Service Training

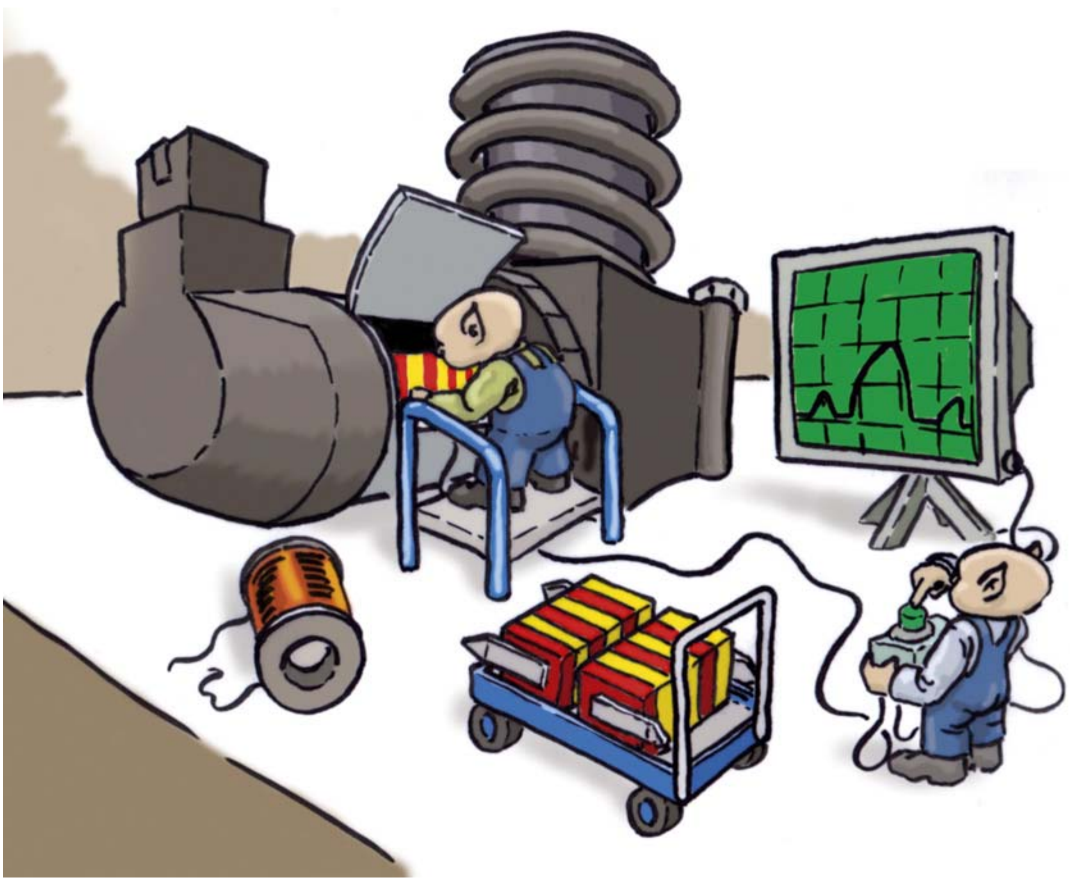
Self-study Programme 352

Unit Injectors with Piezo Valves

Design and Function

Low consumption and excellent performance have made the rise of the diesel engine unstoppable. Nevertheless the targets for diesel engines in terms of emissions, driving comfort and engine performance are also being raised constantly. Customer satisfaction, environmental protection and the fulfilment of legal requirements are always at the forefront and can only be achieved through continued development.

The introduction and ongoing development of unit injectors has created considerable competitive advantages in the areas of injection pressure, injection precision and efficiency. In collaboration with Siemens VDO Automotive AG, we have developed a unit injector with the same or even greater advantages. It also allows new flexibility in the configuration of the pilot, main and secondary injection phases.
Improved mixture, higher efficiency and lower noise emissions are the innovative results.



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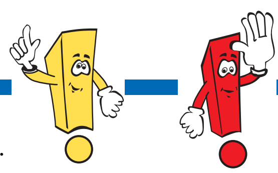

The self-study programme shows the design and function of new developments.
The contents will not be updated.

For current testing, adjustment and repair instructions, refer to the relevant service literature.

Contents

Introduction **4**
General Information 4
Improvements 5

Design **8**
Overview 8
The Piezo Valve 9
Nozzle Spring Chamber 11

Injection Process **13**
Pilot Injection Phase 13
Main Injection Phase 16
Secondary Injection Phase 18

Service **20**

Test Yourself **23**

Introduction

General Information

The unit injector with piezo valve (version: PPD 1.1) is a further development of the solenoid-type unit injector. As the name says, the solenoid valve has been replaced by a faster and more controllable piezo
valve. Furthermore the mechanical control of the varying injection pressures within the unit injector has been improved so that there is no need for a retraction piston. It has therefore been possible to reduce the high-pressure volume in favour of efficiency.

This new type uses the same fitting as the unit injector with solenoid valve (PDE-P2) and is also secured with 2 screws to avoid additional engine assembly costs. In future, the new unit injectors will be used in the new 2.0l-125kW 4V TDI engine and later in other 4-valve TDI engines.

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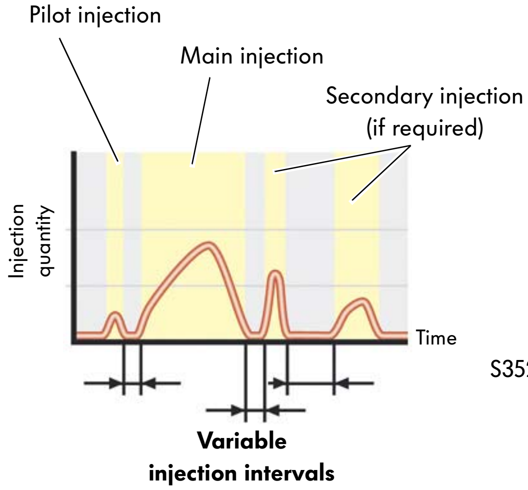
Volkswagen Mechatronic GmbH & Co. KG has been founded for production of the unit injector with piezo valve in collaboration with Siemens VDO Automotive AG. The new production site is located in Stollberg in Saxony.

200 employees are currently working on the production of the new unit injector.

Improvements



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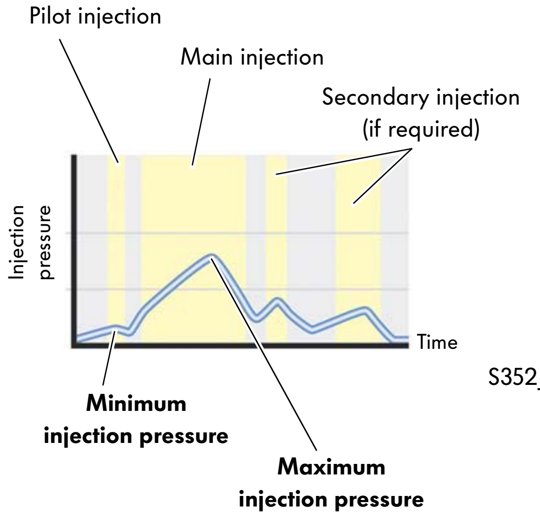

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Control of the injection phases

As the new piezo valve switches approximately four times faster than the previous solenoid valve, it is now possible to close the switching valve and open it again for each injection phase. This allows more precise control of the injection phases and flexible control of the injection quantities.

Injection pressure

Each injection phase has different requirements in terms of injection pressure. For example, the pilot injection phase requires a lower injection pressure and the main injection phase a very high injection pressure. The extended injection pressure range (130-2200 bar) has allowed a further change in this area. As a result, the emission levels are improved and greater performance is possible.

Noise emissions

The typical noise emissions occur when TDI engines are idling above all due to the noise generated by the unit injectors, not due to the combustion. These noises are caused by rapid, large-scale pressure changes within the unit injector that are transmitted to the engine via the unit injector drive.

The pressure changes can now be influenced with the aid of the faster and more precise piezo valve to reduce the noise.
The piezo valve can be controlled so precisely that the pressure build-up and pressure reduction of the individual injection phases can be influenced.

The mechanical noises transferred by the drive are reduced by the smaller pump plunger diameter. The power required to drive the unit injector is therefore also lower.

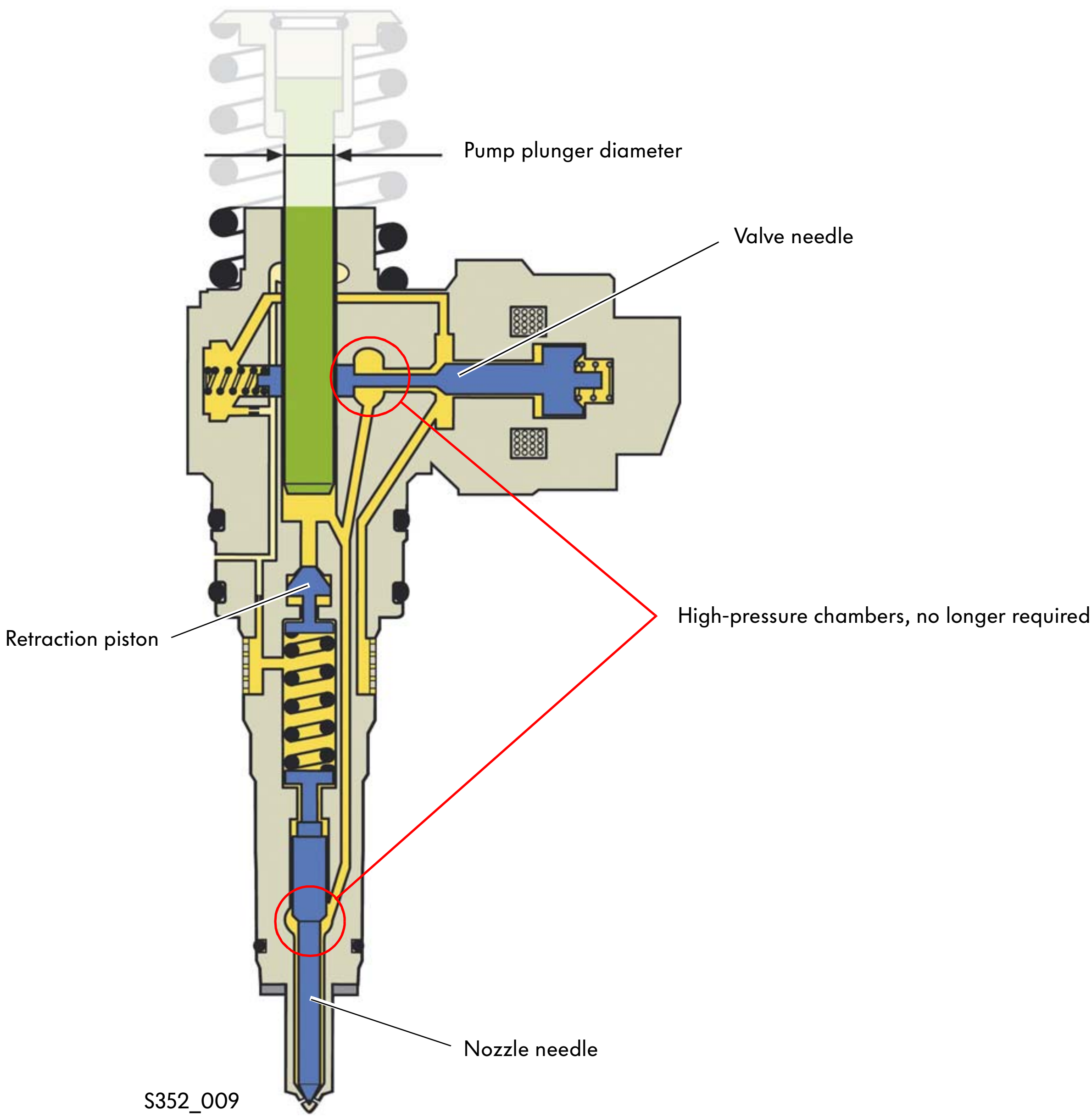
Introduction

Efficiency

In this case, higher efficiency means lower driving power and also lower fuel consumption.
The higher degree of efficiency has been achieved by saving on the high-pressure chambers and the retraction piston.

This reduces the high-pressure volume and therefore a pump plunger diameter of just 6.35mm is required to generate the required injection quantities.

Unit injector with solenoid valve



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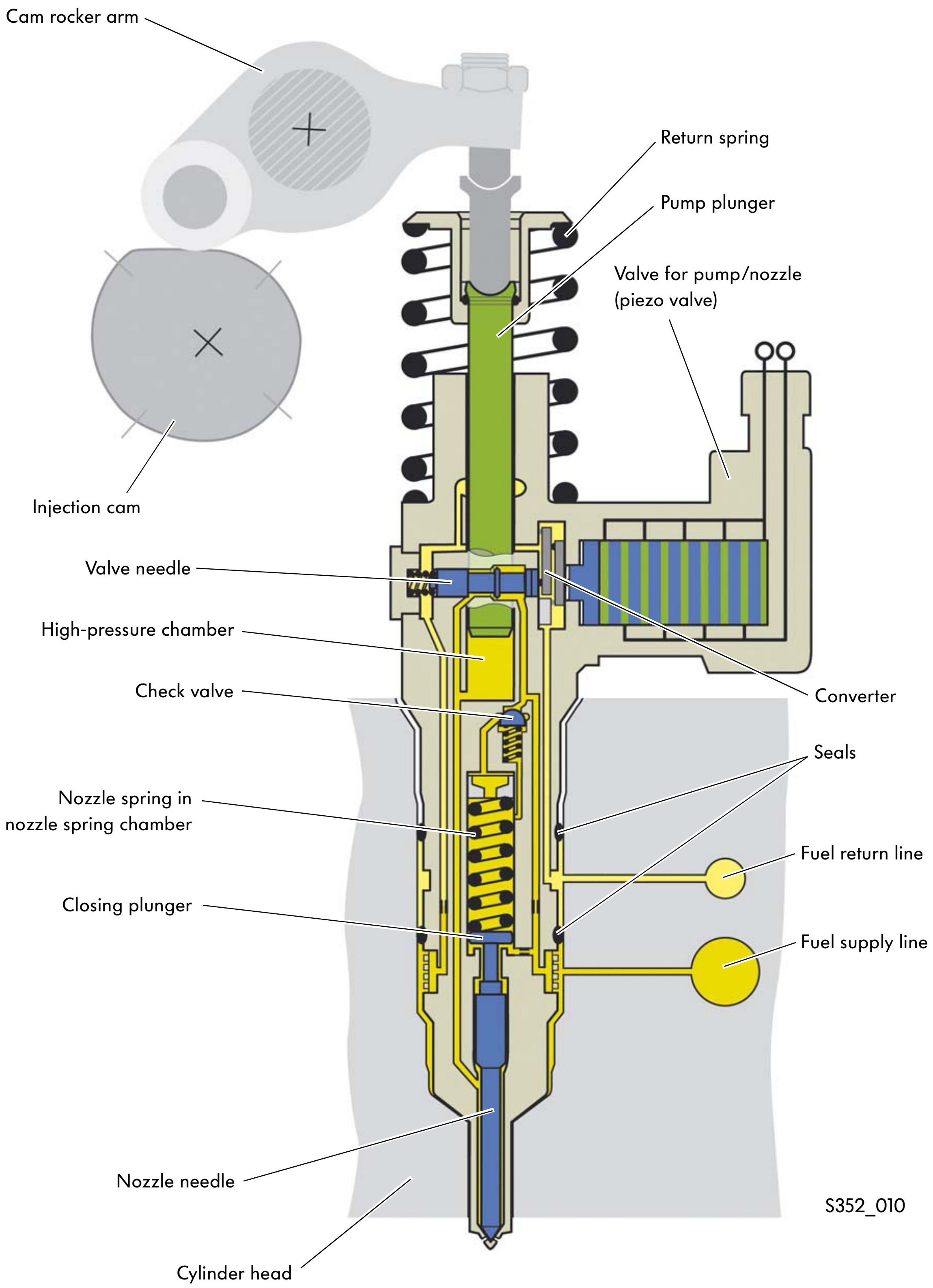
Technical data at a glance

	Unit injector with piezo valve (PPD 1.1)	Unit injector with solenoid valve (PDE-P2)
Pump plunger diameter [mm]	6.35	8.0
Minimum injection pressure [bar]	130	160
Maximum injection pressure [bar]	2200	2050
Possible number of pilot injections	0-2 (variable)	1 (fixed)
Possible number of secondary injections	0-2 (variable)	0 or 2
Distance between pilot, main and secondary injection [° crank angle]	> 6 (variable)	approx. 6-10 (fixed)
Pilot-injection quantity [mm^3]	Any (> approx. 0.5)	approx. 1-3
Control of pilot injection	Piezo valve (electronic)	Retraction piston (mechanical/hydraulic)
Pressure raise for main injection	Closing plunger, check valve	Retraction piston

Design

Overview



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Piezo Valve

The most important new feature on the new unit injector is the piezo valve that replaces the previously used solenoid valve. The piezo valve has higher switching rates and its actuator travel can be controlled via the voltage supply. It comprises a piezo actuator with housing and connector, the converter and valve needle in the pump barrel.

Piezo actuator

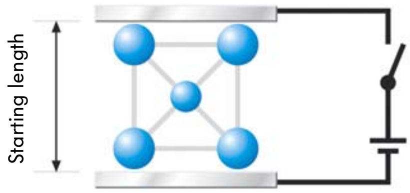
Piezo (Greek) = pressure

A well-known application area for piezo elements is sensors. Pressure is applied to a piezo element and a measurable voltage is generated. This behaviour of a crystal structure is called a piezo-electrical effect.

When a piezo actuator is used, this effect is reversed. The inverse piezo-electrical effect is used.
That means a voltage is applied to the piezo element and the crystal structure of the piezo element reacts by changing in length.

Inverse piezo-electrical effect
(simplified crystal structure of a piezo element)

Piezo element without voltage U



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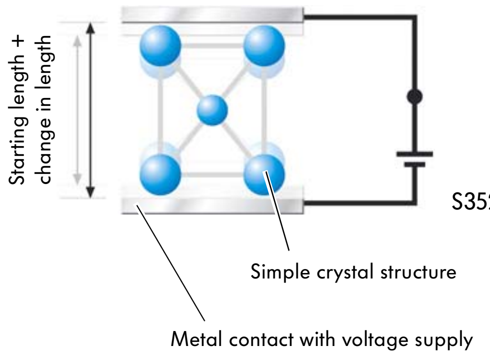
Piezo element with voltage U



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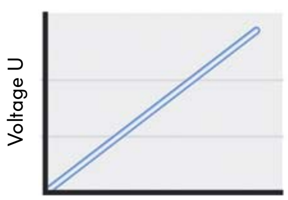
Change in length of a piezo element



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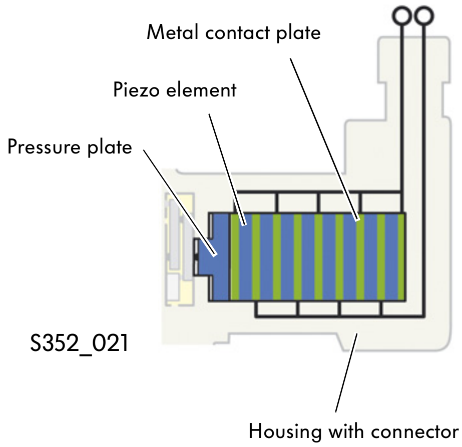
The change in length of a piezo element is proportional to the voltage applied. That means that the change in length of a piezo element, or the piezo actuator, can be controlled with the voltage.
The control voltage of the piezo actuator is between 100V and 200V.

Design

A piezo element is approx. 0.08 mm thick and the change when the voltage is applied is only 0.15 %.
To achieve a maximum actuator travel of approx. 0.04 mm, several piezo elements need to be stacked. In this piezo stack, the individual piezo elements are separated by metal contact plates (voltage supply).

The piezo stack forms the piezo actuator together with the pressure plate.

Piezo actuator (schematics)



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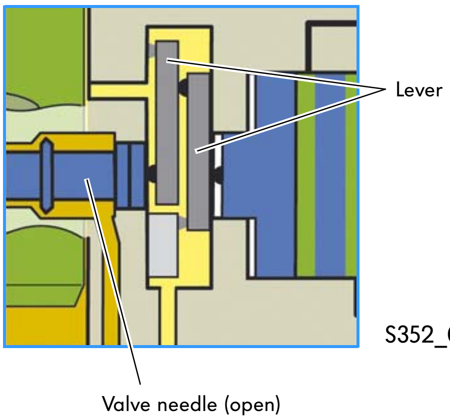
Converter

The piezo actuator has an actuator travel of approx. 0.04 mm. The valve needle requires an actuator travel of approx. 0.1 mm. To balance out this difference, a converter in the form of a lever is used.

If the piezo actuator is not activated, the converter will be in the rest position. The valve needle is opened by the valve needle spring.

Converter in rest position



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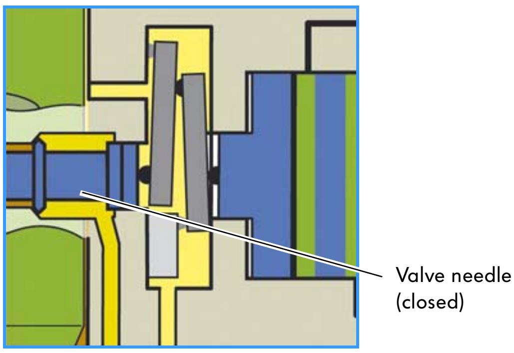
If the piezo actuator is activated, the pressure plate will press against the converter. The actuator travel is extended to approx. 0.1 mm due to the ratio of the lever assembly.
The valve needle is closed and the injection pressure is built up.

Converter operated



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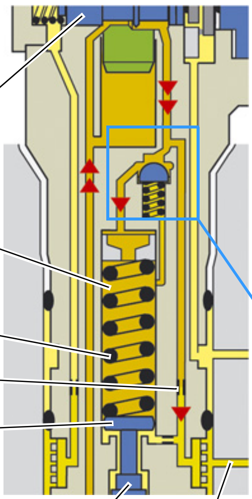
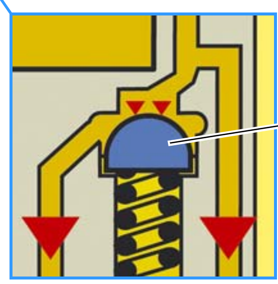
Nozzle Spring Chamber

The nozzle spring chamber contains the nozzle spring that is responsible for closing the nozzle needle and also prevents early opening when an injection phase begins. The requirements for the nozzle spring force (nozzle needle closing force) are very different, however. For example, the nozzle needle needs to open even with a low fuel pressure for a pilot injection while it can only open at a high fuel pressure during the main injection phase. In addition, the nozzle needle should close very quickly after an injection phase. To meet the requirements for nozzle spring force, the nozzle spring needs to be supported for the main injection and for closing of the nozzle needle by high fuel pressure in the nozzle spring chamber. This support is provided by the check valve and the closing plunger.



Check valve

At the end of each injection phase, the nozzle spring chamber is filled with high-pressure fuel. The pressure is released via the valve needle back into the fuel supply line and is then held by the supply throttle.
The check valve is opened by the high pressure of the fuel thus opening the path to the nozzle spring chamber.

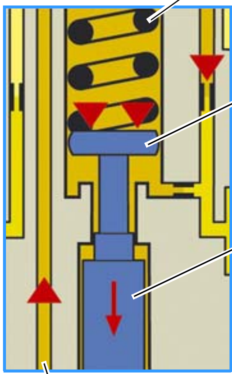


The fuel pressure is reduced in the fuel supply line.
The check valve closes as the fuel pressure falls.
The pressure that is built up is thus held in the nozzle spring chamber.

Closing plunger

Close nozzle needle

When an injection phase is completed, the nozzle spring chamber is filled with high-pressure fuel. This high-pressure fuel pushes against the closing plunger helping the nozzle spring to close the nozzle needle. Closing the nozzle needle fast has a positive effect on the exhaust emissions and means the retraction piston used in the solenoid-type unit injectors is not required.



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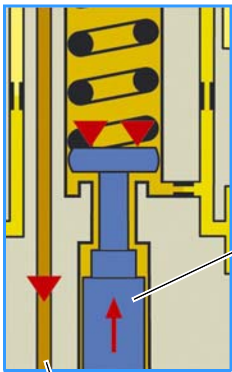
Open nozzle needle

The fuel pressure held back in the nozzle spring chamber after completion of the injection phase has an effect on the next injection phase.
The high fuel pressure also supports the nozzle spring and thus prevents the nozzle needle opening too early.
The injection phase starts with a high injection pressure.
This high injection pressure is particularly important for combustion and the development of exhaust emissions in the main injection phase.



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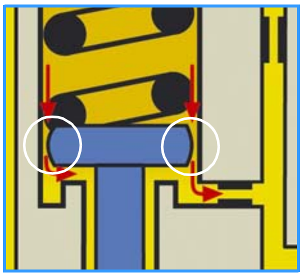
Pressure reduction

The pilot injection phase needs a low injection pressure, however. Therefore, after an injection cycle (pilot, main and secondary injection phases), it is important that the fuel pressure can be reduced in the nozzle spring chamber. This is achieved with a leakage gap on the closing plunger. The fuel pressure is reduced between the injection cycles, the nozzle spring is no longer supported and the pilot injection phase can begin at a low injection pressure.

Leakage gap on closing plunger



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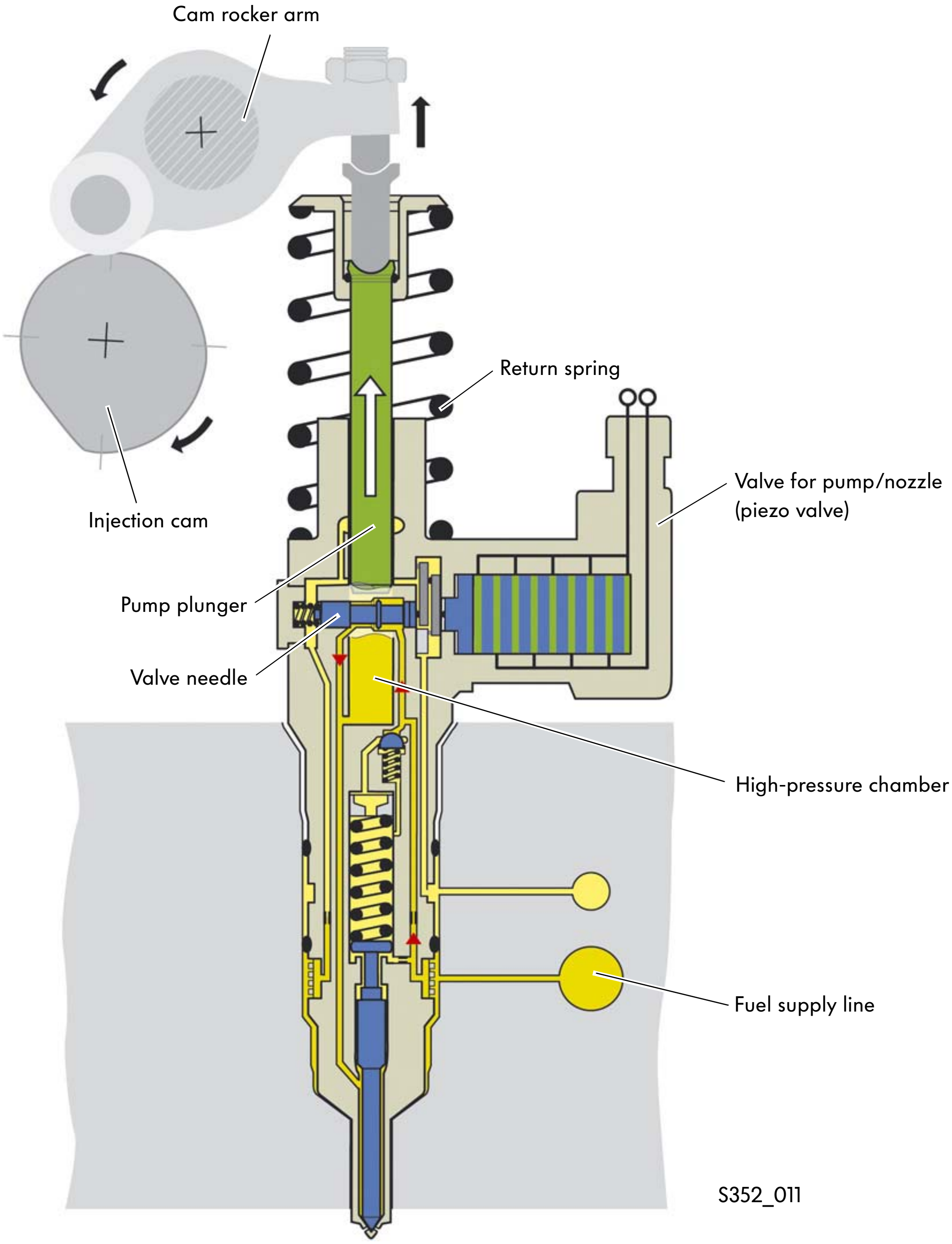
Pilot Injection Phase

Fill high-pressure chamber

The injection cam movement and the subsequent upwards movement of the cam rocker arm allow the return spring to push the pump plunger upwards. The special shape of the injection cam causes a slow upwards movement.
The high-pressure chamber is enlarged.

The piezo valve is not actuated and the valve needle is therefore open. The high-pressure chamber is filled via the fuel supply line.



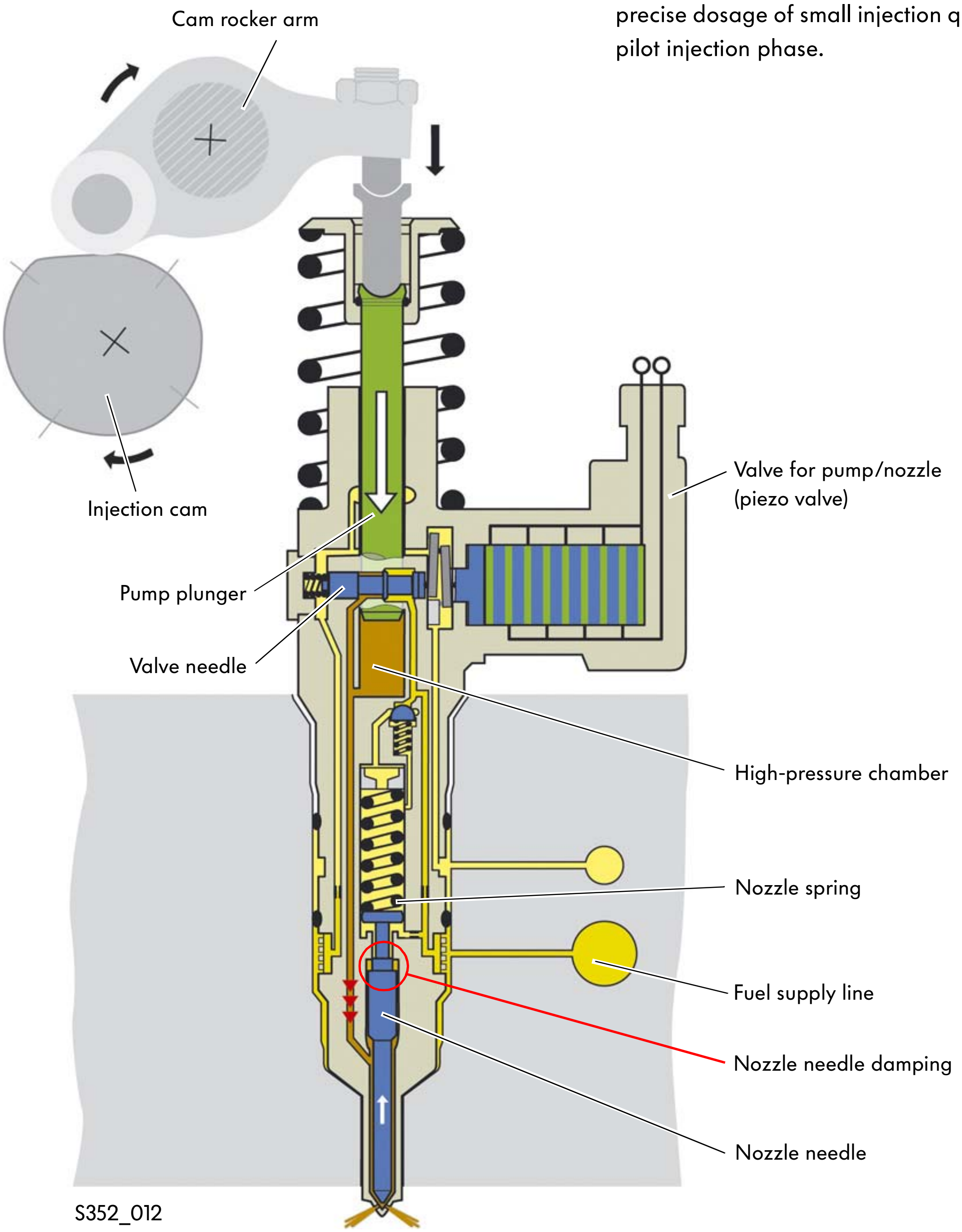
Injection Process

Pilot injection starts

The injection cam presses the pump plunger downwards at high speed via the cam roller arm.
 The fuel is pushed back into the fuel supply line until the piezo valve is actuated and thus closed. Once the piezo valve has been closed, the fuel is compressed and the pressure build-up begins. From 130 bar, the fuel pressure on the nozzle needle is greater than the nozzle spring force.

The nozzle needle is raised and the pilot injection phase begins.

The nozzle needle damping works in exactly the same way as in the unit injector with solenoid valve.
The nozzle needle displacement is limited by a hydraulic cushion between the nozzle needle and nozzle barrel during the pilot injection phase. This limited opening stroke of the nozzle needle allows precise dosage of small injection quantities during the pilot injection phase.



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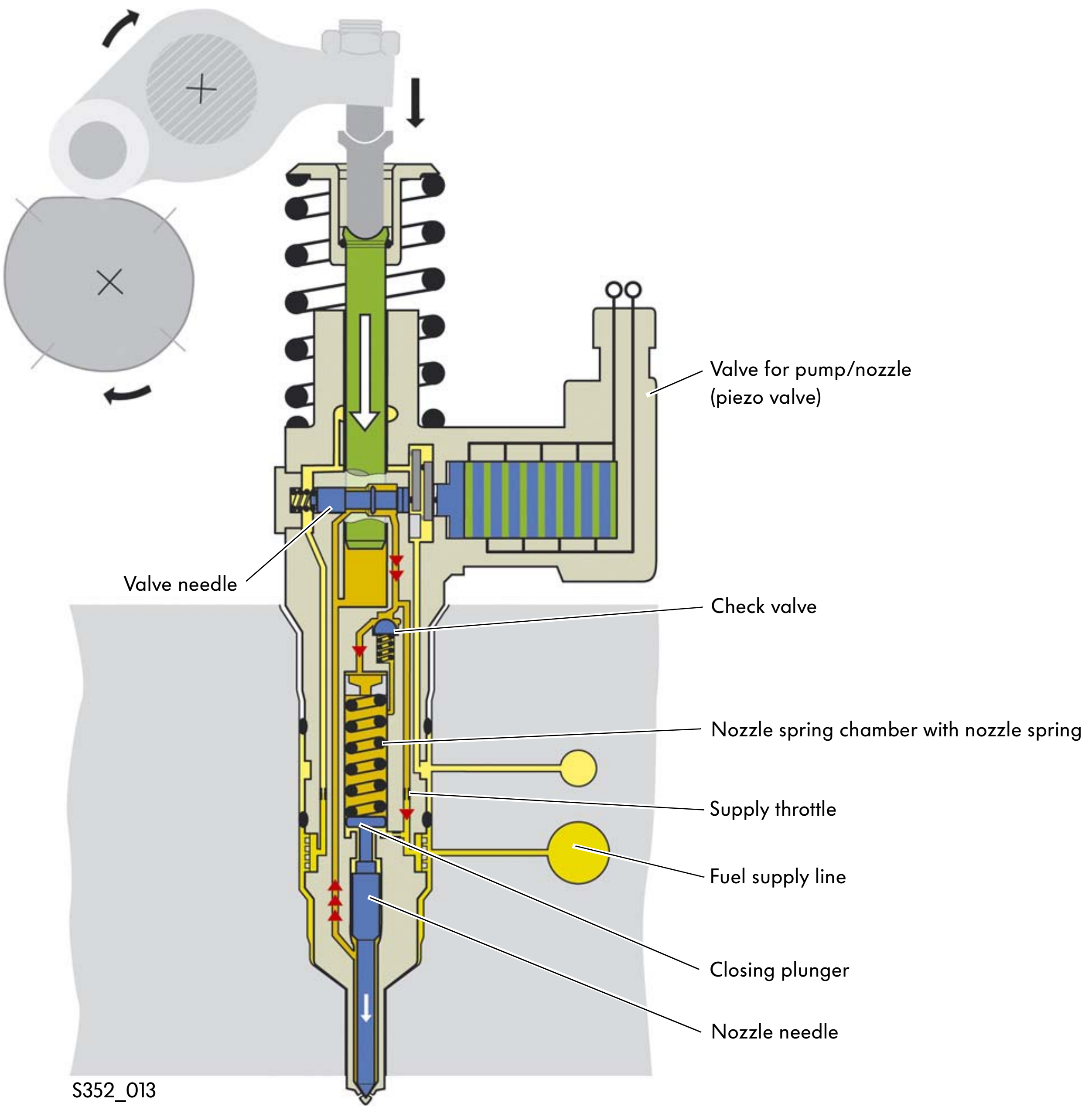
Pilot injection phase ends

The pilot injection phase ends with the piezo valve opening the valve needle. The fuel pressure is reduced in the fuel supply line and the nozzle needle is closed by the nozzle spring.
The nozzle spring is supported by the decreasing fuel pressure that is held back by the supply throttle and reaches the nozzle spring chamber via the open check valve.

The high-pressure fuel pushes the closing plunger and thus speeds up the closing of the nozzle needle.

Depending on the engine operating mode, the engine control unit can trigger one or two pilot injection phases per injection cycle.

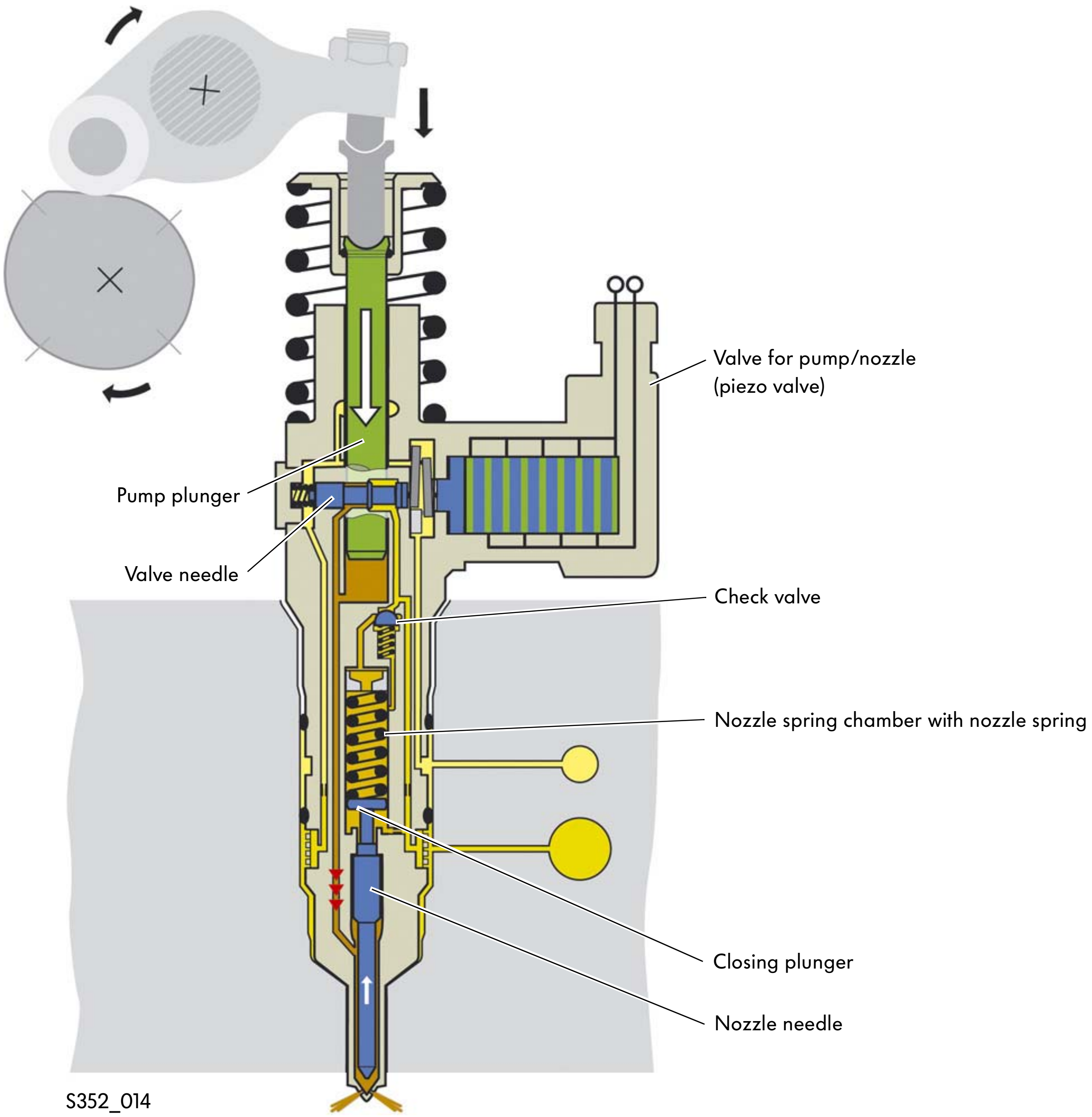


Main Injection Phase

Main injection phase begins

The pump plunger is still being moved downwards. Once the valve needle has been closed, the fuel pressure is built up again and the main injection phase can begin. To ensure that the nozzle needle only opens at a higher pressure, the nozzle spring is supported by the fuel pressure in the nozzle chamber. The high fuel pressure that was built up after the pilot injection is maintained by the check valve in the nozzle chamber closing and presses against the closing plunger.

The injection pressure rises to up to 2,200 bar during maximum engine output.



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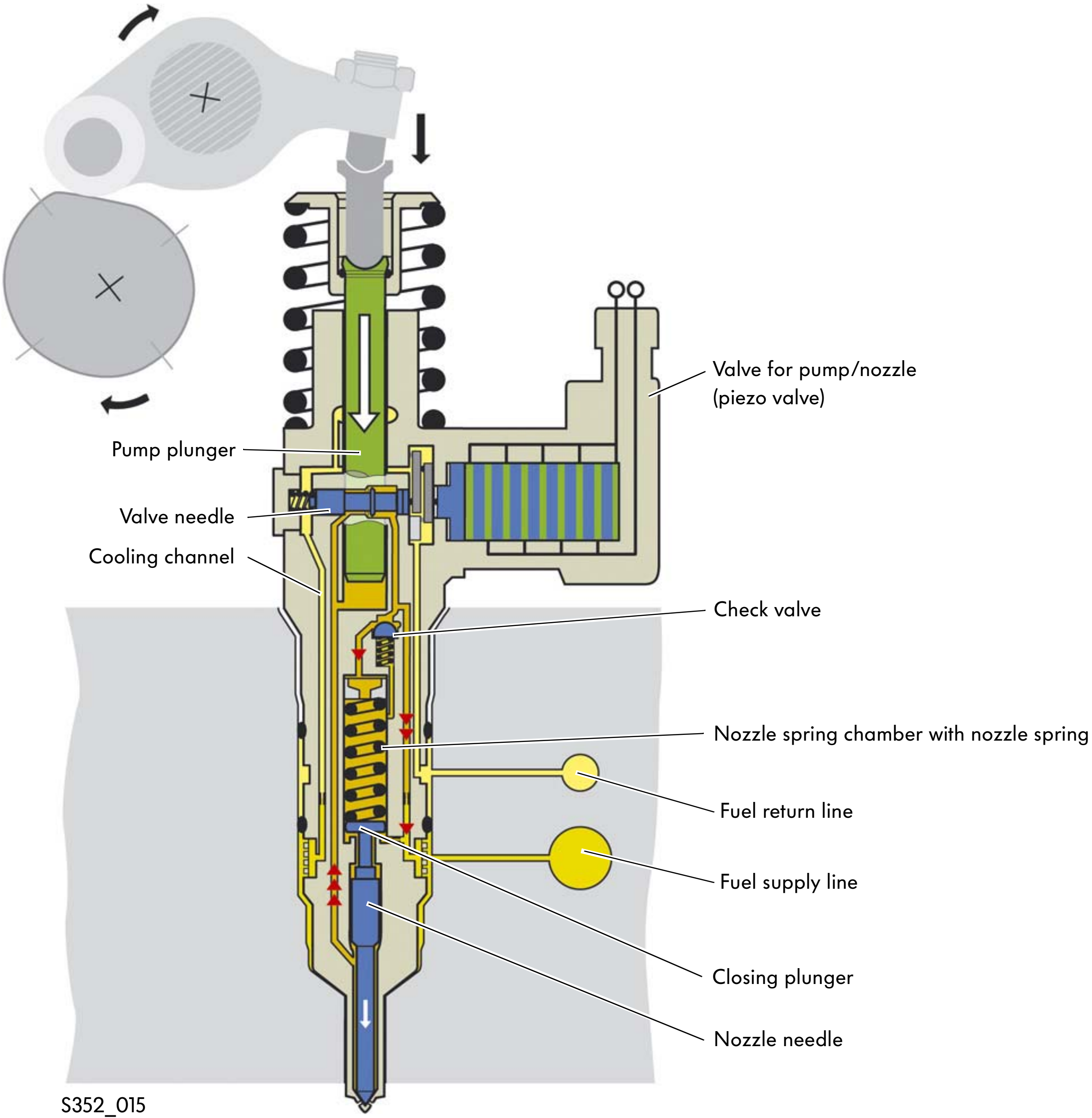
End of main injection phase

The main injection phase ends when the valve needle is opened. The high fuel pressure is reduced in the fuel supply line and nozzle spring chamber.
The nozzle needle is closed by the nozzle spring and closing plunger.

It is cooled in the same way as the unit injector with solenoid valve. The fuel is throttled as it flows through the injector into the fuel return line and also allows the fuel that leaked into the pump barrel to flow out.



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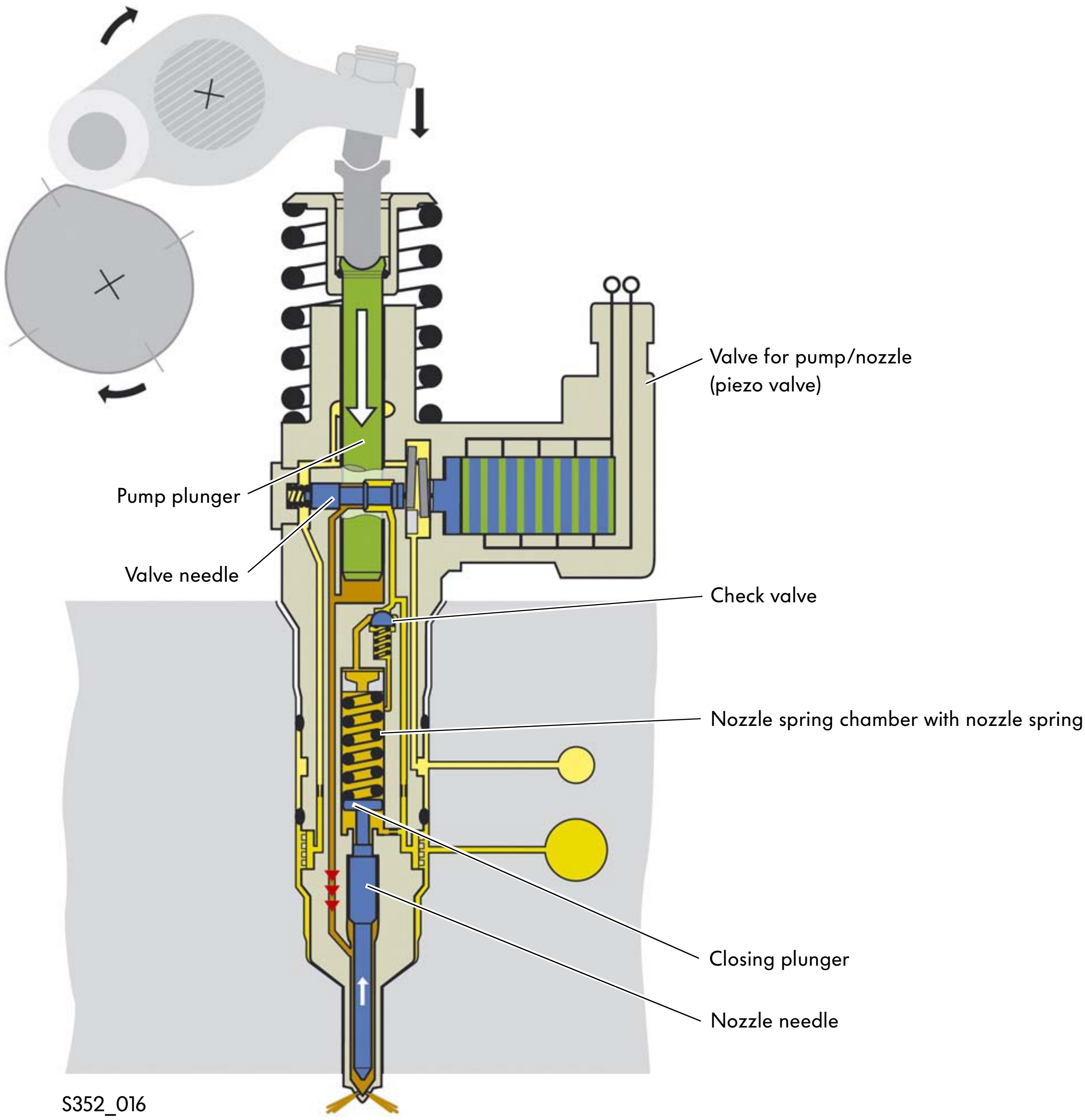
Secondary Injection Phase

Secondary injection phase starts

The secondary injection process will be explained using a secondary injection phase. In practice, at least two secondary injections are triggered that are identical in principle.
Secondary fuel injections are only triggered when they are required to regenerate a diesel particulate filter.

The pump plunger continues to move downwards and the secondary injection phase begins once the valve needle closes and the nozzle opening pressure is reached.
The secondary injection phase works like the main injection phase. The only difference is that the injected quantity may be lower as the injection duration is shorter.

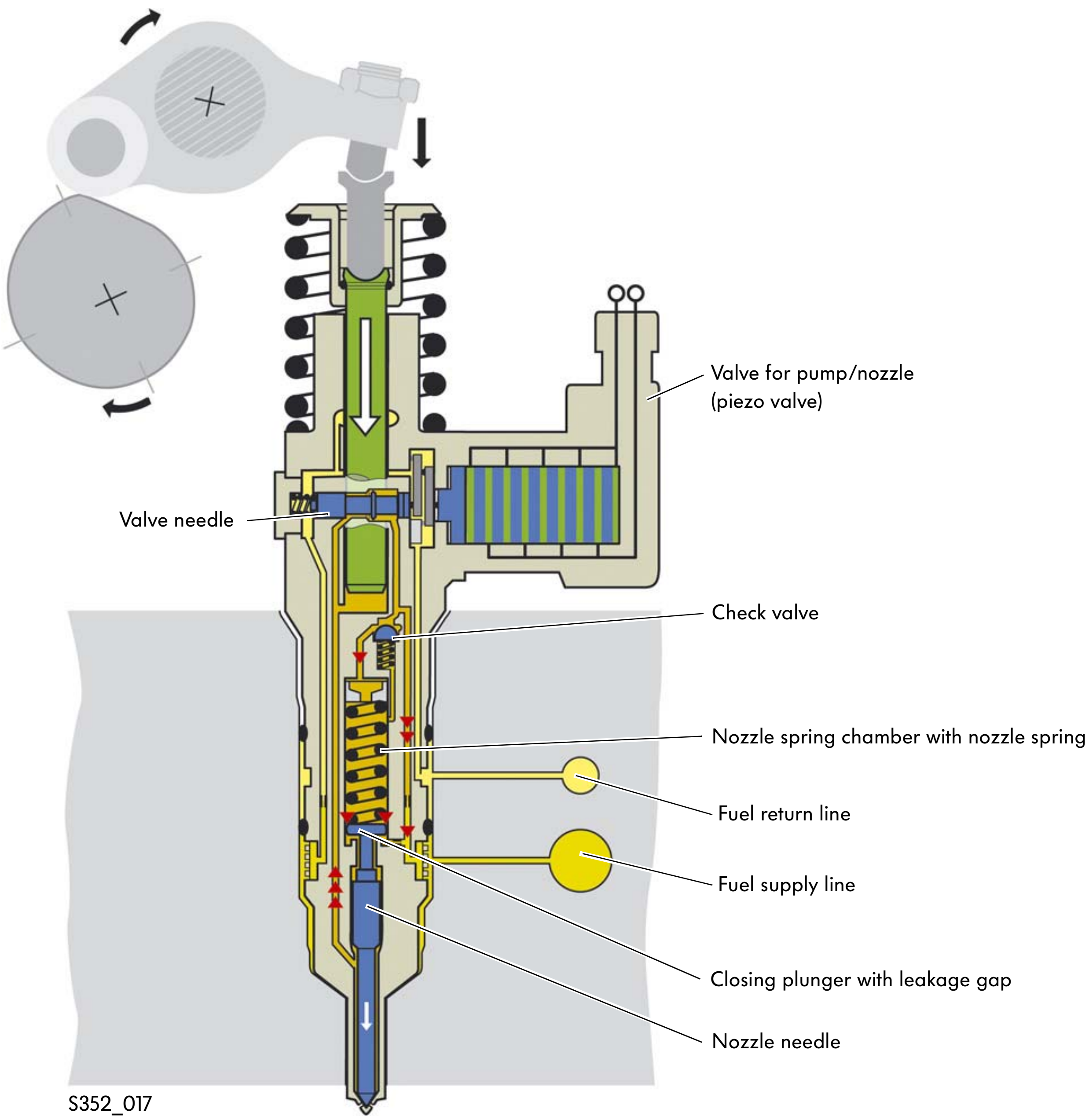


Secondary injection phase ends

The secondary injection phase ends when the valve needle opens. The high pressure of the fuel is reduced and the nozzle needle closes.

At this point, high fuel pressure is built up again in the nozzle spring chamber as the check valve is open.
To ensure that the next injection can be carried out again at a low fuel pressure, the high-pressure fuel needs to escape from the nozzle spring chamber.

The time between the individual injection cycles is sufficient to allow the fuel to flow away into the fuel supply line via a leakage gap on the closing plunger.



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Diagnosis

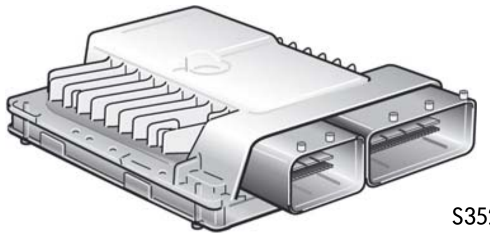
Monitoring the unit injector valve (piezo valve)

A new engine control unit called Simos PPD 1 is being introduced together with the new unit injector with piezo valve.
The Simos PPD 1 diagnostics work in a similar way to the Motronic with the solenoid-type unit injector.

The actual closing time of the valve needle is measured by means of a turn in the voltage curve (BIP = Beginning of Injection Period).
This voltage change is created by the valve needle hitting the valve seat and the resulting force counteracting the piezo actuator movement.

A test pulse is triggered for all 5 injection phases between the injection cycles to close the valve needle without interfering influences (e.g. high fuel pressure).

Simos PPD 1



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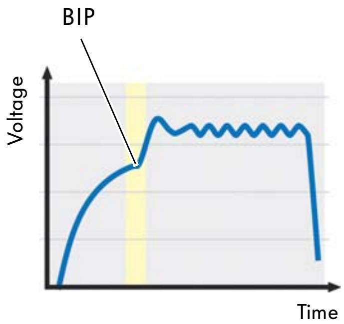
Piezo valve voltage curve



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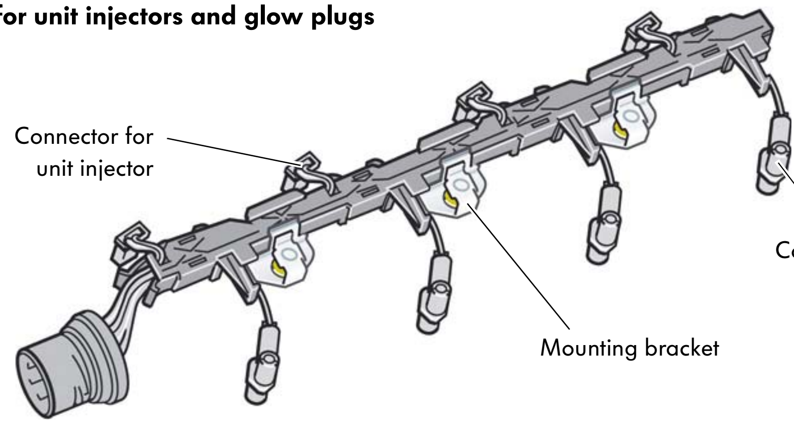
Exceeding or falling below the control limit

If the BIP is not within a specific control limit, a fault entry will be written to the fault memory. Depending on the type of fault found, the unit injector involved will be triggered or switched off. If it is switched off, this will prevent further damage to the unit injector and the engine.

Removal and installation

Wiring harness for unit injectors and glow plugs



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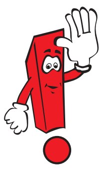
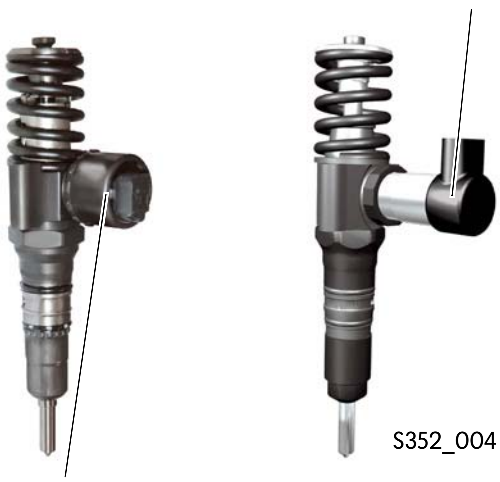


When you remove the wiring harness for the unit injectors and glow plugs, the wiring duct may not be separated from the mounting brackets. Bending back the mounting brackets and removing the wiring duct may break wires.
ELSA provides detailed information on the procedure.

Size and screw mounting

The unit injector with solenoid valve (PDE-P2/ 2 mounting screws) and the unit injector with piezo valve are the same size and have the same thread size for the cylinder head. However, solenoid-type unit injectors cannot be replaced with piezo-type unit injectors due to the different connections and control units.



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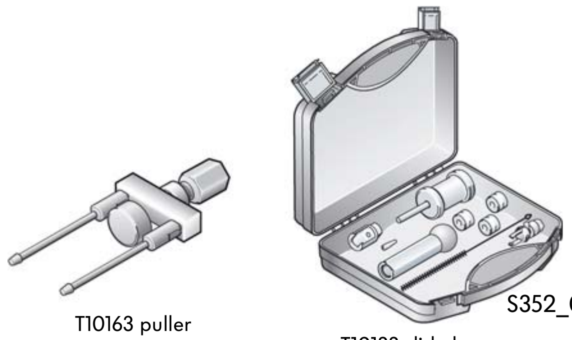
Versions of piezo-type unit injector

There are two versions of the piezo-type unit injector, the first model (PPD 1.0) and the model described in this self-study programme (PPD 1.1). The first version is already being used in the 2.0l, 103kW, 4V TDI engine for the Passat from model year 2006 and will be gradually replaced by the latest version (PPD 1.1). These two types can only be distinguished by the parts numbers stamped on them and are not interchangeable. If a combination of the two is fitted, the engine will run poorly.

Check the outside appearance and the parts numbers of the different unit injectors so you do not mix them up when replacing them.

Information on special tools

The T10163 puller together with the T10133 slide hammer is not just used to remove the piezo unit injector, but also to fit it.



T10163 puller

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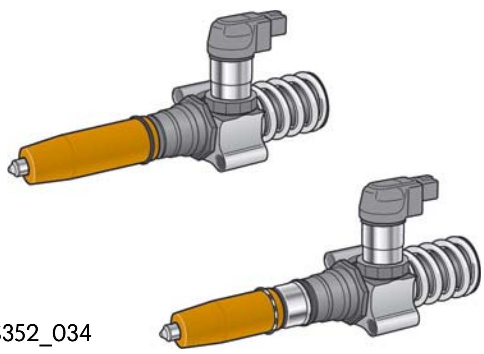
T10133 slide hammer

The new T10308 assembly sleeves are used to fit the seals for the unit injector with piezo valve.



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T10308 assembly sleeves

ELSA provides detailed information on the procedure.

Which answers are correct?

One, several or all answers could be correct.

1. Which statements on the unit injector with piezo valve are correct?

☐ a) A connection to the engine control unit is not needed as a solenoid valve is not used. The injection pressures are controlled purely mechanically with the aid of the closing plunger.

☐ b) The piezo valve is so fast that it can be opened and closed for each injection phase (pilot, main, secondary).

☐ c) Due to the smaller pump plunger diameter, the unit injector with piezo valve has a lower high-pressure volume and is therefore only suitable for diesel engines with a small capacity.

☐ d) It has been possible to reduce the noise emissions due to lower drive forces and better configuration of the pressure change inside the unit injector.

2. Complete the following statements.

a) Inverse piezoelectrical effect means that a piezo element .... when voltage is applied.

b) To ensure that the main injection phase starts with a higher injection pressure than the pilot injection phase, the nozzle spring is supported by the ....

3. When removing or installing the unit injectors with piezo valve, make sure that ...

☐ a) they are removed together with the wiring harness.

☐ b) the fitting size and mounting (fastening with two screws) are the same as the unit injector with solenoid valve.

☐ c) the wiring harness can only be removed as a complete unit (wiring duct and mounting brackets).

Answers

1. b), d)
2. a) enlarged (also: expanded)
2. b) Closing plunger/high-pressure fuel
3. b), c)

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