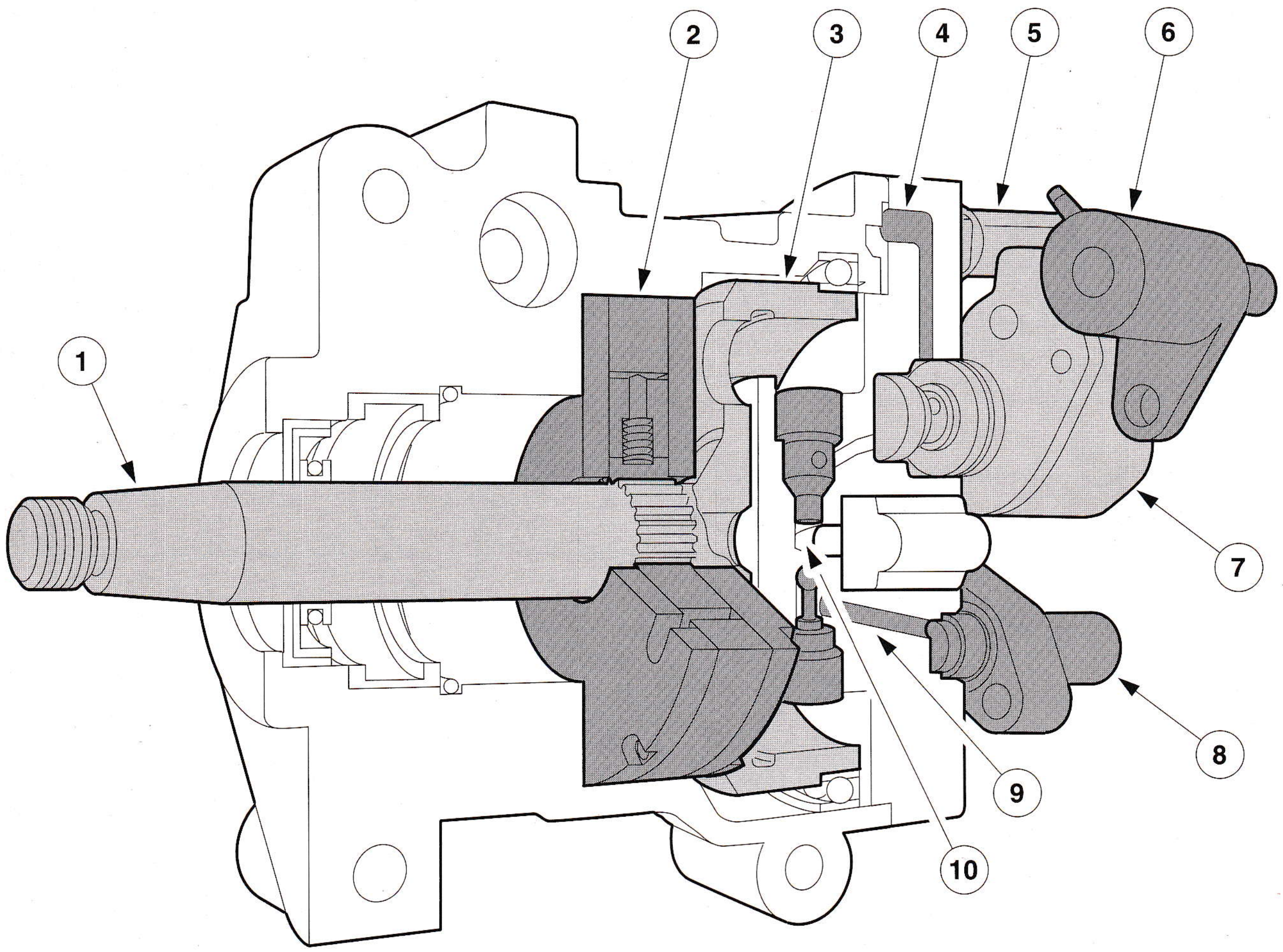
High-pressure pump

- The fuel passes from the fuel transfer pump via an inlet bore into the high-pressure chamber.
- The fuel metering valve is located in the inlet bore between the transfer pump and the high-pressure chamber.
- The fuel metering valve is controlled by a solenoid and varies the cross-section of the inlet bore actuated by the injector driver module (IDM) according to the operating state. In this way the injector driver module regulates the quantity of fuel which is to pass into the high-pressure chamber.



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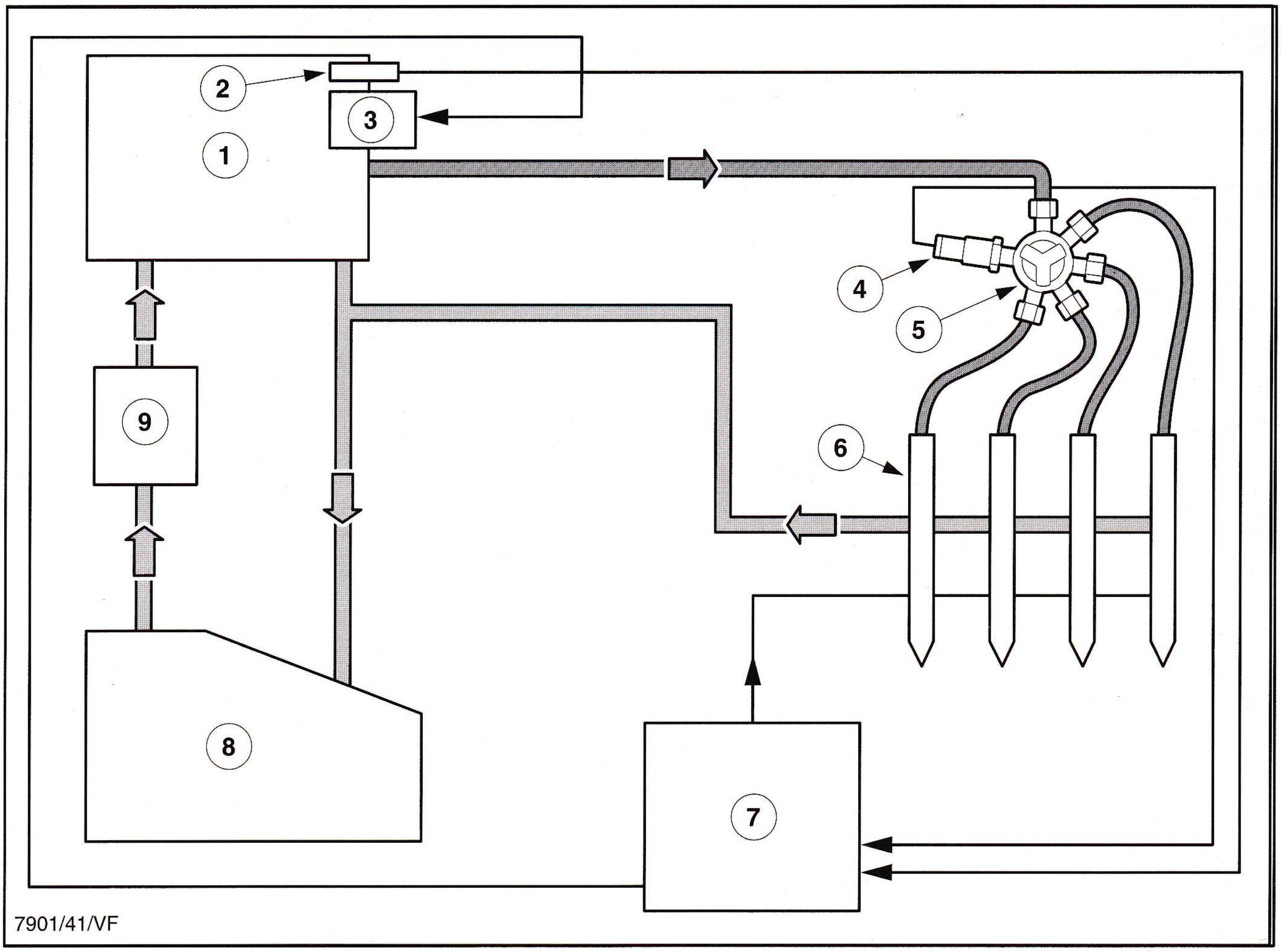
1 Driving shaft
2 Transfer pump
3 Eccentric ring
4 Inlet bore
5 Fuel temperature sensor
6 Venturi in fuel return
7 Fuel metering valve
8 High-pressure connection to fuel injection supply manifold
9 High-pressure channel
10 High-pressure chamber

Low-pressure system

- The low-pressure system consists of the following components:
  - a fuel tank
  - a fuel filter
  - a transfer pump
  - low-pressure fuel pipes



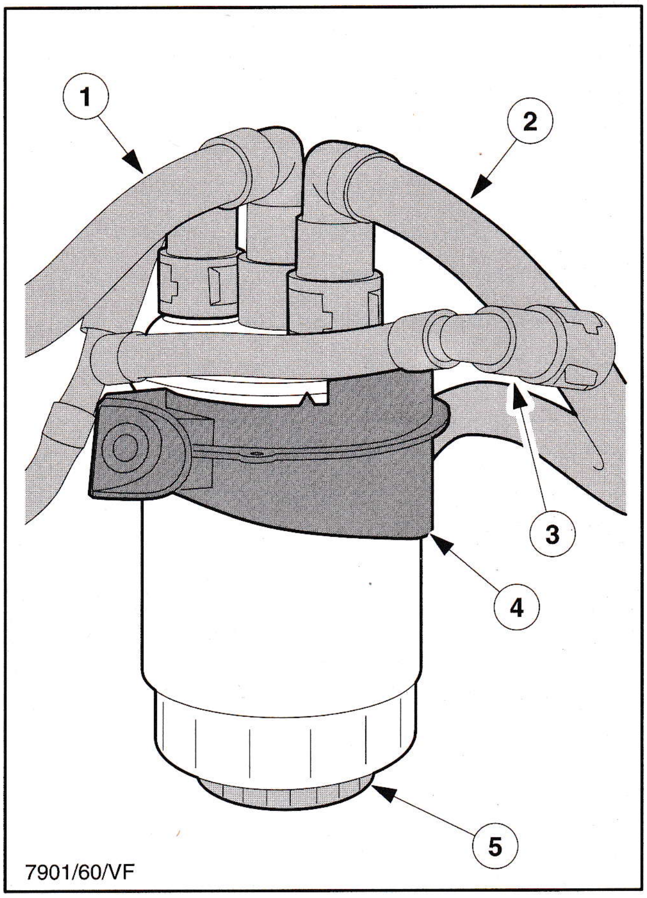
1 High-pressure pump
2 Fuel temperature sensor
3 Fuel metering valve
4 Fuel pressure sensor
5 Fuel injection supply manifold
6 Fuel injectors
7 Injector driver module (IDM)
8 Fuel tank
9 Fuel filter

Fuel filter

- A Delphi fuel filter specially adapted to the requirements of the fuel injection system, has been introduced to guarantee trouble-free operation of the fuel injection system.
- The filter is installed in the same position as on the 1.8L Endura-DI engine.
- The fuel filter has an integral control valve which closes the return to the tank at low temperatures. This warms the fuel in the fuel filter.
- The fuel pipes are secured on the top of the fuel filter housing with clips.
- The fuel pipes have different color codes for the inlet (white) and return (red).
- To avoid damage to the fuel injection system due to condensation and from water in fuel, the fuel filter has a water collecting chamber.
- The water collecting chamber can be drained by means of the threaded water drain plug on the underside of the housing.

NOTE: The fuel filter must be changed in service every 60000 km (40000 mls).

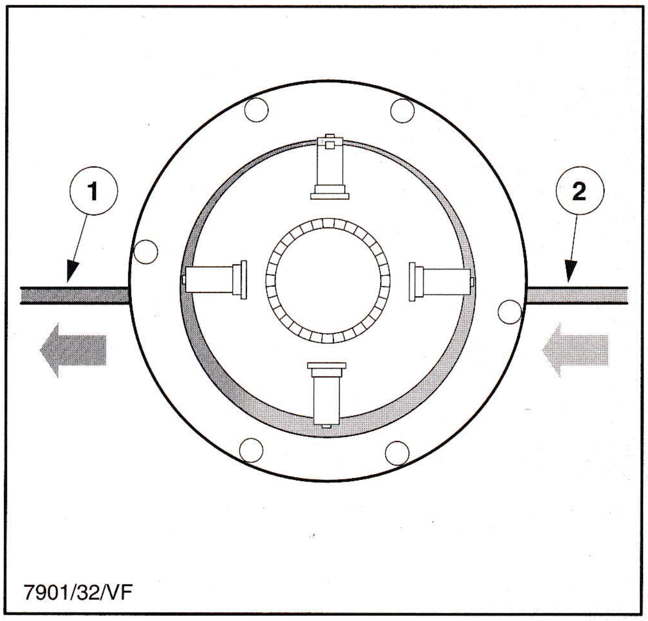
NOTE: The water collecting chamber must be drained every 20000 km (10000 mls).



1 Outlet to the high-pressure pump
2 Inlet from the fuel tank
3 Return flow from the high-pressure pump
4 Bracket
5 Water drain plug

Transfer pump

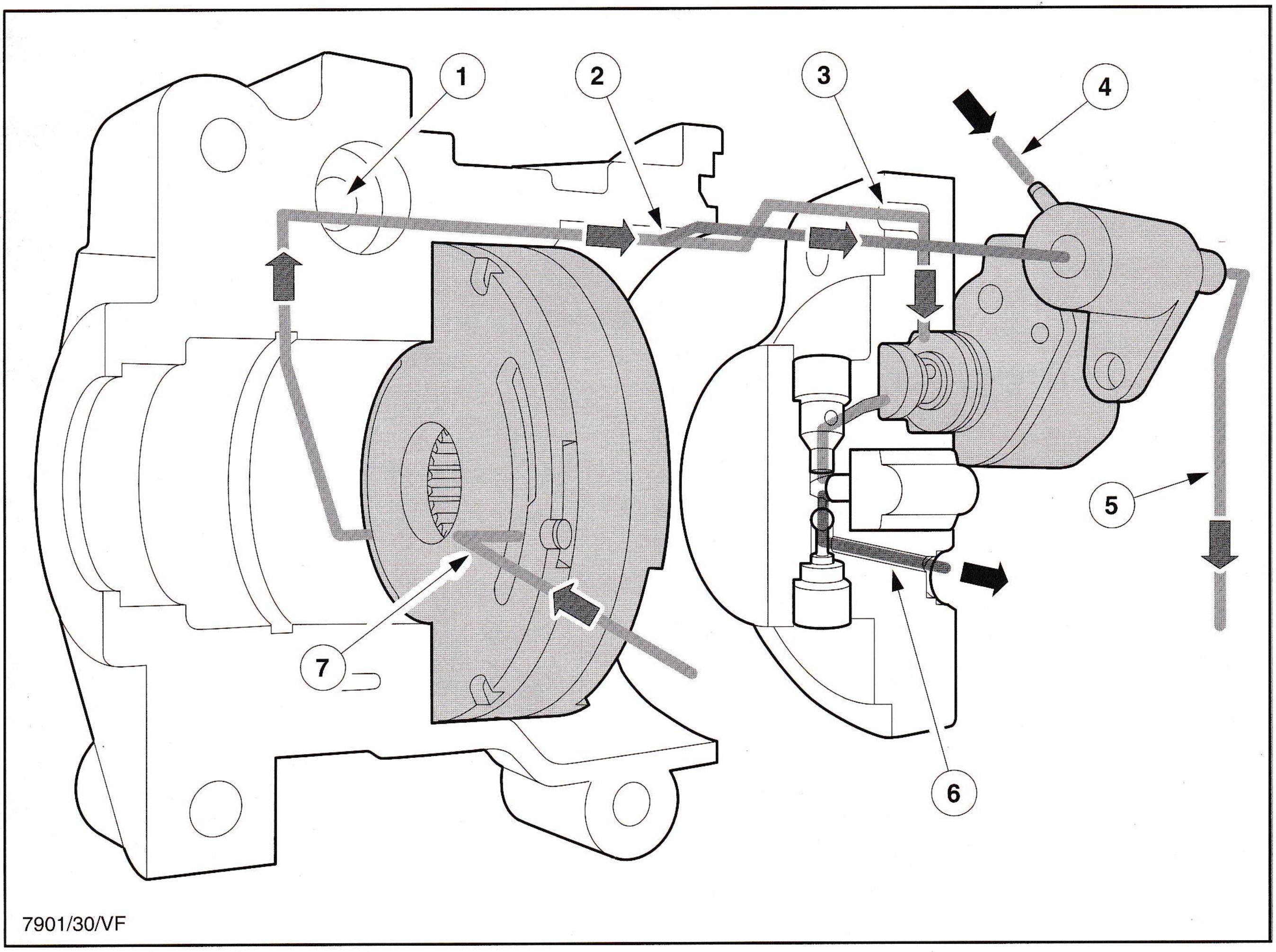
- The transfer pump is a vane cell pump driven mechanically through the pump driving shaft.
- The transfer pump sucks the fuel out of the fuel tank with a maximum vacuum of 0.65 bar depending on the engine speed, and conveys the fuel to the high-pressure chamber.
- In the low-pressure circuit between the transfer pump and the high-pressure chamber there is a pressure regulating valve which regulates the transfer pressure to a maximum of 6 bar.



1 Pressure side
2 Suction side

Low-pressure fuel return

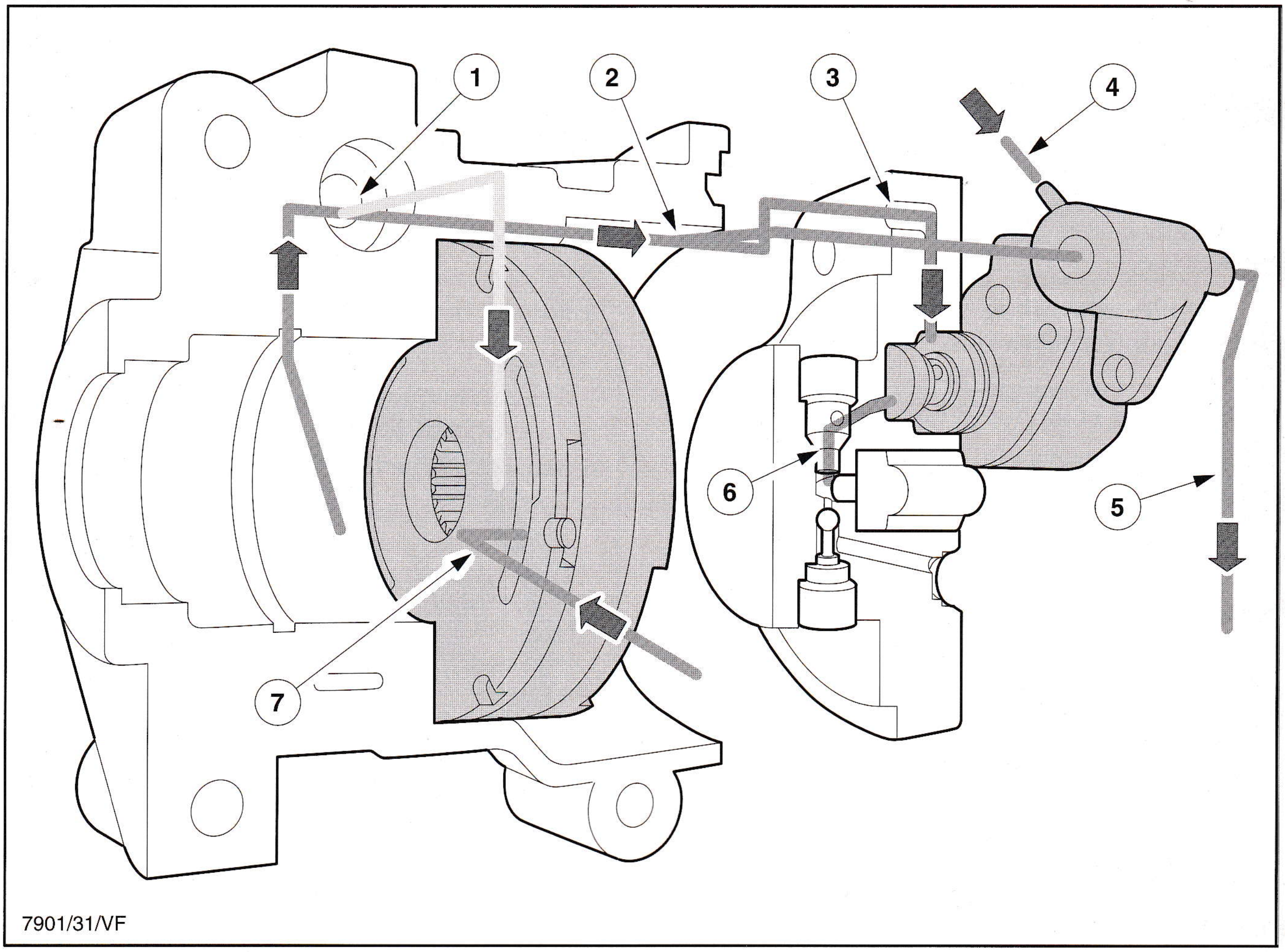
- The low-pressure fuel return has the following functions:
  - to cool and lubricate the high-pressure pump through the internal return of the low-pressure fuel to the fuel tank
  - to return the leak-off fuel from the fuel injectors to the fuel tank
- During the acceleration phase the fuel is pumped permanently into the high-pressure chamber.
- At the same time some of the fuel is used to lubricate the pump and returns through the venturi in the fuel return to the tank.
- The venturi in the fuel return works on the principle of a suction pump and creates a slight vacuum in the leak-off pipes which improves the return of the leak-off fuel.



Fuel return during acceleration

1 Pressure regulating valve
2 Fuel return orifice
3 Inlet bore to high-pressure chamber
4 Leak-off fuel from fuel injectors
5 Fuel return to fuel tank
6 High-pressure channel to fuel injection supply manifold
7 Transfer pump

- In overrun, the fuel metering valve closes the inlet to the high-pressure chamber.
- This produces a rise in pressure in the inlet bore. As soon as the low-pressure reaches the maximum value of 6 bar at 2500 rpm, the pressure regulating valve is opened. This is connected through a bore to the transfer pump.
- The surplus fuel flows partly back to the suction side of the transfer pump and through the venturi in the fuel return back to the fuel tank.



Fuel return in overrun

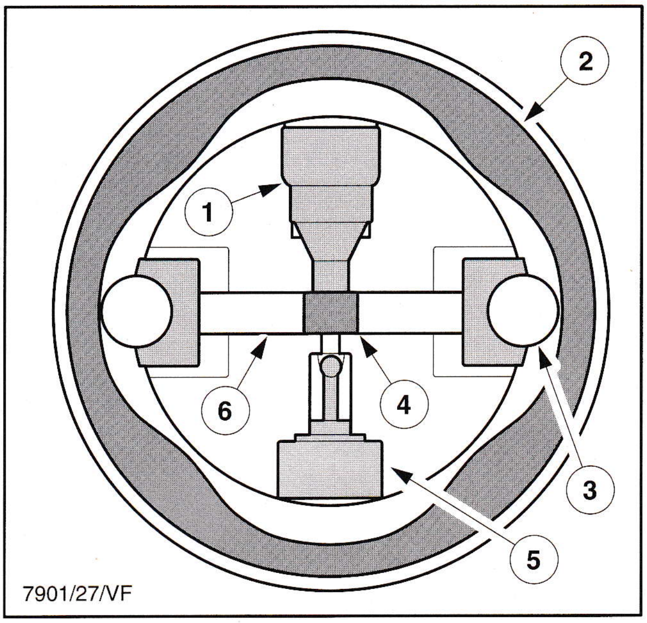
1 Pressure regulating valve
2 Fuel return orifice
3 Inlet bore to high-pressure chamber
4 Leak-off fuel from fuel injectors
5 Fuel return to the fuel tank
6 High-pressure chamber
7 Transfer pump

High-pressure system

- The high-pressure system consists of the following components:
  - a high-pressure pump
  - a fuel metering valve
  - a fuel injection supply manifold
  - a fuel pressure sensor
  - high-pressure pipes
  - four fuel injectors controlled by solenoid valve

High-pressure chamber

- The function of the high-pressure chamber of the high-pressure pump is to compress the fuel supplied.
- The high-pressure chamber consists of an inlet valve and an outlet valve, both of which are equipped with a non-return valve, two pump pistons and a driving shaft with four eccentric cams.
- The eccentric cams move the pump pistons up and down.
- When the transfer pressure exceeds the internal pressure in the high-pressure chamber, the inlet valve opens. Fuel then flows into the high-pressure chamber and forces the pump pistons with their rollers and rollershoes outwards against the eccentric cams.
- The outlet valve remains closed due to the higher pressure in the high-pressure channel lying behind it.

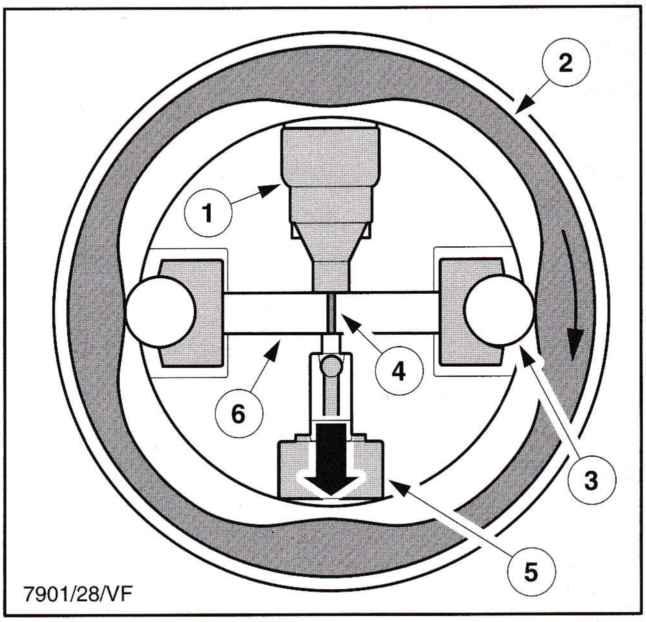


High-pressure chamber (outlet valve closed)

1 Inlet valve
2 Eccentric ring with eccentric cams
3 Roller and rollershoe
4 High-pressure chamber
5 Outlet valve
6 Pump piston

High-pressure chamber (continued)

- When an eccentric cam runs over the pump pistons, the fuel in the high-pressure chamber is compressed.
- As soon as the pressure in the high-pressure chamber is greater than the pressure in the high-pressure channel, the outlet valve opens and the fuel is conveyed through the high-pressure outlet to the fuel injection supply manifold.
- Fuel is conveyed into the high-pressure circuit until the pump pistons have reached the end of the conveying phase.
- The pressure conditions are now reversed so that the pressure in the high-pressure circuit is greater than the pressure in the high-pressure chamber.
- The outlet valve closes so that no more fuel is conveyed into the high-pressure circuit.
- The quantity of fuel conveyed to the fuel injection supply manifold depends on the quantity of fuel injected or the pressure drop in the high-pressure system which depends on the operating state of the engine.

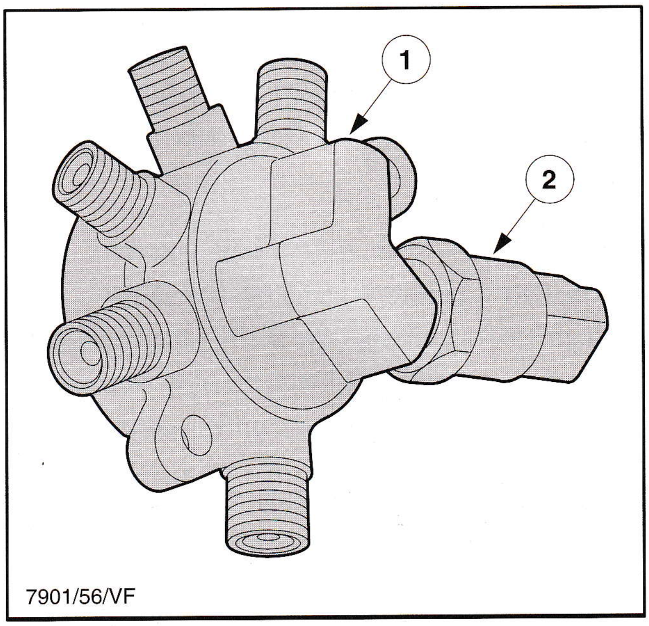


High-pressure chamber (outlet valve opened)

1 Inlet valve
2 Eccentric ring with eccentric cams
3 Roller and rollershoe
4 High-pressure chamber
5 Outlet valve
6 Pump piston

Fuel injection supply manifold (common rail)

- The fuel is stored in the fuel injection supply manifold at high pressure ready for injection.
- On the fuel injection supply manifold there is a fuel pressure sensor which transmits information about the current fuel pressure in the fuel injection supply manifold to the IDM.
- The fuel injection supply manifold is designed so that the volume is large enough to largely damp pressure fluctuations in the system.
- On the other hand, the volume must be as small as possible so that the required pressure can be built up rapidly in order to guarantee rapid starting of the engine.
- Additionally, with a volume too large more leak-off fuel would need to be returned to the fuel tank with the result that fuel temperature rises.



1 Fuel injection supply manifold

2 Fuel pressure sensor

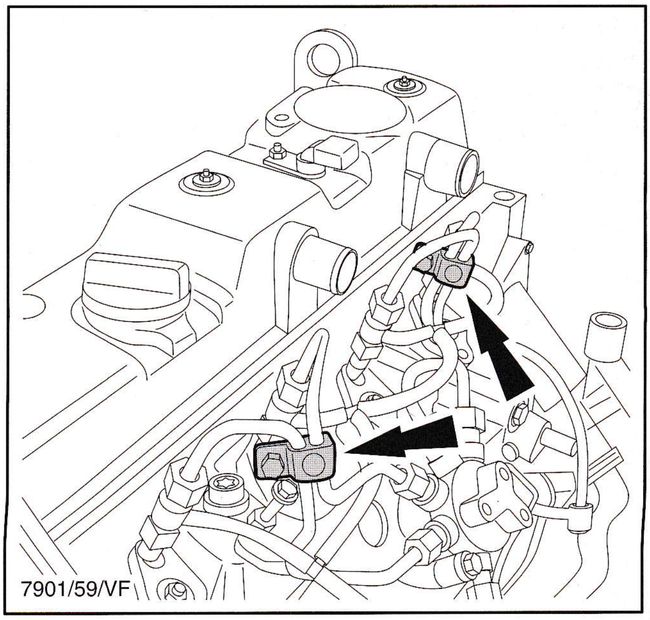
High-pressure fuel pipes

- The high-pressure fuel pipes connect the high-pressure pump to the fuel injection supply manifold and the fuel injection supply manifold to the individual fuel injectors.
- The fuel pipes conveying fuel at high pressure must withstand the maximum system pressure and the pressure fluctuations.
- The fuel pipes have an outside diameter of 6.0 mm and an inside diameter of 2.4 mm.
- New pipe clamps have been used to reduce pipe stress from vibration and pressure pulsation.
- The clamps are now made of metal with a rubber lining and are screw clamped to hold them in place.

NOTE: When fuel injectors are changed, the fuel pipes must also be changed to guarantee freedom from leaks.

NOTE: The length and bending radii are matched precisely to the system and must not be changed.

NOTE: The fuel injection system does not need bleeding.

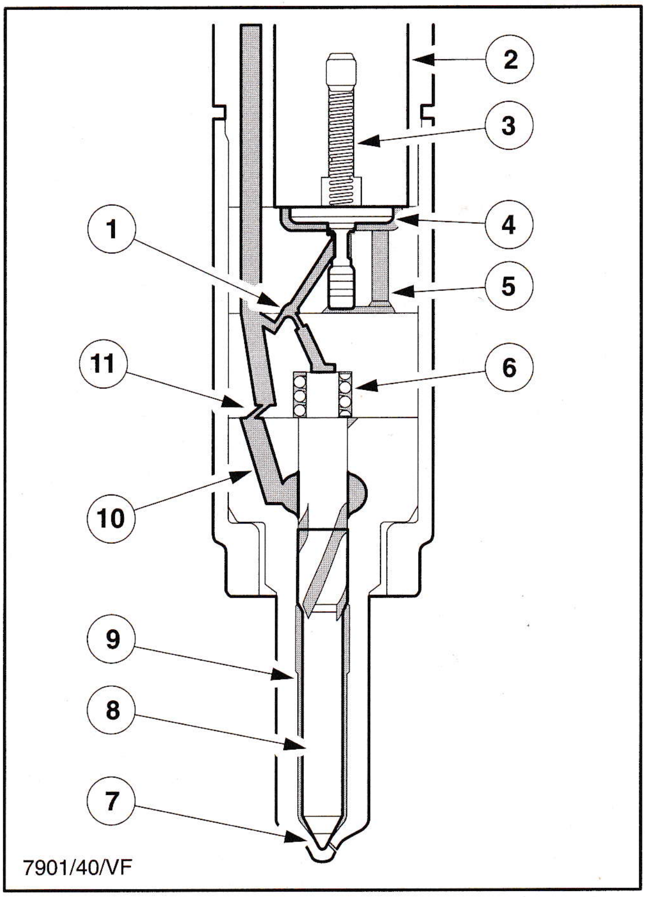


Fuel pipe clamps

Fuel injectors

- The function of the fuel injectors which are controlled by solenoid valves, is to regulate the start of fuel injection and the quantity of fuel injected according to the instructions received from the IDM.
- 6-hole fuel injectors are used for the 1.8L DuraTorq-TDCi-Engine.
- The tiny moving masses of the control valves have made it possible to achieve the rapid switching time of 0.3 ms. This is the response time which the fuel injection system requires to be able to react rapidly to changes in the operating states.
- For manufacturing reasons, the fuel injectors have different production tolerances which can be identified by a number on the injector.
- To calculate the correct quantity of fuel, the IDM must be aware of any change to the system due to changing of fuel injectors.

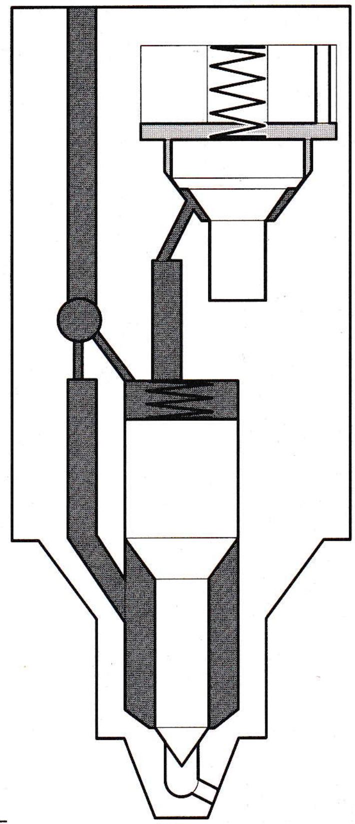
NOTE: When a fuel injector is changed the fuel injector number found on the injector and the appropriate cylinder assignment must be entered in the injector driver module by means of WDS.



1 Inlet choke (control chamber)
2 Solenoid valve
3 Solenoid valve spring
4 Control valve
5 Drain bore
6 Control chamber
7 Nozzle openings
8 Nozzle needle
9 Nozzle chamber
10 Inlet channel
11 Inlet choke (inlet channel)

- The operation of the fuel injectors can be divided into four operating states:
  - fuel injector closed
  - fuel injector beginning to open
  - fuel injector completely opened (fuel injection)
  - fuel injector closing

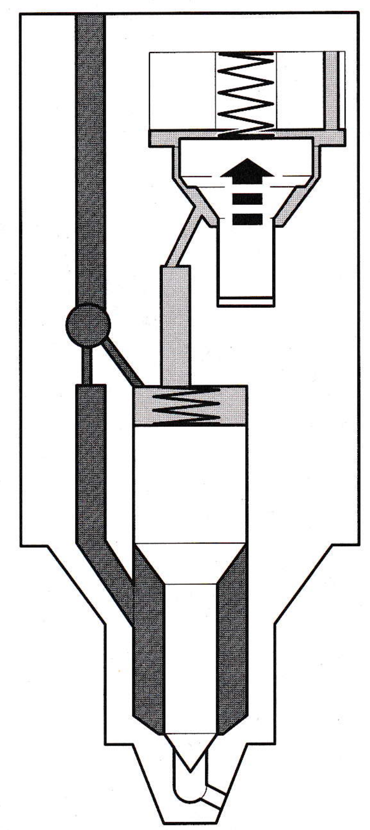
Fuel injector closed


7901/70/VF

- The fuel is passed from the high-pressure connection through an inlet channel to the nozzle chamber and through the inlet choke into the control chamber.
- As a result, fuel injection supply manifold pressure is present in the control chamber and in the nozzle chamber.
- The solenoid valve is de-energized, the control valve is closed.
- In addition, the force of the nozzle spring acts on the nozzle needle in the valve control chamber.
- The hydraulic force and the spring force acting on the top of the nozzle needle outweigh the force in the nozzle chamber acting on the taper of the nozzle needle.
- The nozzle needle remains in its lowest position and closes the nozzle.

Fuel injector beginning to open

- The solenoid valve is energized with the pull-up current by means of the IDM and the control valve opens.
- The opening of the control valve connects the control chamber to the drain bore.
- This allows the leak-off fuel to flow away through the low-pressure connectors of the fuel injectors.
- The pressure in the control chamber begins to fall.
- The fuel injector nozzle is still closed.



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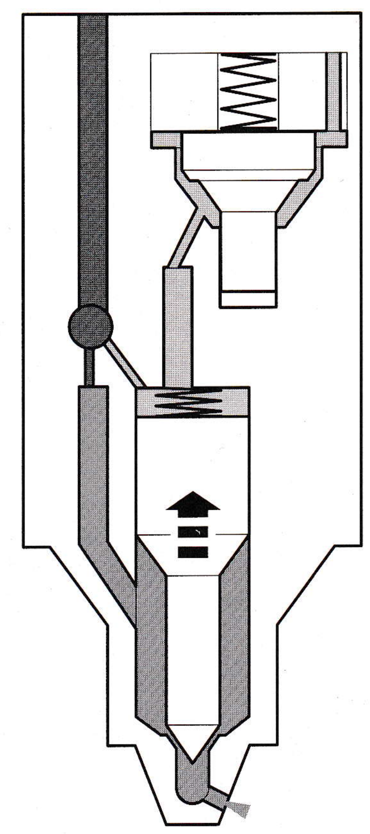
Fuel injector completely opened (fuel injection)

- The high pull-up current of 12 A is reduced to a low holding current of 6 A. The drain bore is still opened.
- As soon as the pressure in the nozzle chamber is higher than the pressure in the control chamber, the nozzle needle begins to open.
- The fuel injector nozzle is now opened and fuel injection begins.



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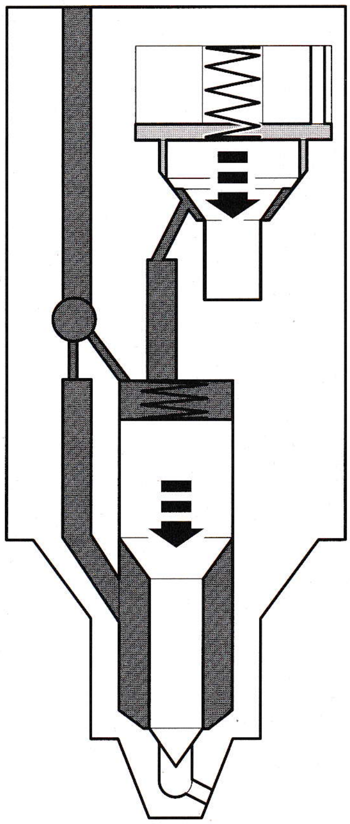
Fuel injector closing

- When the solenoid valve is no longer actuated by the IDM, the control valve is pressed into the seat by the spring of the solenoid valve.
- This closes the drain bore and the fuel pressure in the control chamber rises through the inlet of the inlet choke.
- As soon as the pressure in the control chamber is greater than the pressure in the nozzle chamber, the nozzle needle moves downwards and closes the fuel injector nozzles.
- The fuel injection is ended.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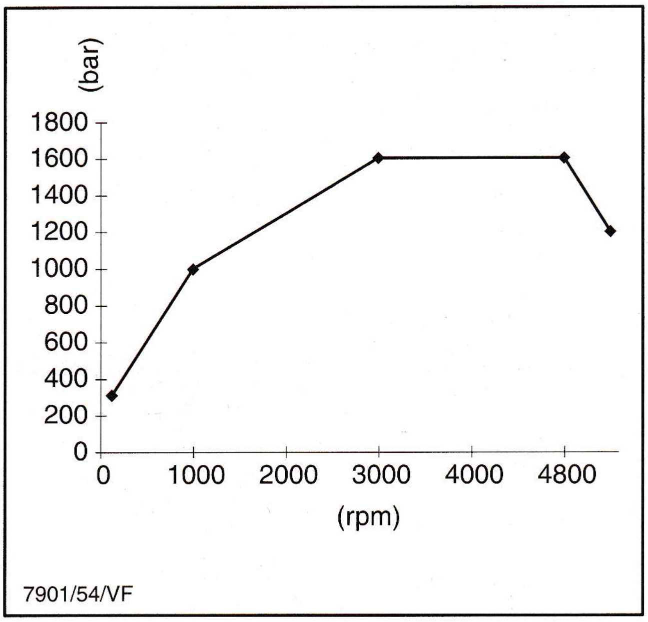
Pressure regulation

- The reduction in pressure is achieved by repeated actuation of the control valves by the IDM.
- The pull-up current is large enough to open the control valve. However, the actuating currents remain so small that the control valve only opens a very tiny amount.
- This opening range is so small that it is sufficient to reduce the pressure but not large enough to produce a pressure drop to open the control valve.
- The system pressure is also regulated according to the engine operating state on the same principle.
- This measure eliminates the need for a pressure regulating valve on the fuel injection system.

Fuel injection process

Pilot injection

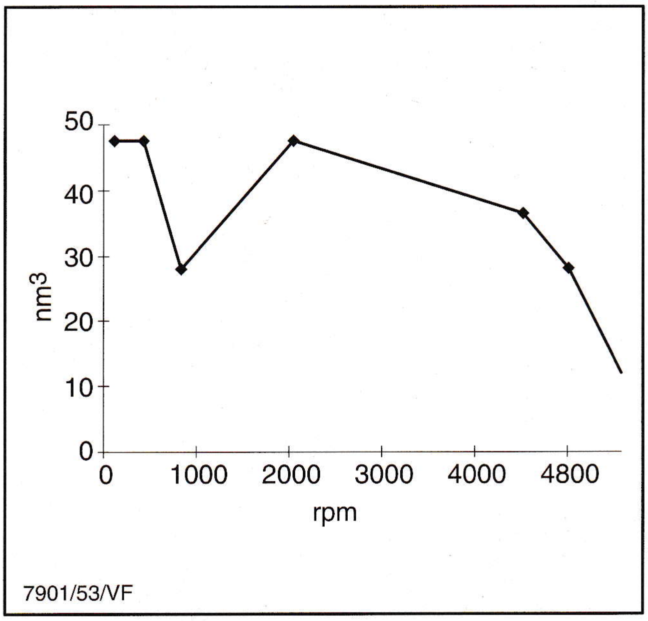
- The pilot-injection takes place in the range from 0 degrees to 40 degrees before top dead center.
- The pilot-injected quantity of fuel is variable over the entire speed range and lies in the range from 0.8 mm³/stroke to 5 mm³/stroke.
- The pilot-injected quantity of fuel is obtained through the actuation time of the fuel injectors in relation to the pressure in the fuel injection supply manifold.



Variation in pressure over engine speed

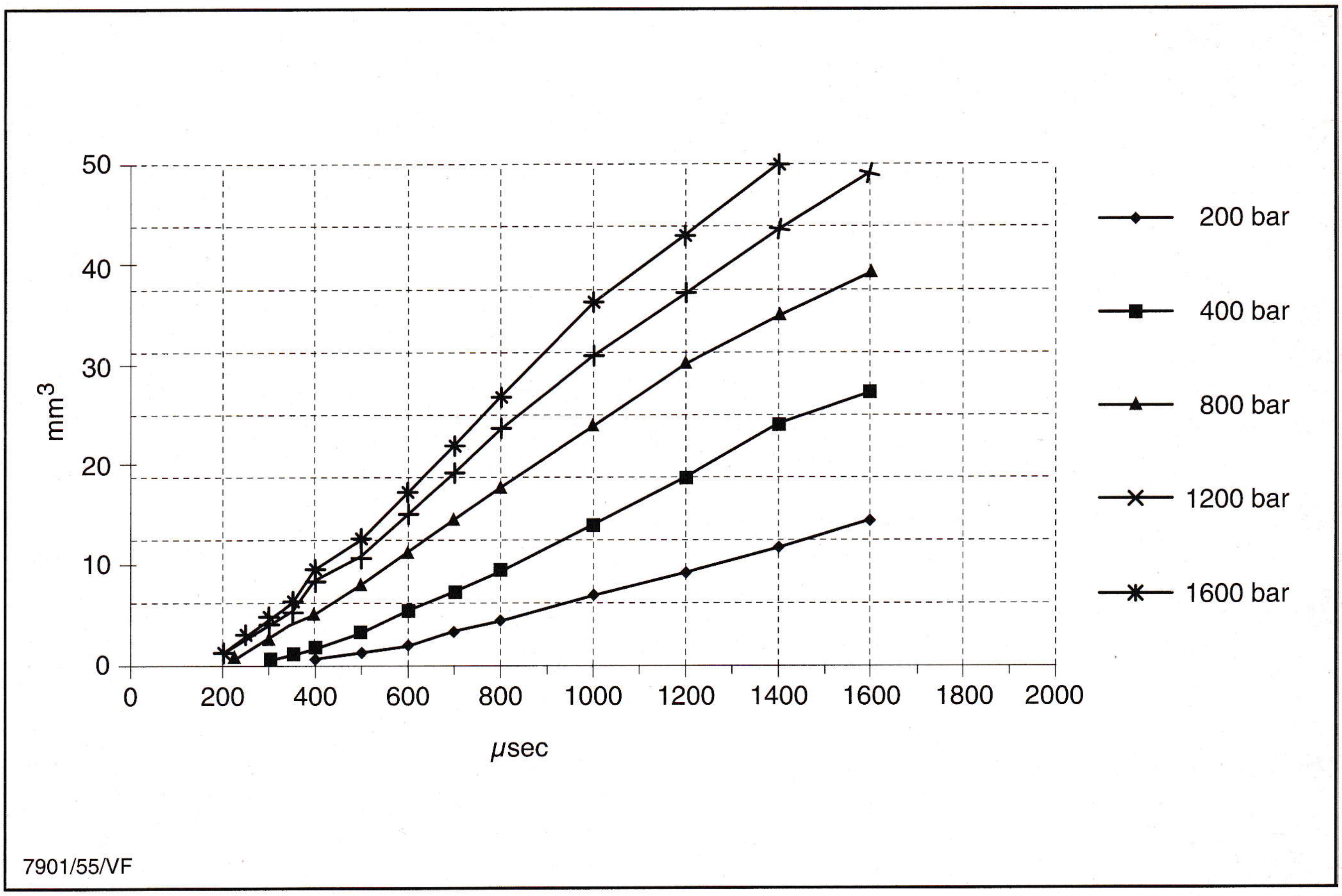
Main injection

- The main injection takes place after the pilot-injection in the range from 25 degrees before top dead center to 15 degrees after top dead center.
- There is a break in fuel injection between the pilot-injection and main injection phases.
- The quantity of fuel injected during the main injection phase is variable, like the pilot-injected quantity, over the entire engine speed range and amounts to up to 50 mm³/stroke.
- Like the pilot-injected quantity, the quantity of fuel injected during the main injection phase is measured by the actuation time of the fuel injectors and the pressure in the fuel injection supply manifold.



Total quantity of fuel injected per stroke over engine speed

Fuel injection process (continued)



Total quantity of fuel injected per stroke depending on actuation time related to fuel pressure

Find the correct answer.

1. **What is the function of the fuel metering valve?**

- ☐ a) It regulates the quantity of fuel conveyed by the transfer pump.
- ☐ b) It passes the fuel into the nozzle chamber.
- ☐ c) It conveys the fuel out of the fuel tank into the high-pressure pump.
- ☐ d) It adjusts the cross-section of the inlet bore to the high-pressure chamber.

2. **Which statement about the fuel filter is incorrect?**

- ☐ a) The fuel pipes for the inlet and return are color coded.
- ☐ b) The fuel filter has an integral regulating valve.
- ☐ c) The fuel filter should be changed at intervals of 60000 km (40000 mls).
- ☐ d) The fuel filter has no water collecting chamber.

3. **Which components are not incorporated in the high-pressure pump?**

- ☐ a) Transfer pump
- ☐ b) Eccentric cams
- ☐ c) Fuel temperature sensor
- ☐ d) Control valve

4. **Which function is performed by the nozzle spring in the control chamber?**

- ☐ a) The nozzle spring closes the nozzle needle.
- ☐ b) The nozzle spring controls the pressure regulation in the inlet bore.
- ☐ c) During fuel injection the nozzle spring prevents pulsing of the nozzle needle.
- ☐ d) The quantity of fuel in the control chamber is regulated by means of the nozzle spring.

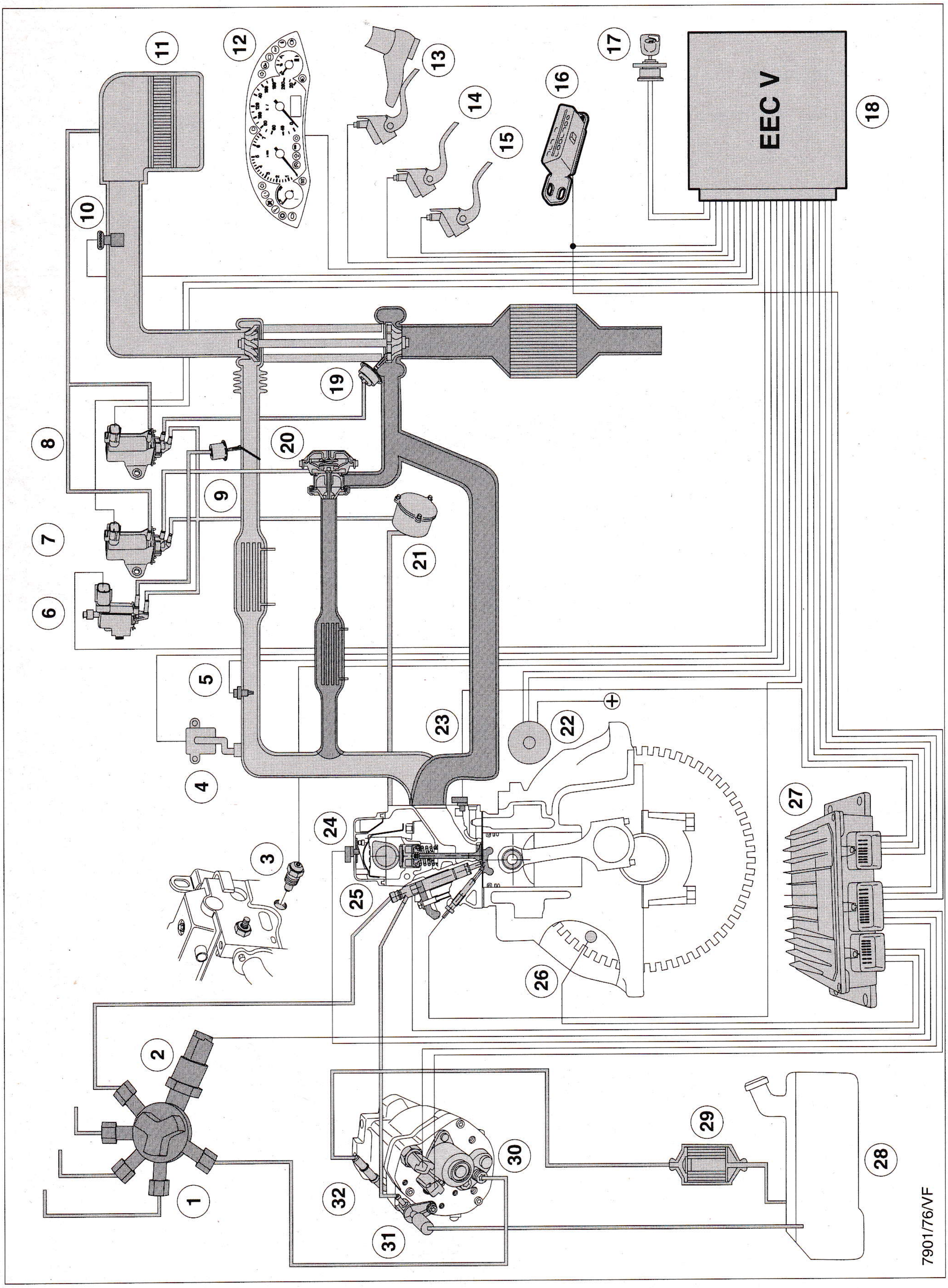
5. **Why has the fuel injection system of the 1.8L DuraTorq-TDCi-Engine no high-pressure regulating valve?**

- ☐ a) The function of the high-pressure regulating valve is performed by the IDM.
- ☐ b) The pressure is regulated by repeated momentary actuation of the fuel injectors.
- ☐ c) The function of the high-pressure regulating valve is performed by the pressure sensor.
- ☐ d) There is no need to regulate the pressure with the common rail fuel injection system.

Objectives

On completing this lesson, you will be:

- familiar with the system as a whole and the engine management components of the common rail fuel injection system
- familiar with the design and operation of the sensors and actuators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7901/76/VF

Key to the illustration opposite:

1 Fuel injection supply manifold

2 Fuel pressure sensor

3 Cylinder head temperature (CHT) sensor

4 Manifold absolute pressure (MAP) sensor

5 Intake air temperature (IAT) sensor in intercooler

6 Vaccum diaphragm unit solenoid valve

7 (EGR) solenoid valve

8 Boost pressure solenoid valve

9 Vacuum diaphragm unit

10 Mass air flow (MAF) sensor

11 Air cleaner

12 Instrument cluster

13 Accelerator pedal position (APP) sensor

14 Clutch pedal position (CPP) switch

15 Brake pedal position (BPP) switch

16 Data link connector (DLC)

17 Ignition switch

18 EEC V powertrain control module (PCM) with 104 pins and integral passive anti-theft system (PATS)

19 Turbocharger vacuum diaphragm unit

20 Exhaust gas recirculation (EGR) valve **without** EGR valve position sensor

21 Vacuum pump

22 Controlled battery charging (smart charging)

23 Knock sensor (KS)

24 Camshaft position (CMP) sensor

25 Fuel injectors

26 Crankshaft position (CKP) sensor

27 Injector driver module (IDM)

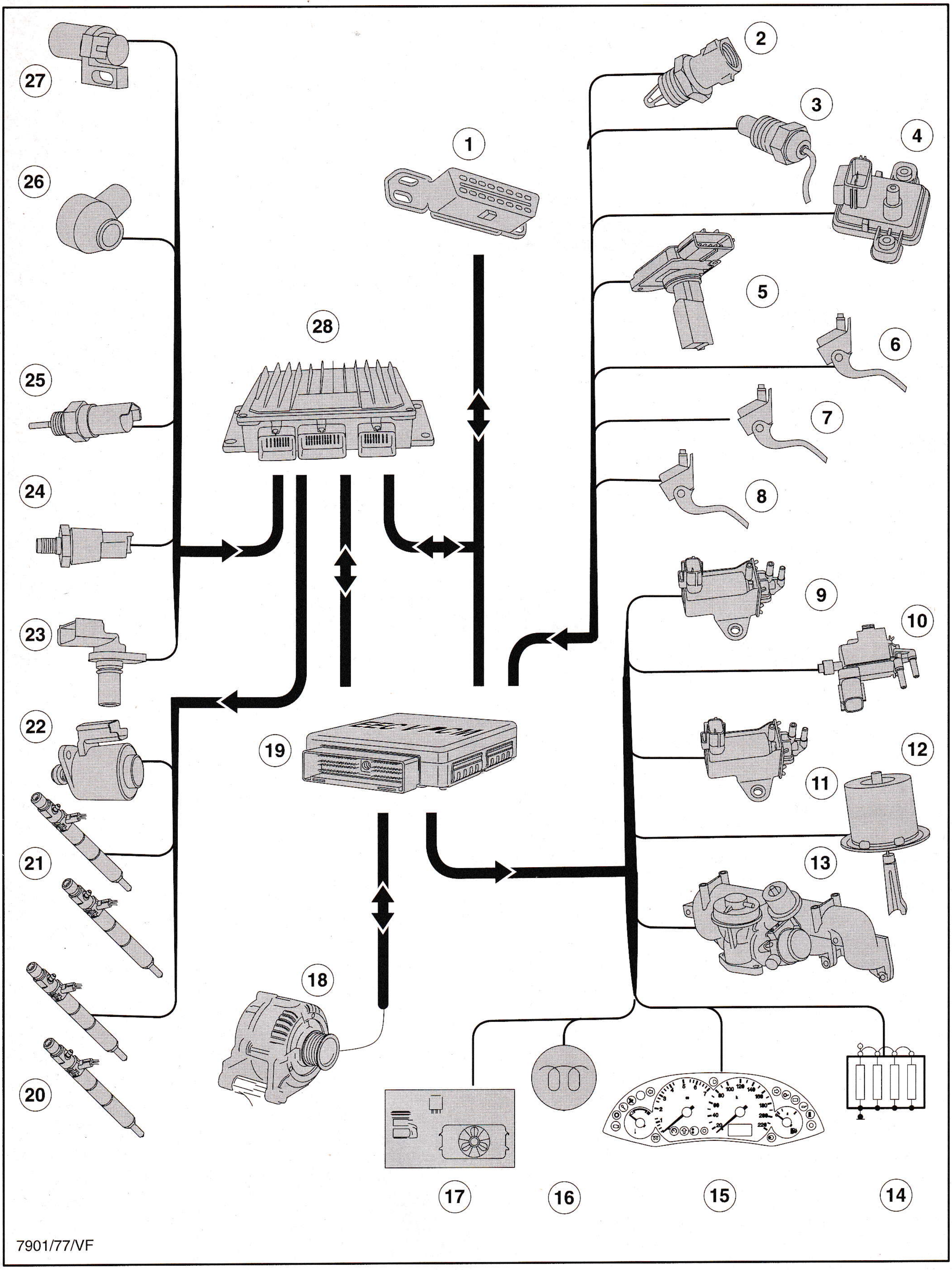
28 Fuel tank

29 Fuel filter

30 High-pressure pump with fuel temperature sensor and fuel metering valve

31 Venturi in the fuel return

32 Fuel inlet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7901/77/VF

Key to the illustration opposite:

1 Data link connector (DLC)

2 Intake air temperature (IAT) sensor in intercooler

3 Cylinder head temperature (CHT) sensor

4 Manifold absolute pressure (MAP) sensor

5 Mass air flow (MAF) sensor

6 Accelerator pedal position (APP) sensor

7 Clutch pedal position (CPP) switch

8 Brake pedal position (BPP) switch

9 Exhaust gas recirculation (EGR) solenoid valve

10 Vaccum diaphragm unit solenoid valve

11 Boost pressure solenoid valve

12 Vacuum diaphragm unit

13 Exhaust gas recirculation (EGR) valve **without** EGR valve position sensor

14 Pre-heat module

15 Instrument cluster

16 Glow plug indicator

17 Air conditioning compressor and cooling fan control

18 Controlled battery charging (smart charging)

19 EEC V powertrain control module (PCM) with 104 pins and integral passive anti-theft system (PATS)

20 Fuel injectors

21 Fuel injectors

22 Fuel metering valve

23 Camshaft position (CMP) sensor

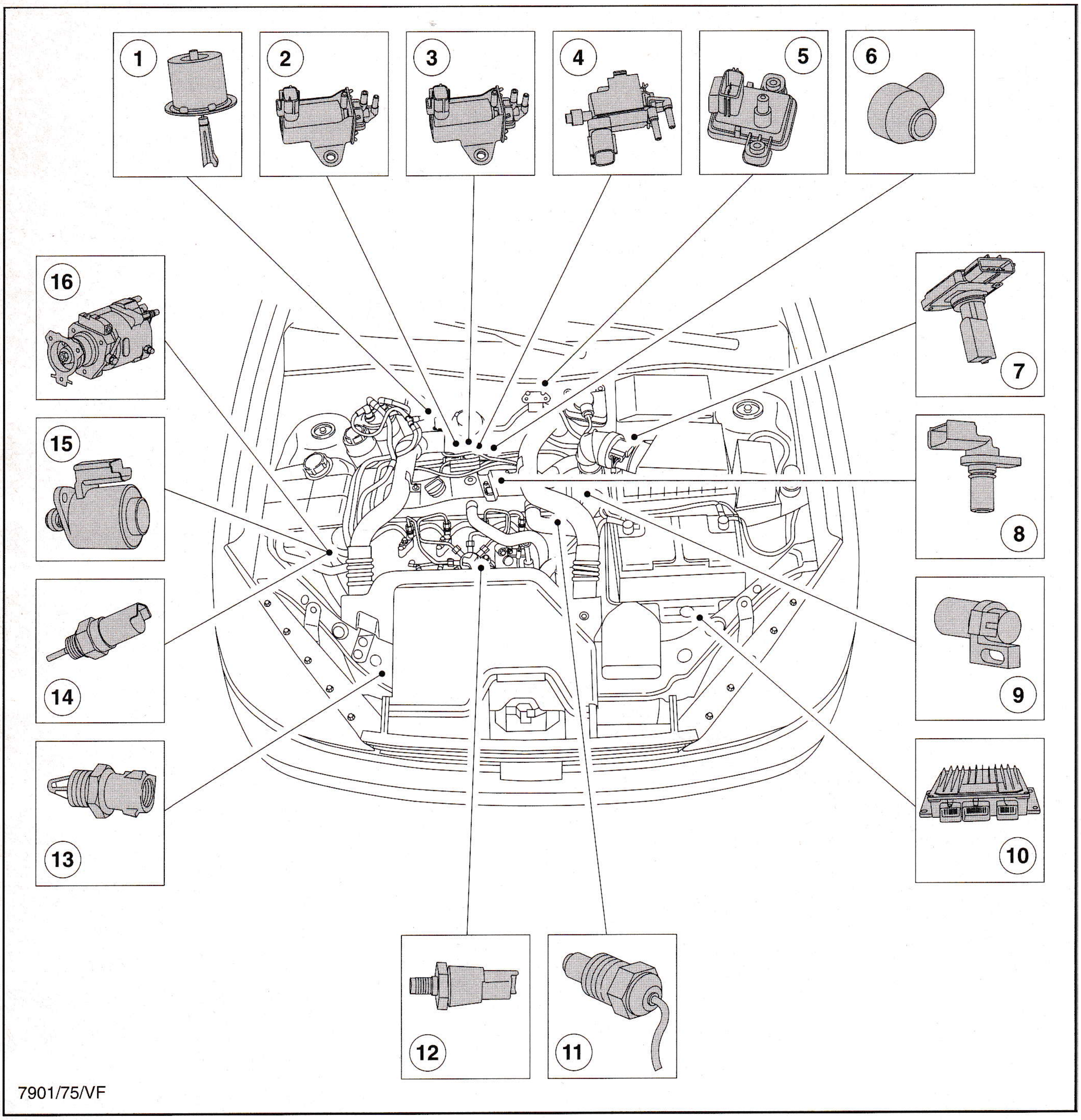
24 Fuel pressure sensor

25 Fuel temperature sensor

26 Knock sensor (KS)

27 Crankshaft position (CKP) sensor

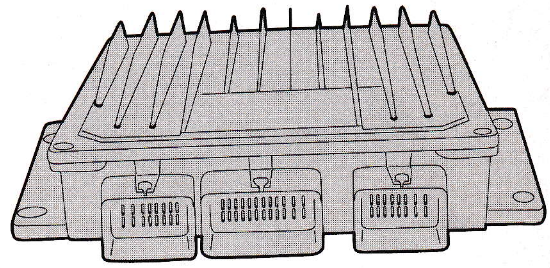
28 Injector driver module (IDM)



1 Vacuum diaphragm unit
2 Exhaust gas recirculation (EGR) solenoid valve
3 Boost pressure solenoid valve
4 Vaccum diaphragm unit solenoid valve
5 Manifold absolute pressure (MAP) sensor
6 Knock sensor (KS)
7 Mass air flow (MAF) sensor
8 Camshaft position (CMP) sensor
9 Crankshaft position (CKP) sensor
10 Injector driver module (IDM)
11 Cylinder head temperature (CHT) sensor
12 Fuel pressure sensor
13 Intake air temperature (IAT) sensor
14 Fuel temperature sensor
15 Fuel metering valve
16 High-pressure pump

Injector driver module (IDM)

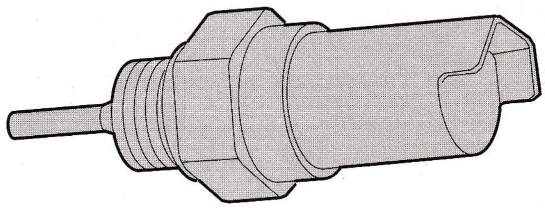
- The injector driver module is mounted under the battery tray and connected to the EEC V.
- The IDM processes and monitors the input signals from the following sensors:
  - KS
  - CKP sensor
  - CMP sensor
  - fuel temperature sensor
  - fuel pressure sensor
  - barometric pressure (BARO) sensor
- The IDM uses this information to calculate the position of the fuel metering valve, the system pressure and the fuel injection timing and the quantity of fuel injected during the pilot injection and main injection.
- A barometric pressure (BARO) sensor is integrated in the IDM to adjust the boost pressure and the quantity of fuel injected.
- The IDM can be checked with the WDS through the data link connector (DLC).



7901/23/VF

Fuel temperature sensor

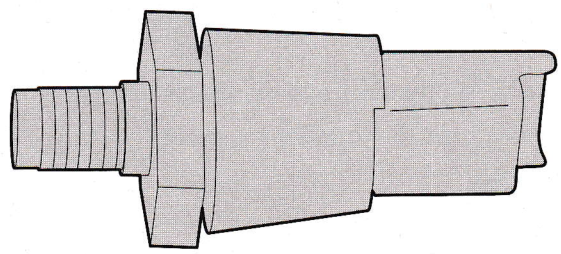
- The fuel temperature sensor is screwed into the inlet bore at the rear of the high-pressure pump.
- It measures the fuel temperature in the low-pressure system and transmits the signal to the injector driver module.
- The signal is taken into account when calculating the quantity of fuel to be injected.



7901/45/VF

Fuel pressure sensor

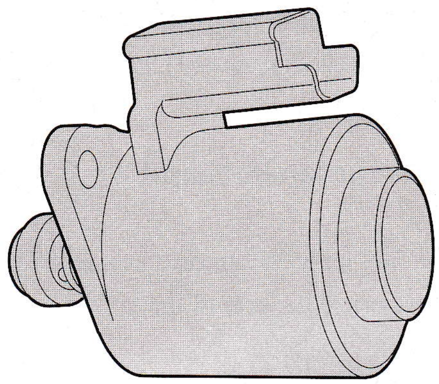
- The fuel pressure sensor is screwed into the fuel injection supply manifold.
- It measures the fuel pressure and transmits this information to the injector driver module. It is used to calculate the fuel injection timing and quantity of fuel injected.
- The fuel pressure sensor incorporates a diaphragm on which a sensor element is mounted.
- The electrical resistance of the layers on the diaphragm varies when their shape changes due to the action of the pressure.
- This change in the electrical resistance produces a change in voltage in the sensor element which is supplied with 5 V.



7901/33/VF

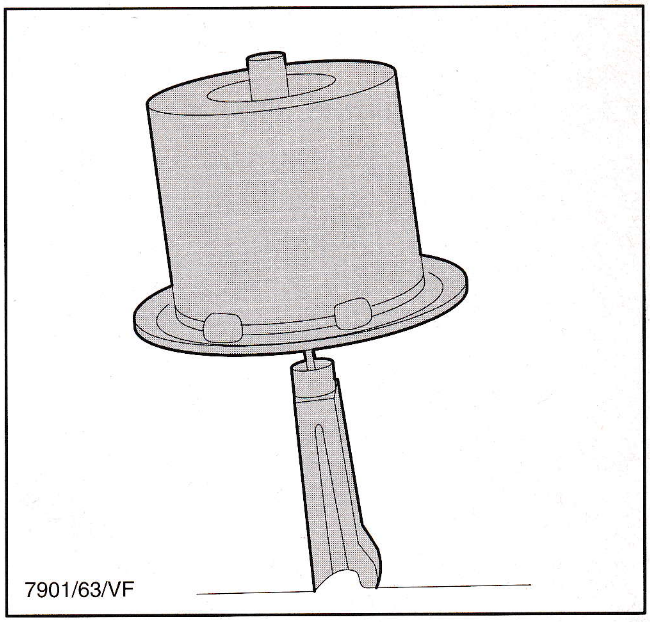
Fuel metering valve

- The fuel metering valve is mounted at the rear of the high-pressure pump and controls the quantity of fuel supplied to the high-pressure pump according to the fuel requirement.
- The fuel requirement is composed of the quantity of fuel to be injected, the leak-off fuel and the quantity of fuel required to control the nozzle needles.
- In this way the quantity of fuel returned to the tank can be minimized. This eliminates the need for a fuel cooler.
- The fuel metering valve is controlled by pulse width modulation and has a maximum current consumption of 1 A. When de-energized, it is opened.



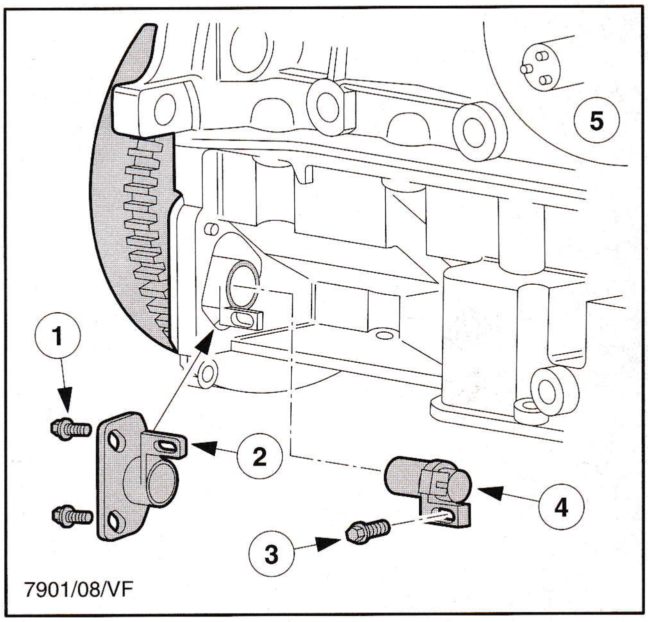
7901/46/VF

Vacuum diaphragm unit



- The 1.8L DuraTorq-TDCi-Engine is equipped with a vaccum diaphragm unit.
- The vaccum diaphragm unit consists of a vacuum box with a diaphragm which is connected to an actuating rod.
- The actuating rod is connected to the throttle plate.
- The vaccum diaphragm unit is supplied with vacuum by a solenoid valve as actuated by the EEC V.
- The function of the air shut-off throttle is to cut the supply of air by closing the throttle plate when the engine is switched off.
- This is a reliable means of stopping the vehicle shaking when the engine is switched off.

Crankshaft position (CKP) sensor

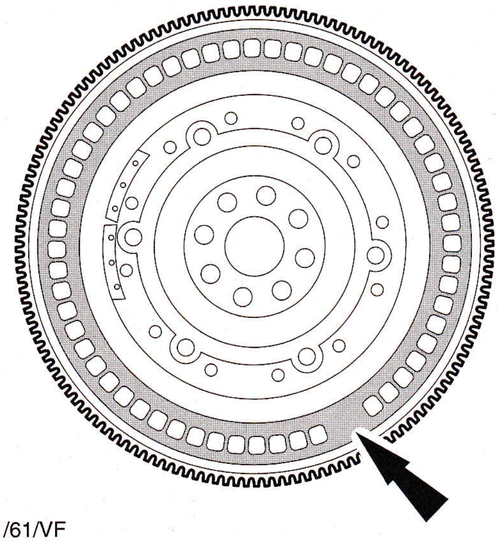


1 Retaining bolts
2 Sensor mounting plate
3 CKP sensor retaining bolt
4 CKP sensor
5 Frontview CKP sensor

- The sensor signal is processed in the IDM, e.g. EEC V.
- The sensor mounting plate and the CKP sensor itself have a slot.
- At the front the CKP sensor has three spacing brackets which break off when the engine is used for the first time.
- The need for the spacer used on the Endura-DI engine to set the gap has been eliminated.

Flywheel

- A flywheel with 60 minus 2 openings is used with the introduction of the common rail fuel injection system.
- This marking is located 90 degrees before top dead center for cylinder No. 3 and is used by the IDM or EEC V as a reference mark for the crankshaft position.



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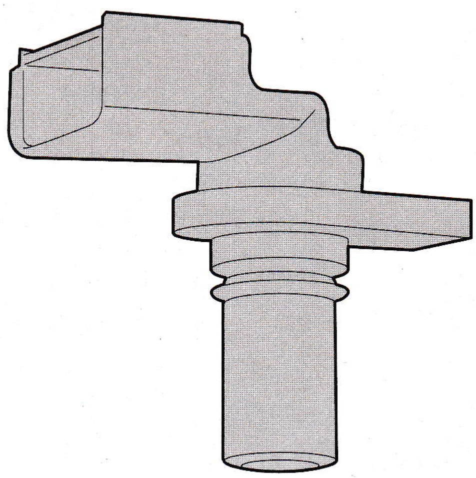
Camshaft position (CMP) sensor

- The CMP sensor signal is used together with the signal from the CKP sensor to identify cylinder No. 3 when starting the engine.
- The CMP sensor signal is processed in the IDM.
- If the signal does not reach the injector driver module, the power supply to the fuel injectors is cut so that the engine stops.



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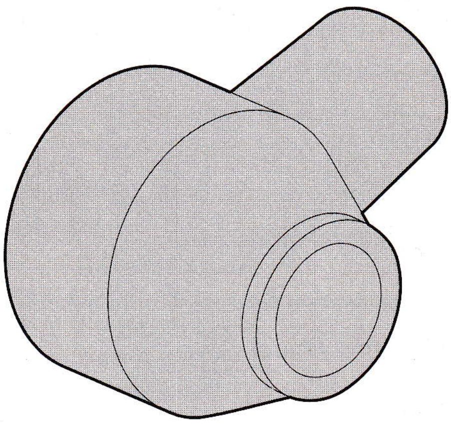
Knock sensor (KS)

- The knock sensor is mounted on the rear of the cylinder block level with cylinders No. 2 and 3.
- The piezo electric sensor detects vibrations of the cylinder block initiated by the combustion in the cylinder block.
- The signal is used by the injector driver module to determine the timing of the pilot injection.
- If the pilot injection is initiated at an unfavourable time, the vibrations are increased.
- The IDM adjusts the timing of the pilot injection until the signal matches the values stored in the IDM.



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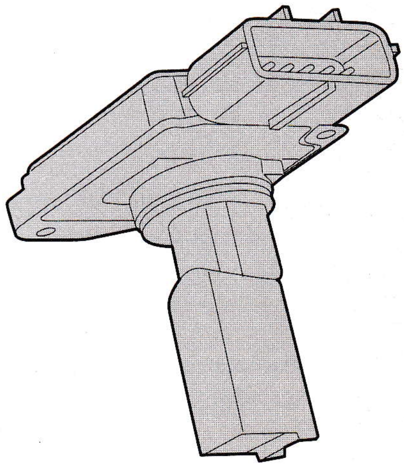
Mass air flow (MAF) sensor

- Location:
  in the air intake pipe behind the air cleaner.
- The MAF sensor works on the hot wire principle.
- This is used mainly to detect the engine load and to control the EGR system.



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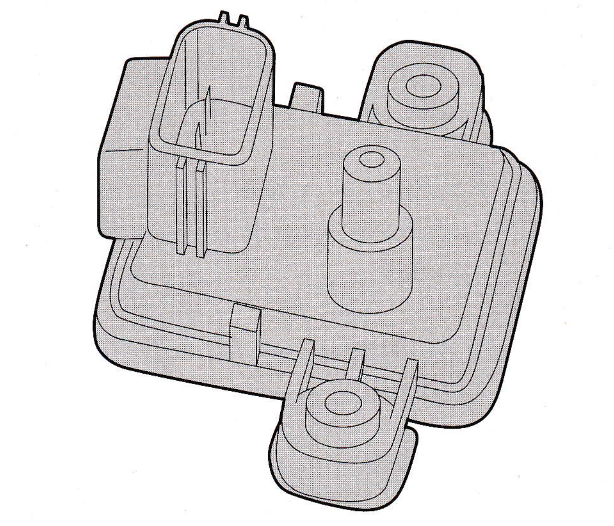
Manifold absolute pressure (MAP) sensor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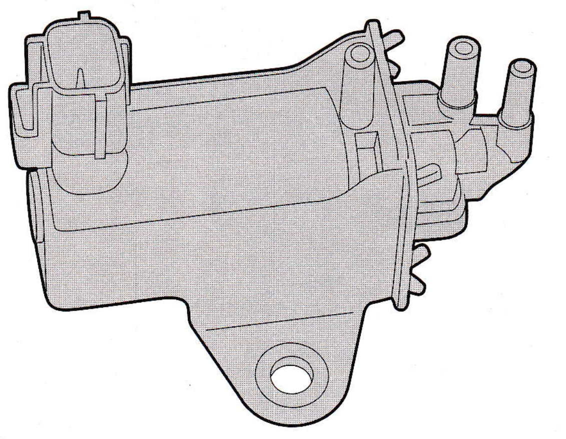
- The signal of the MAP sensor is used to control the boost pressure of the variable turbocharger.
- The signal is sent to the EEC V and is used to control the boost pressure of the variable turbocharger.
- The boost pressure adjustment is achieved by the boost pressure solenoid valve.
- This allows the boost pressure to be adjusted to the operating state of the engine by adjusting the vanes of the turbocharger.

Boost pressure solenoid valve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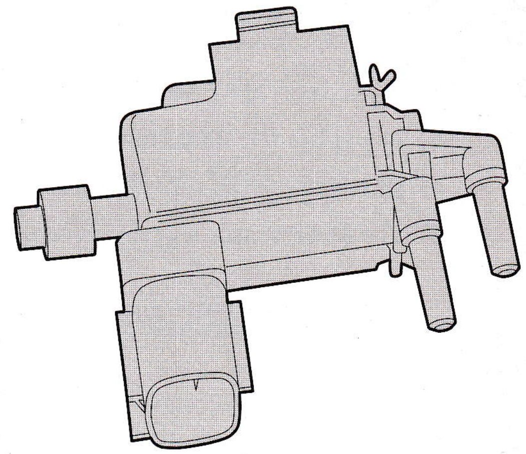
- The boost pressure solenoid valve is located with the vacuum diaphragm unit solenoid valve and the EGR solenoid valve on a bracket on the intake manifold.
- The boost pressure solenoid valve controls the position of the vacuum diaphragm unit according to the instructions from the EEC V.
- This makes it possible to set the optimum boost pressure for the particular engine operating state by means of the adjustable vanes of the turbocharger.

Vacuum diaphragm unit solenoid valve

- The vacuum diaphragm unit solenoid valve controls the vaccum diaphragm unit by means of a control vacuum, again in accordance with commands from the EEC V.



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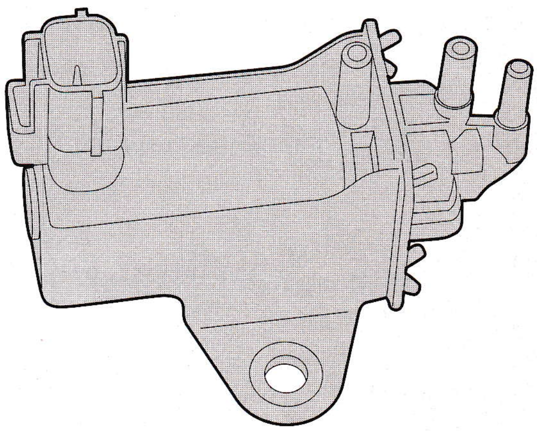
EGR solenoid valve

- A more compact EGR solenoid valve has been introduced for the 1.8L DuraTorq-TDCi-Engine.
- The technical specifications match those of the EGR valve used on the 1.8L Endura-DI engine.
- The pulsed signals from the EEC V are used to the control the EGR solenoid valve.



7901/68/VF

Find the correct answer.

1. Which statement about the manifold absolute pressure (MAP) sensor is correct?

- ☐ a) There is no MAP sensor on the 1.8L DuraTorq-TDCi-Engine.
- ☐ b) It supplies the signal to control the variable turbocharger.
- ☐ c) Its signal is used for calculation in the event of failure of the MAF sensor.
- ☐ d) The MAP sensor signal is processed in the IDM.

2. What happens if the camshaft position (CMP) sensor fails?

- ☐ a) The fuel pressure sensor opens the fuel return.
- ☐ b) The vehicle begins to buck.
- ☐ c) The engine stops.
- ☐ d) The CKP sensor signal is used as a substitute value.

3. Which statement about the knock sensor (KS) is correct?

- ☐ a) The timing of the pilot injection is adjusted by the signal of the KS.
- ☐ b) The signal is used to control the IDM.
- ☐ c) The engine is switched off if it should overheat.
- ☐ d) The timing of the main injection is regulated with the signal.

The abbreviations conform to standard SAE J1930 with the exception of those marked with an asterisk *.

APP*	**A**ccelerator **P**edal **P**osition
BARO	**Baro**metric Pressure
BPP*	**B**rake **P**edal **P**osition
CHT*	**C**ylinder **H**ead **T**emperature
CKP	**C**ran**k**shaft **P**osition
CMP	**C**a**m**shaft **P**osition
CPP	**C**lutch **P**edal **P**osition
DLC	**D**ata **L**ink **C**onnector
EEC V*	**E**lectronic **E**ngine **C**ontrol 5th generation
EGR	**E**xhaust **G**as **R**ecirculation
IAT	**I**ntake **A**ir **T**emperature
IDM*	**I**njector **D**river **M**odule
KS	**K**nock **S**ensor
MAF	**M**ass **A**ir **F**low
MAP	**M**anifold **A**bsolute **P**ressure
PATS*	**P**assive **A**nti-**T**heft **S**ystem
PCM	**P**owertrain **C**ontrol **M**odule
WDS*	**W**orld wide **D**iagnostic **S**ystem

Lesson 1 – Introduction

1. b)

2. a)

3. b)

Lesson 2 – Engine mechanical systems

1. c)

2. d)

3. b)

Lesson 3 – Common rail fuel injection system

1. d)

2. d)

3. d)

4. a)

5. b)

Lesson 4 – Engine management

1. b)

2. c)

3. a)