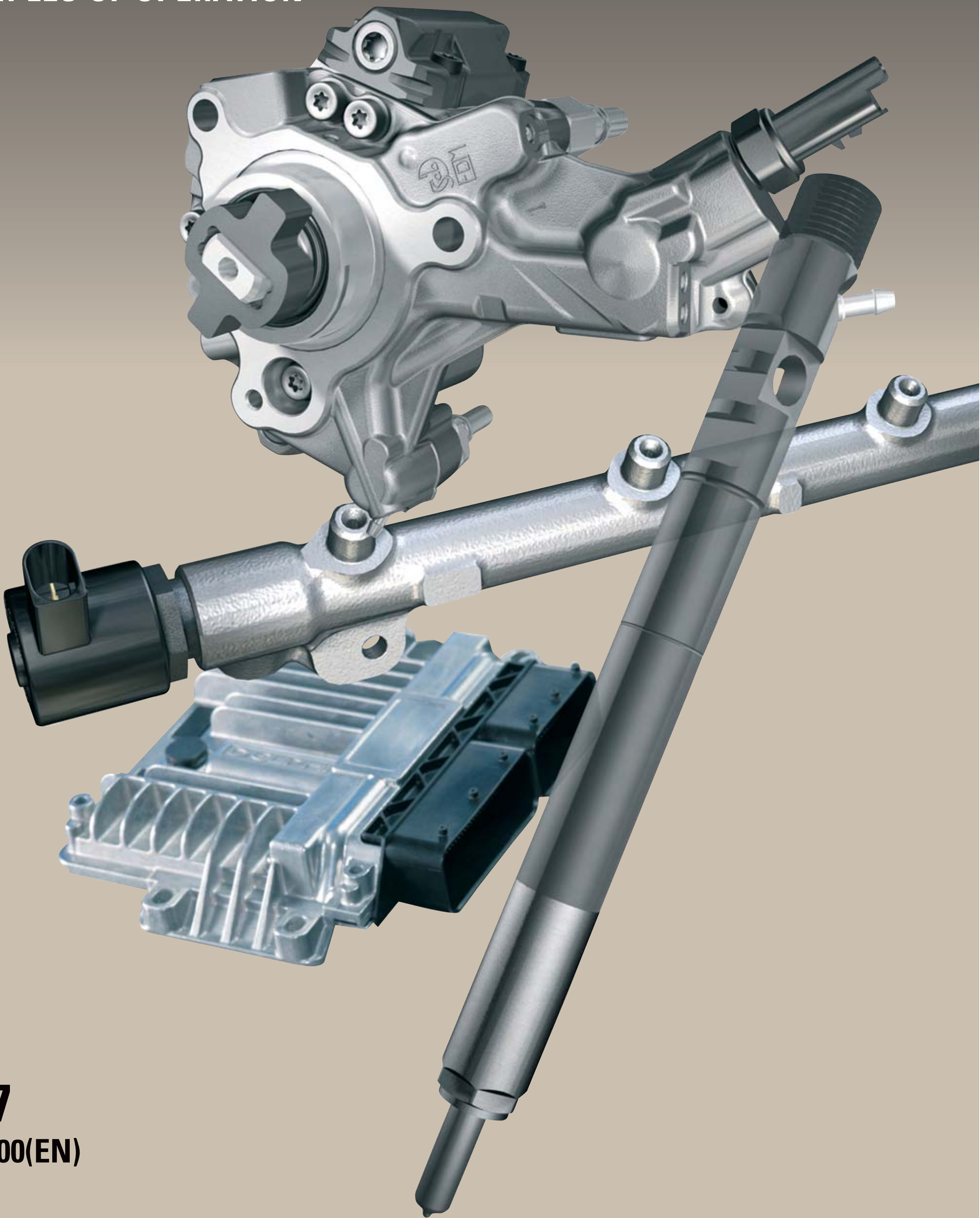
COMMON RAIL MANUAL

PRINCIPLES OF OPERATION



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(D) Kommen Sie nicht mit dem Hochdruckstrahl in Verbindung! Besonders nicht, wenn Druckrohrleitung oder Dichtung geprüft werden! Hochdruckflüssigkeiten können tödliche Verletzungen verursachen! Im Falle einer Berührung mit der Haut, kontaktieren Sie sofort einen Arzt. Bitte beachten Sie die Gesundheits-/und Sicherheitsunterlagen.

(E) Mantenga las manos y el cuerpo lejos del rociado del líquido, especialmente inyectores, tuberías y juntas de alta presión con fugas. La inyección de alta presión puede perforar la piel humana y producir una lesión fatal. En caso de que la inyección atraviese la piel, consiga atención médica inmediatamente. Vea la hoja de Datos de Sanidad y Seguridad.

(EN) Do not put your skin into the fuel jets under pressure, especially those due to pressure pipe or seal leaks. High pressure liquids can cause deadly injuries. In case of an injection under the skin, contact a doctor immediately. Please refer to the health and security fuel documents.

(F) Ne pas approcher les mains ni le corps des jets de liquides, particulièrement ceux provenant des fuites de tuyaux et des joint soumis a la haute pression. Le liquide sous haute pression injecté sous la peau peut causer des blessures mortelles. En cas d'injection sous la peau, consulter immédiatement un médecin. Se reporter à la fiche de santé et de sécurité du gazole.

(IT) Non esporre le mani o altre parti del corpo a getti di gasolio ad alta pressione, specialmente a quelli provenienti da tubi o paraolii. I getti di liquidi ad alta pressione possono causare ferite anche mortali. In caso di iniezione sotto pelle contattare immediatamente un medico. Fare riferimento alle schede di sicurezza del gasolio.

(NL) Zorg dat uw handen of andere lichaamsdelen niet in contact komen met vloeistofstralen onder hoge druk, met name bij een lek aan een leiding of dichting. Als de vloeistof onder hoge druk onder de huid terechtkomt, kan dit zelfs tot dodelijke verwondingen leiden. Als de vloeistof onder de huid terechtkomt, onmiddellijk een arts raadplegen. Lees de gezondheids- en veiligheidsfiche met betrekking tot de brandstof.

(P) Não exponha a pele a jactos de combustível sob pressão, especialmente os devidos a fugas de tubos de pressão ou vedantes. Líquidos a alta pressão podem causar ferimentos mortais. No caso de injecção subcutânea, consulte imediatamente um médico. Consulte por favor a documentação respeitante a saúde e segurança de combustíveis.

(D) Schutzbrille/Gesichtsschutz tragen.
(E) Úsese protección para los ojos/la cara.
(EN) Wear eye/face protection.
(F) Porter un appareil de protection des yeux / du visage.
(IT) Proteggersi gli occhi/la faccia.
(NL) Veiligheidsbril/-masker gebruiken.
(P) Use protecção da face/olhos.

(D) Von Zündquellen fernhalten - Nicht rauchen.
(E) Conservar alejado de toda llama o fuente de chispas -No fumar.
(EN) Keep away from sources of ignition - No smoking.
(F) Conserver à l'écart de toute flamme ou source d'étincelles - Ne pas fumer.
(IT) Conservare lontano da fiamme e scintille - Non fumare.
(NL) Ver van open vuur en ontstekingsbronnen houden – Niet roken.
(P) Mantenha afastado de fontes de ignição – Proibido fumar.

(D) Geeignete Schutzhandschuhe tragen.
(E) Usen guantes adecuados.
(EN) Wear suitable gloves.
(F) Porter des gants appropriés.
(IT) Usare guanti adatti.
(NL) Aangepaste veiligheidshandschoenen dragen.
(P) Use luvas apropriadas.

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Note: The aim of this document is to provide generic information concerning all Delphi Common Rail systems.

The Common Rail injection system has been developed to do the following:

- Reduce noise.
- Reduce polluting emissions.
- Reduce fuel consumption.
- Increase performance.

1.1 REDUCING NOISE

Combustion noise is the result of the rapid pressure rise in the cylinder. The violent ignition of the air/fuel mixture in the cylinder causes this pressure rise.

Note: *The noise from combustion is particularly loud at idling speeds and under light loading.*

In a diesel engine, combustion does not start immediately after the fuel has been injected into the cylinder. This delay is called the ignition delay. The increase in cylinder pressure at the time of fuel ignition causes more or less combustion noise depending on the amount of fuel actually injected.

It is thus necessary to reduce ignition time to reduce combustion noise. Increasing cylinder temperature and pressure will reduce this time. There are several methods for doing this:

- Reducing the amounts injected
- Preheating
- Reheating supercharged air
- Multi-injection *(Adding an injection before the main injection)*

Note: *Preheating and multi-injection are the two most commonly used procedures.*

1.2 REDUCING POLLUTING EMISSIONS

1.2.1 COMBUSTION

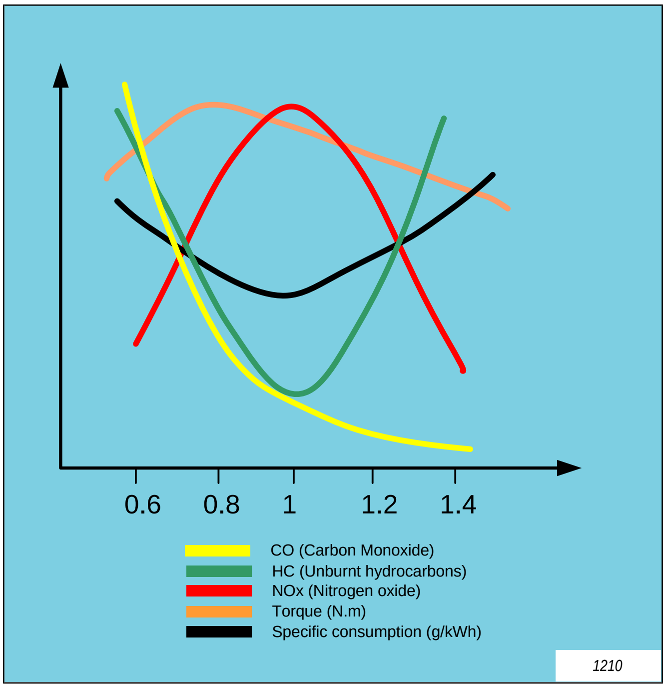
In comparison with a petrol engine, the air/fuel mixture in a diesel engine is far less homogeneous: Diesel injection takes place a little time before mixture ignition. Diesel engines operate principally using an excess of air. If the air amount is too small, polluting emissions increase.

Note: *The air/fuel coefficient commonly denoted by lambda (λ) is equal to 1 when the air/fuel mixture is stoichiometric (14,7 / 1).*

λ<1 Air deficit, rich mixture

λ>1 Air excess, poor mixture

Note: *Some diesel engines are now fitted with lambda (λ) probing, mainly to correct any flowmeter and injector drift during the lifetime of the vehicle.*



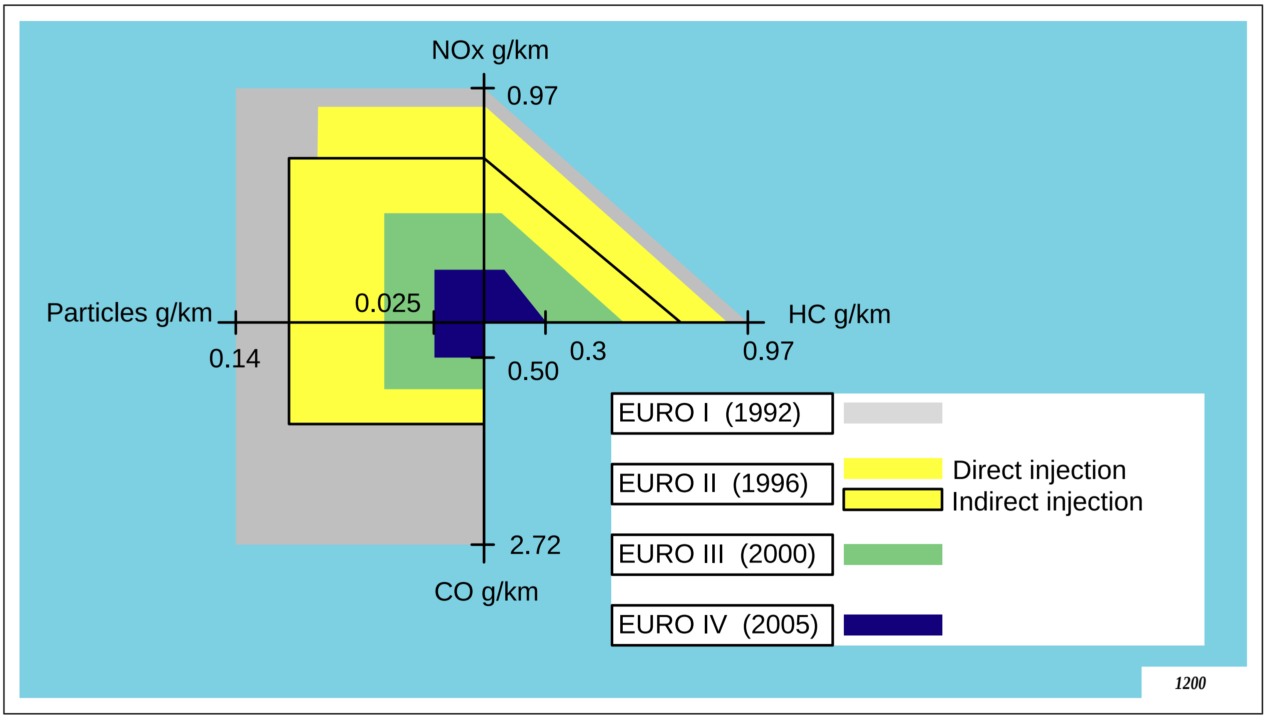
Influence of λ on pollutants, torque and consumption

1.2.2 STANDARDS

Anti-pollution standards regulate the following pollutants:

- Oxides of nitrogen *(NOx).*
- Particles. *(PM)*
- Carbon monoxyde *(CO).*
- Unburnt hydrocarbons *(HC).*

Note: *The standard threshold levels are expressed in grams per kilometer (g/km). These have been in force since 1992(EURO 1) and are updated every four years on average.*



Emissions in g/km

Standard levels (g/km)	Euro1	Euro2		Euro3	Euro 4	Euro 5
Motorisation	Diesel	IDI Diesel	DI Diesel	Diesel	Diesel	Diesel
HC+NOx	0.97	0.7	0.9	0.56	0.3	0.23
CO	2.72	1		0.64	0.5	0.5
PM	0.14	0.08	0.1	0.05	0.025	0.005
NOx	No standard	No standard		0.5	0.25	0.18

Note: *When the Euro2 standards were adopted in 1996, restrictions on HC emissions and particles had been less severe for direct injection engines (DI) compared to indirect injection engines (IDI). The Euro5 standards are due to come into force on 1 September 2009.*

1.2.3 POLLUTANTS

- Oxides of nitrogen **(NOx)**.

  NOx is produced from oxidation of the nitrogen in the air. This reaction only happens at very high temperatures when there is a great excess of air.

  To limit oxides of nitrogen emissions, a device is used that diverts part of the exhaust gas back to the inlet manifold to limit the amount of fresh air taken into the engine. This Exhaust Gas Recirculation (EGR) device regulates the amount of exhaust gas diverted back to the inlet. If this diverted amount is insufficient, the efficiency of the system has not been optimised. In the opposite situation - insufficient fresh air - there is an increase in smoke and soot along with unstable running of the engine.

  Using a DENOX catyliser to post-process exhaust gases can also reduce oxides of nitrogen emissions. The principle in this process is to reduce the amount of NOx molecules generated during combustion. The process produces oxygen and nitrogem molecules separately. Diesel fuel can be used as a catalyst for reducing NOx. Given this fact, a small amount of diesel is injected into the cylinder just before the cylinder exhaust valve opens. This promotes NOx emission reduction within the DENOX catalyser, and is known as post injection.

- **PM** particles

  Smoke and soot can be produced in the following situations:

  - The mixture is too rich. In this case there is insufficient air for complete combustion. This causes particles to form.
  - There is incomplete fuel vaporisation in the combustion chamber. The greater the size of fuel droplets, the greater the time needed to complete the vaporisation process. If this time period is too long, the central part of the droplet will not have time to vaporise. Given the very high combustion chamber temperature, the non-vaporised fuel molecules go through a cracking process. This physical phenomenon produces very hard carbon components that form soot and the other characteristic diesel engine particulates.

- Unburnt hydrocarbons **HC**

  Unburnt hydrocarbons *HC* are generated when there is a lack of local oxygen *(inadequate fuel distribution)* or when fuel is injected into cold areas in the combustion chamber *(typically where the fuel touches the cylinder walls)*.

  A toroidal combustion chamber combined with new intake systems *(swirl)* and direct injection creates the following:

  - Very high turbulence that ensures good fuel distribution within the combustion chamber. This eliminates the fuel-rich areas that cause unburnt elements to form.
  - A compact combustion chamber where the walls are hot enough to prevent unburnt particles forming.

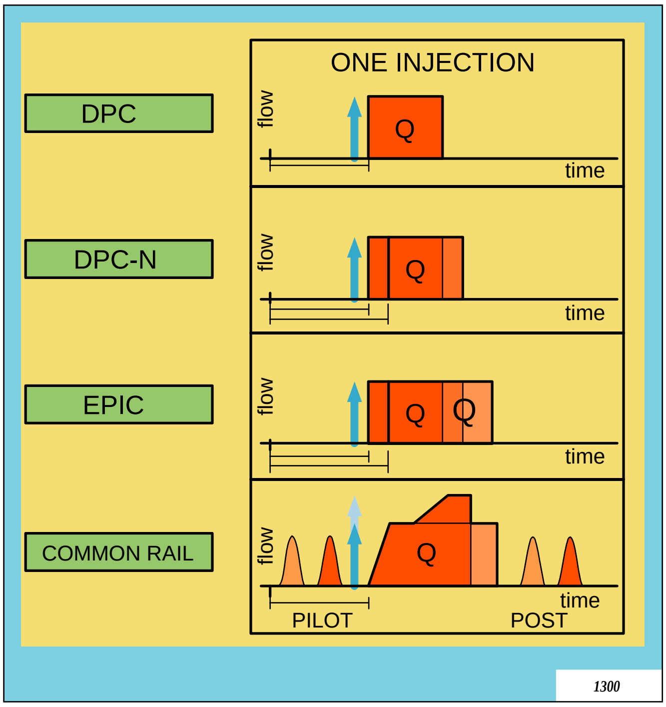
- Carbon monoxide **CO**.

  Its presence in the exhaust gases causes incomplete oxidation of the carbon in the diesel fuel. This incomplete oxidation is the consequence of general or local combustion in a rich mixture. If the diesel engine is running with a significant exess of air, CO emissions are reduced.

  It is possible to reduce the amount even more by eliminating rich zones in the combustion chamber. To do this it is necessary to optimise the internal aerodynamics of the combustion chamber to generate a very high rate of turbulence.

1.3 REDUCING FUEL CONSUMPTION

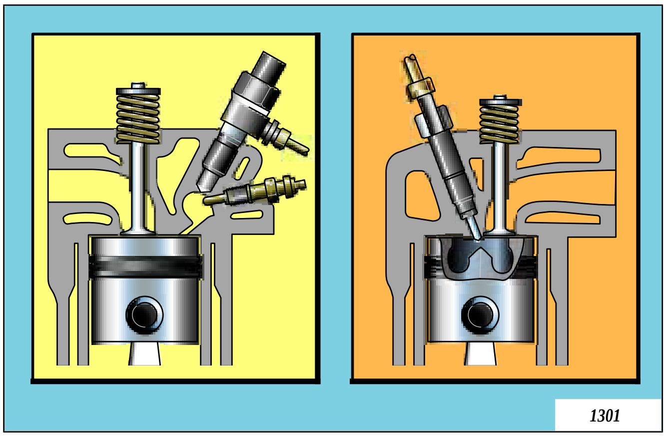
Consumption reduction is obtained by improving combustion control. This is done by modifying the air coefficient, injection flow, timing advance and injection pressure in relation to engine requirements across the whole operating range. In comparison with conventional injection systems, the common rail system provides a flexibility of operation that enables injection flow, timing advance, rate of introduction and injection pressure to be accurately adjusted to engine requirements for all operating conditions.



Specifics of the various Delphi systems

Type of injection	Timing	Amount injected	Number of injections
DPC	Mechanically set	Mechanically set	1
DPC-N	Electronically managed	Mechanically set	1
EPIC	Electronically managed	Electronically managed	1
COMMON RAIL	Electronically managed	Electronically managed	5

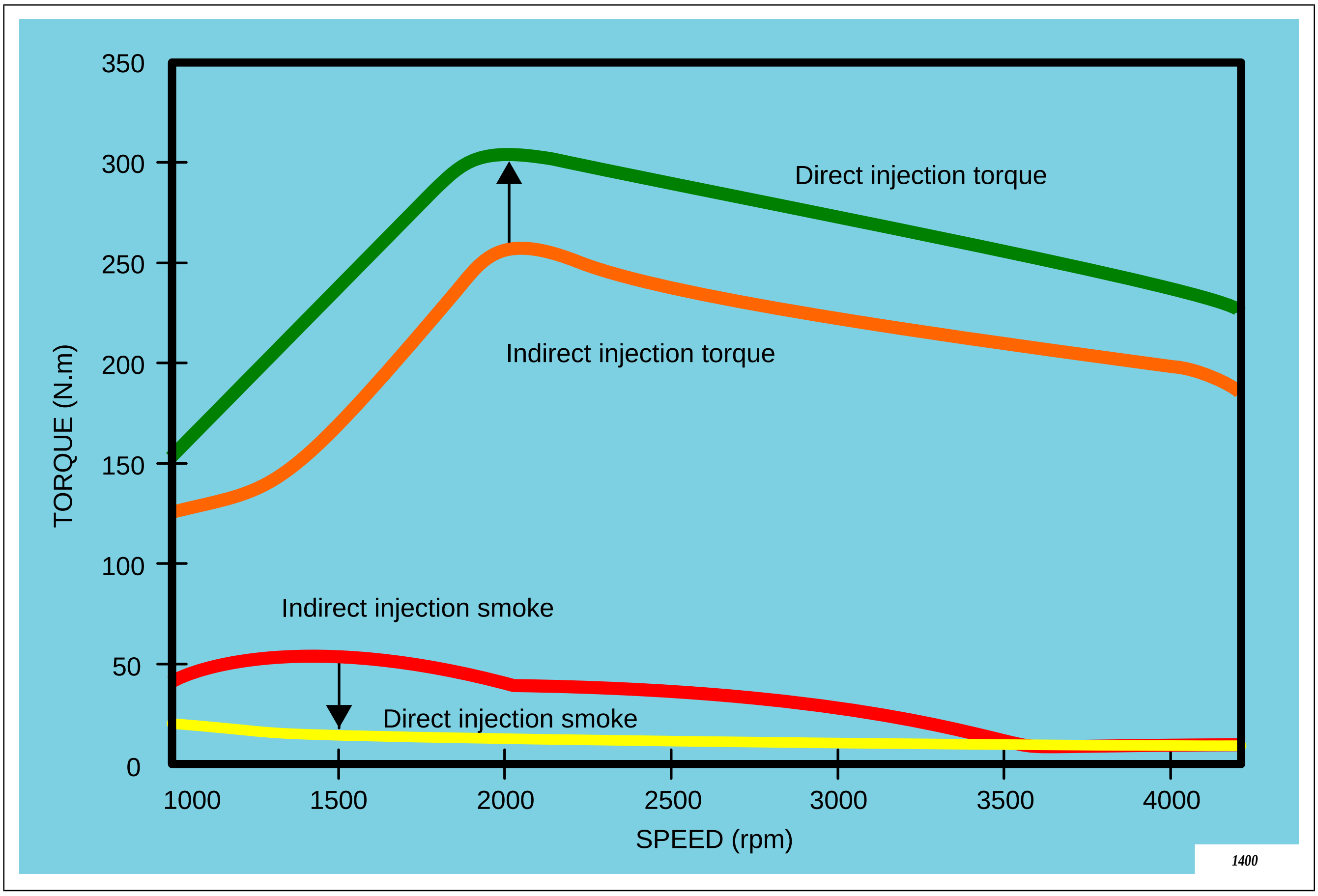
Direct injection also helps improve engine output by reducing the heat loss through cylinder walls.



Indirect Injection / Direct Injection

1.4 INCREASING PERFORMANCE

Increasing torque at low engine speeds means being able to inject a large amount of fuel at the lowest speeds. The amount injected is proportional to injection duration and pressure. Injection pressure has to be increased to increase fuel flow, since the time available for injecting fuel into the cylinder is limited.



Increasing performance

SYSTEM MAKE-UP

2.1 DESCRIPTION

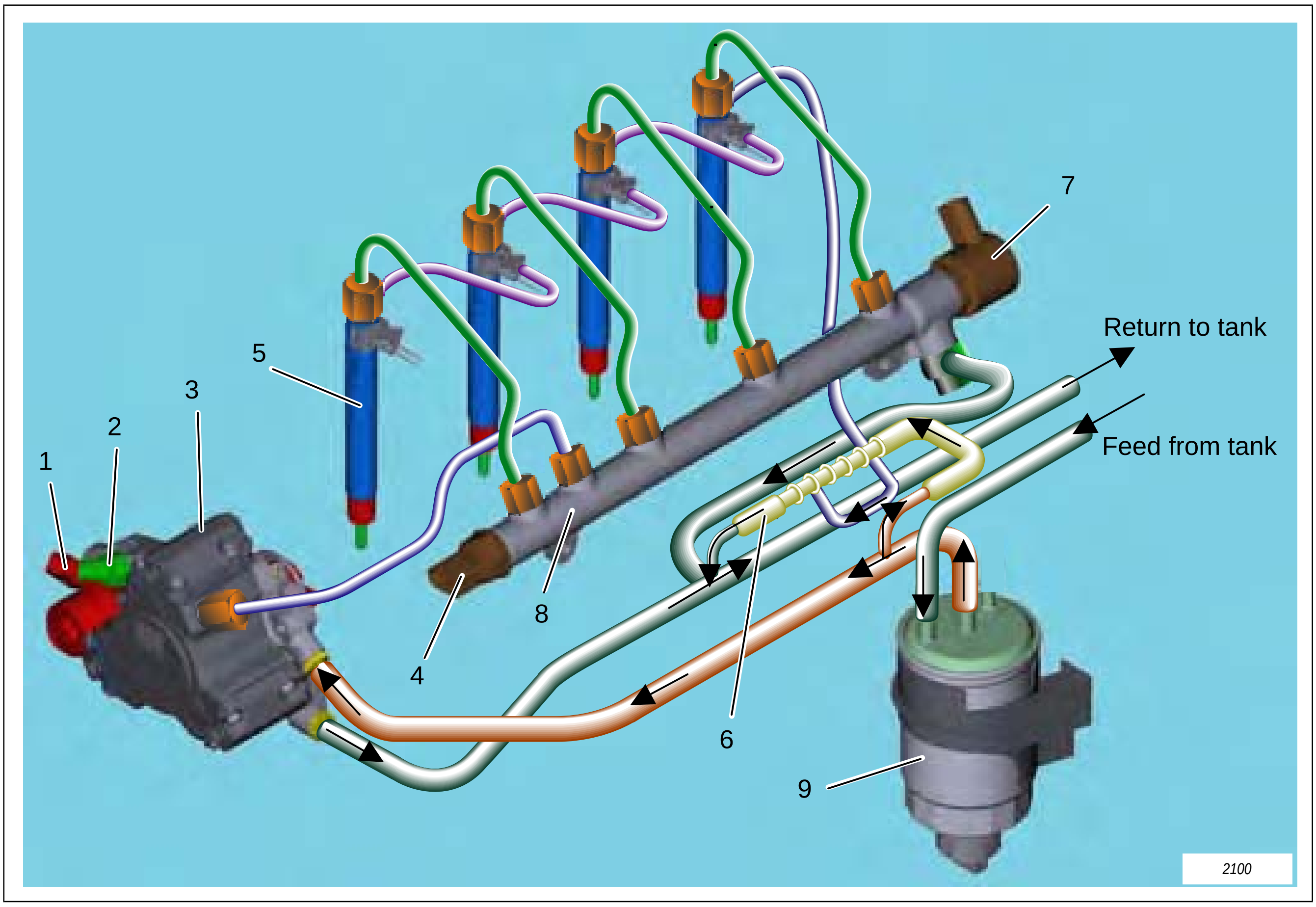
The Common Rail injection system is made up of the following parts:

- **A Transfer Pump** integrated into the High Pressure pump housing.
- **A High Pressure Pump** fed by fuel at transfer pressure. It sends fuel to the rail under very high pressure.
- **A Low Pressure Actuator** named IMV (Inlet Metering Valve). This controls the amount the fuel sent to the high pressure pump depending on engine requirements.
- **A Rail**. This forms a reserve of fuel under pressure.
- **Injectors**. These spray the required quantity of fuel into the combustion chamber at the desired moment.
- Use A or nothing **DCU** (Diesel Control Unit, otherwise known as the ECU: Electronic Control Unit) that controls injection (flow, timing, multiple injection etc) and rail pressure as a function of engine operating conditions. The DCU also controls associated functions such as the exhaust gas recirculation rate (EGR), pre-heating and air conditioning. Moreover the Swap ECU <--> DCU in the vehicle - to manage driveability, for example.
- Options:
  - **A High Pressure Actuator** also known as the HPV (High Pressure Valve). This is fitted to the rail and monitors its prevailing pressure.
  - **A Force-feeding pump** used where the high pressure pump does not have a transfer pump.
- **Sensors** provide the needed information in real time so that the injection process can be controlled:
  - A rail pressure sensor.
  - A fuel temperature sensor.
  - A inlet air temperature sensor.
  - A inlet air pressure sensor.
  - A pedal sensor.
  - A accelerometer sensor.
  - A engine flywheel angular position sensor.
  - A phase position sensor either on camshaft or on pump pinion (as for Renault).

Note: *Other sensors such as the flowmeter sensor, supercharging sensor, and exchanger exit temperature sensor are generally fitted. However these are not necessary for the Common Rail system to function.*

SYSTEM MAKE-UP

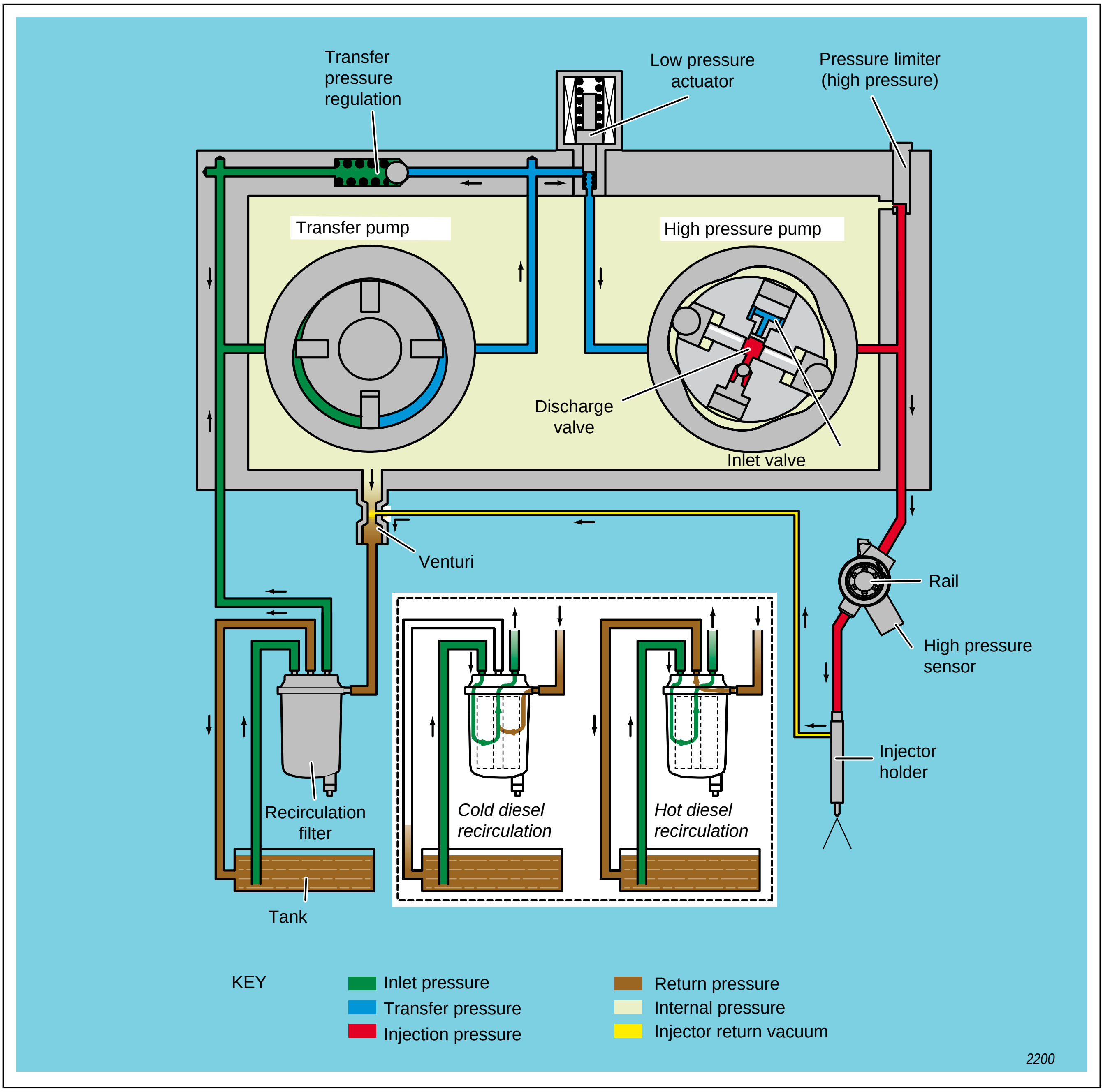
1	IMV	6	Venturi
2	Diesel temperature sensor	7	HPV
3	High Pressure Pump *(Type DFP3)*	8	Rail
4	Rail pressure sensor	9	Diesel filter
5	Injector		



Common Rail System with HPV option

SYSTEM MAKE-UP

2.2 COMMON RAIL HYDRAULIC CIRCUIT (DFP1)



SYSTEM MAKE-UP

HP PUMP

To describe the HP pump operating principle, it is necessary to break down the explanation into several parts:

- Transfer pump
- High pressure pump DFP1
- High pressure pump DFP3
- IMV
- Pressure limiter

Note: *The "transfer pump"chapter is specific to the DFP1 pump in terms of diagrams: the operating principle remains identical to that for a DFP1 or DFP3 unit.*

3.1 TRANSFER PUMP

3.1.1 DESCRIPTION

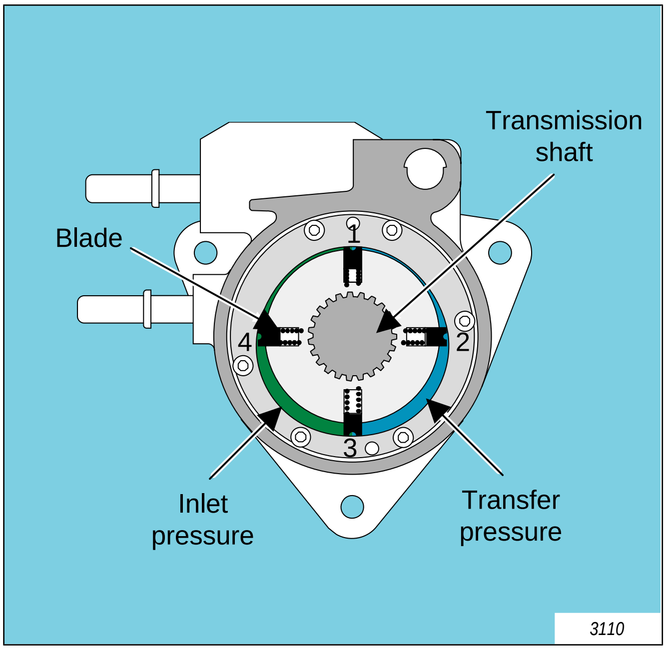
The first transfer pump stage, draws diesel from the vehicle tank through the filter and sends it to the main pump under transfer pressure *(about 6 bar)* The blade pump technology used *(well known from our preceding products)* has the following parts:

- A rotor driven from the HP pump shaft. Torque is transferred by splined shaft.
- An eccentric liner fitted in the HP pump housing. Two off-set pins that locate the liner correctly and ensure correct assembly.
- One plate with two oblong holes: one inlet orifice and one discharge orifice.
- Four blades at 90 degrees to each other. Each blade is held against the liner by a coil spring.

3.1.2 OPERATING PRINCIPLE

Consider the space between the rotor, the liner and two successive blades.

- When the chamber is in position 1, the volume of the chamber is minimal. The volume change related to rotor angular travel is insignificant in this position.
- The rotor makes a quarter-turn anti-clockwise. The previous chamber is now in position 4. The inlet orifice is uncovered. The volume of the chamber quickly rises. The pressure in the chamber drops sharply. Fuel is drawn into the chamber.
- The rotor continues to rotate. It is now in position 3. Inlet and outlet orifices are now sealed off. The volume contained by the rotor, liner and the two blades is now at a maximum. Any changes in volume that depend on the rotor angle of rotation are small.

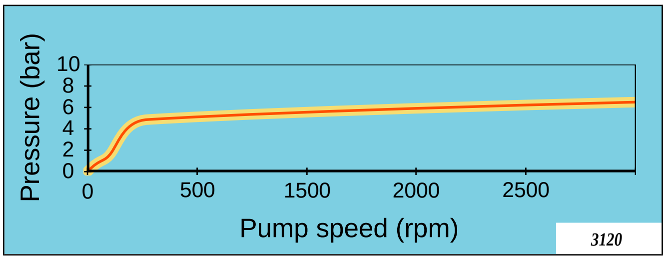


- The rotor continues to rotate. It is finally in position 2. The outlet orifice is uncovered. The volume contained by the rotor, liner and the blades diminishes rapidly. The pressure in this space increases sharply. The fuel is discharged under pressure.

HP PUMP

The vacuum generated by the transfer pump rotation is enough to draw in fuel through the filter. The transfer pump is driven by the HP pump shaft. Transfer pressure thus rises with engine speed.

A regulating valve maintains transfer pressure at a quasi constant value *(about 6 bar)* throughout the engine operating range by sending part of the fuel back to pump inlet.



Transfer pressure

3.1.3 TRANSFER PUMP CHARACTERISTICS

Regulating pressure

- 6 bar

Flow:

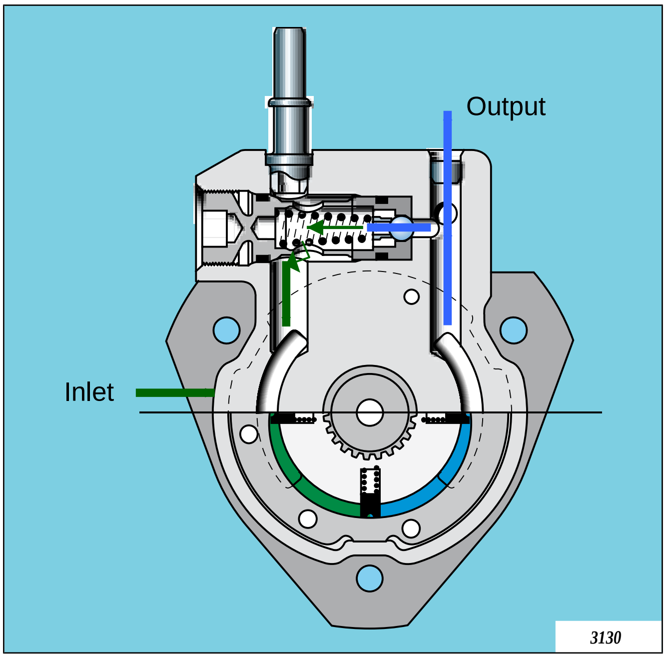
- 90 l/h at 300 rpm
- 650 l/h at 2500 rpm

Swept volume

- 5.6 cm^3/rev.

Intake capacity

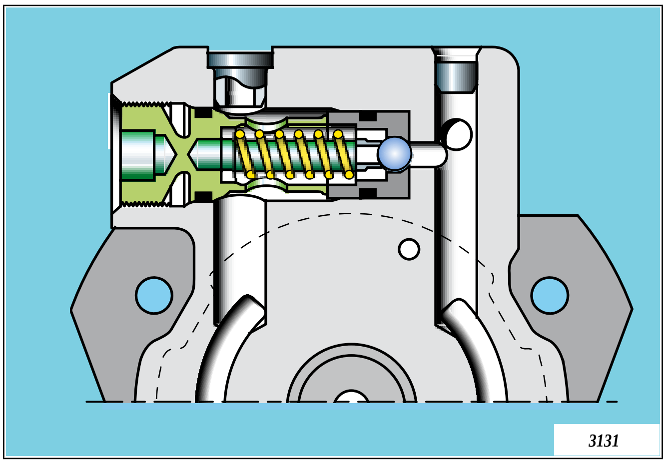
- 65 mBar at 100 rpm



Transfer pump with its pressure regulator

The transfer pressure regulator mechanically controls transfer pressure using a single piston/ spring arrangement to cover and uncover the fuel flow orifices.

As can be seen on the preceding diagram, the output from the regulator is recycled to the transfer pump inlet.



Close-up on transfer pressure regulator section

HP PUMP

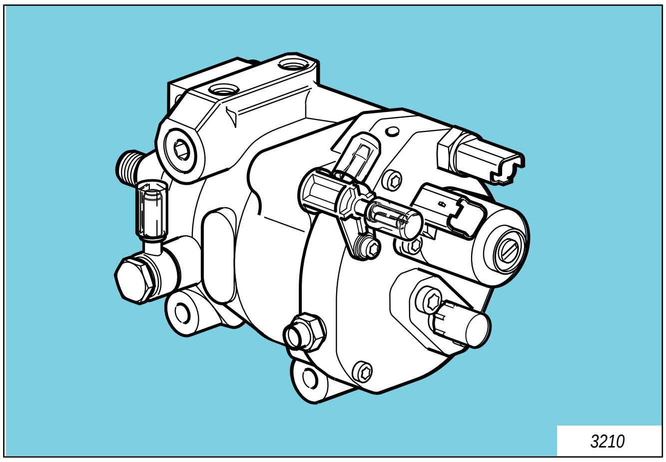
3.2 DFP1 COMMON RAIL PUMP

3.2.1 DESCRIPTION

This high pressure pump uses the cam and radial piston concept already proven on the DPC and EPIC rotating pumps. However the transmission shaft and cam ring make up the one and same assembly. This is driven by chain or belt, rotating in the fixed hydraulic head. This design eliminates dynamic sealing problems since the high pressure is generated in the fixed part of the pump.

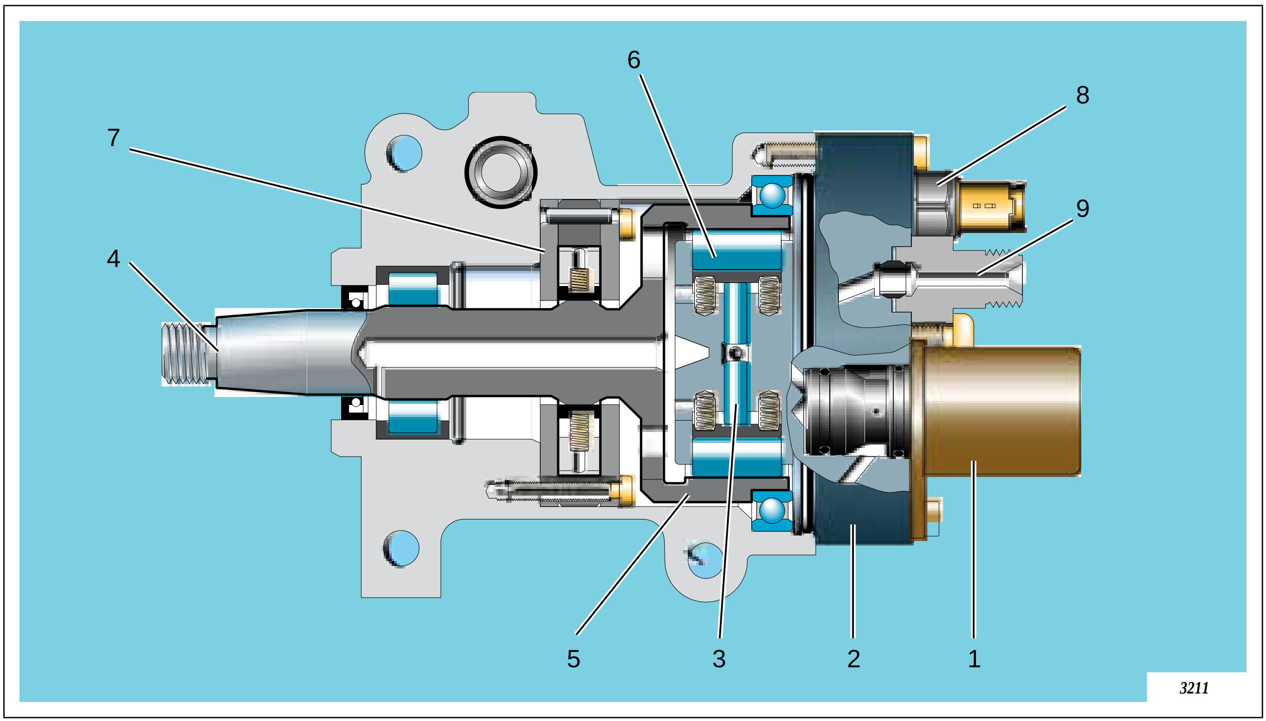
For engines needing substantial flow rates, the pump is fitted with two chambers angularly offset by 45 degrees. This offset reduces torque peaks and rail pressure variations.

The four-lobe cam is identical to that in conventional rotating pumps. However since the pump no longer determines injection procedure, it is possible to lengthen the pumping phase in order significantly to reduce driving torque, vibration and noise.



DFP1 High Pressure Pump

1	IMV	6	Roller
2	High pressure pump / Hydraulic head	7	Transfer pump
3	Plunger Piston	8	Diesel temperature sensor
4	Drive transmission shaft	9	High Pressure Exit
5	Rotary cam		



DFP1 High Pressure Pump section view

HP PUMP

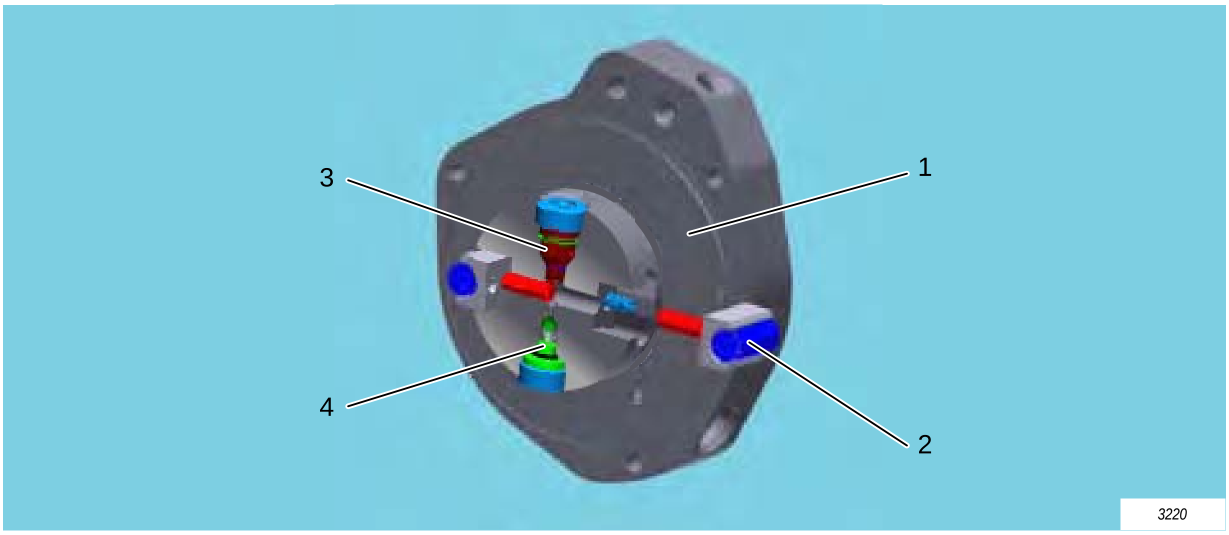
3.2.2 OPERATION

A) PUMP FEED

The transfer pump draws fuel through the filter. This delivers fuel to the HP pump entry point at a quasi-constant pressure known as the transfer pressure.

A filling actuator is fitted upstream of the HP pump. This controls the amount of fuel sent to the pumping system by adjusting the (Inlet Metering Valve IMV) cross-section of the flow path. The ECU determines the coil current to set the flow path cross-section required to achieve the requested pressure for the engine operating conditions. When the requested pressure reduces the current increases, and vice-versa.

1	Hydraulic head body	3	Inlet valve
2	Roller shoe	4	Outlet valve

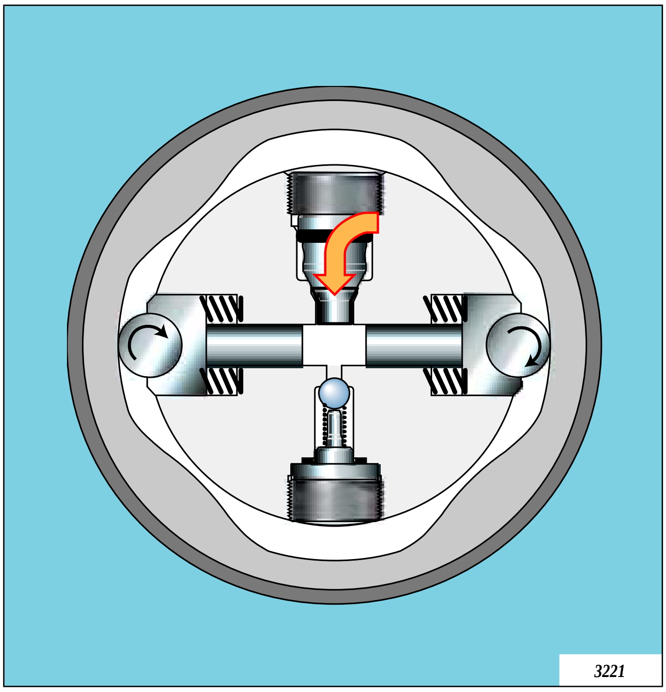


HP PUMP

B) PUMPING PRINCIPLE

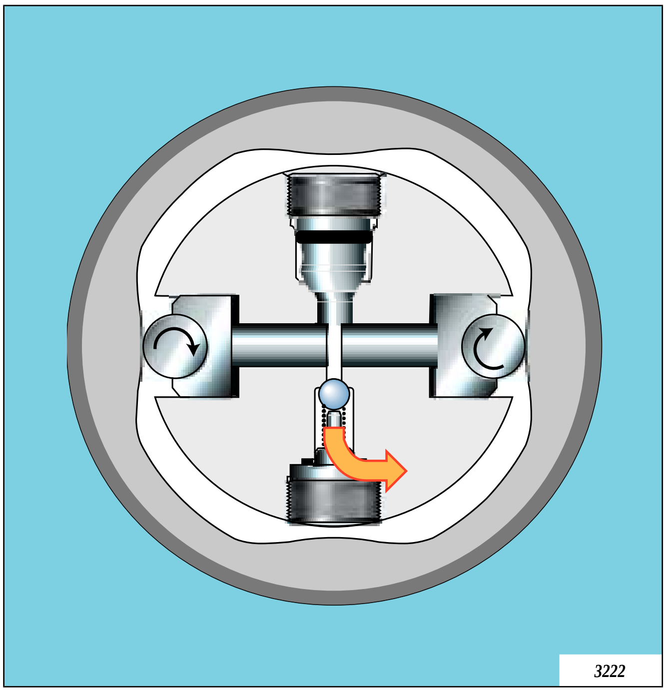
During the filling phase, two helical springs - one on each piston - keep the cam rollers in contact with the cam. The transfer pressure is sufficient to open the inlet valve and to move the plunger pistons apart. In this way the dead space between the two plunger pistons fills with fuel.

When the diametrically opposite rollers simultaneously move over the cam raise profile, the pistons are pushed together. Pressure rapidly increases in the space between the two plunger.



Intake phase

When the pressure rises above transfer pressure the inlet valve closes. When pressure goes above rail pressure the outlet valve opens. The fluid under pressure is then delivered to the rail.

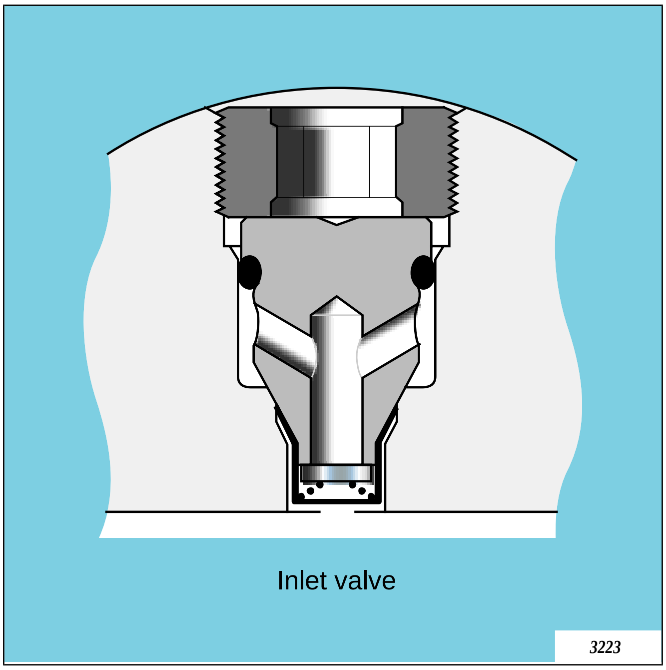


Discharge phase

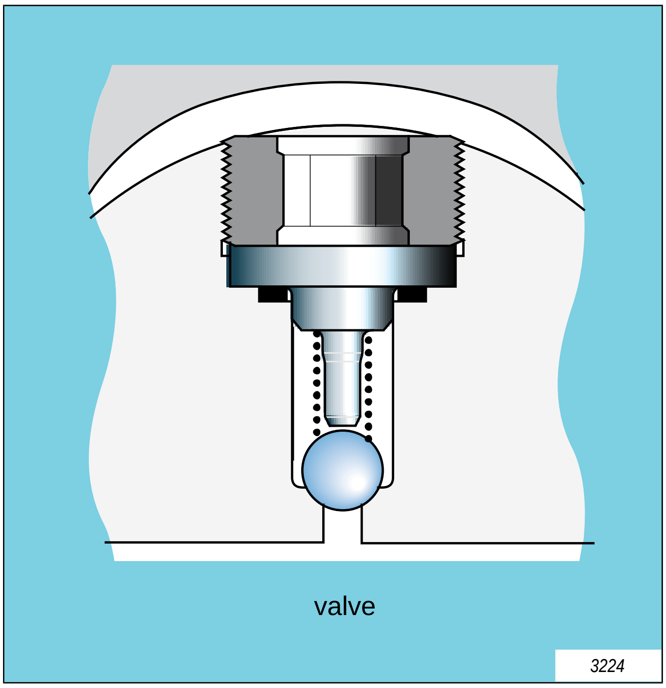
HP PUMP

C) INLET AND OUTLET VALVES

In the intake phase, the transfer pressure opens the valve. Fluid enters the body of the pump element. Under the effect of the transfer pressure, the plunger pistons move apart. When the rollers simultaneously meet the cam raise profile, pressure suddenly increases in the pump element body. The valve closes when the pump element body pressure becomes greater than the transfer pressure.



In the intake phase, the discharge valve ball comes under rail pressure on its external face and under transfer pressure on its internal face. The ball thus remains in its seating thus ensuring pump element body sealing. When the two diametrically opposite rollers simultaneously meet the cam raise profiles, the plunger pistons move towards each other and the pump element body pressure rapidly increases. When the pressure in this element becomes greater than rail pressure, the ball is in disequilibriuim and consquently opens *(the spring loading is negligible in relation to the pressure loading)* Fuel thus flows into the rail under high pressure.



D) PUMP LUBRICATION AND COOLING

The fuel in circulation keeps the pump lubricated and cooled. The mininim flow needed for pump operation is 50 litres/hour.

HP PUMP

E) PUMP PHASING

Conventional injection pumps distribute fuel under pressure to the various injectors. It is thus essential to phase the pump so that injection takes place at the required point in the cycle. The Common Rail system HP pump no longer distributes the fuel so it is not essential to phase the pump with the engine. However phasing the pump has two advantages:

- Variations in torque from the camshaft and the pump can be synchronised to limit stress on the drive belt.
- Pressure control can be improved by synchronising pump-produced pressure peaks with the falls in pressure generated by each injection. This phasing improves pressure stability, which helps reduce the difference in flow between cylinders *(line to line)*.

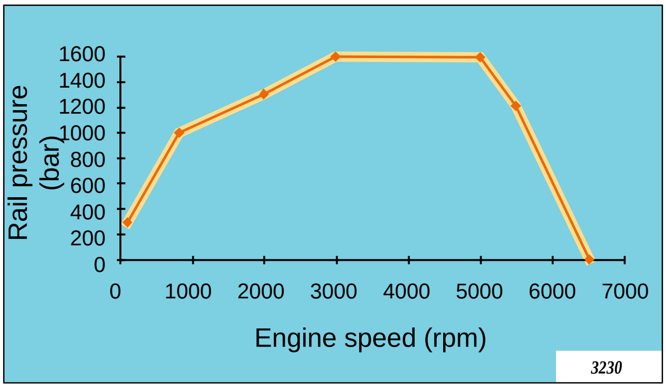
Phasing the pump will be done using a pin inserted in the pump drive shaft.

Note: *Phasing is obligatory on DFP1 pumps fitted on Renault applications . Unlike the practice with other car builders, the phase sensor is not positioned on the camshaft but on the pump pinion. It is therefore essential to phase the pump on Renault applications to avoid any problem with engine synchronisation.*

3.2.3 CHARACTERISTICS

A) DFP1 MAX PRESSURE GRAPH

The time needed to achieve sufficient rail pressure to start, depends on the injection system volume *(rail dimensions, tubing length, etc)*. The object is to achieve a 200 bar pressure in 1.5 revs *(3rd compression)*.



HP PUMP

B) CHARACTERISTICS

Applications	Capacity (cm^3/rev)	No. of plungers	Rack	Ratio	Max Pump Speed	Max Rail pump Speed	Drives
Renault K9	0.6	2	1	1/2	3000 rpm @ 1000bar	1000 - 2500 rpm @ 1600bar	Belt
PSA DV4TED4	0.67	3	1	2/3	3500 rpm @ 1200bar	1170 - 3000 rpm @ 1600bar	Belt
Ford Puma Transit	1.2	4	2	1/2	3000 rpm @ 1000bar	1000 - 2500 rpm @ 1600bar	Chain
Ford Lynx/ Puma	0.9	4	2	1/2	3000 rpm @ 1000bar	1000 - 2500 rpm @ 1600bar	Chain
Kia	0.9	4	2	1/2	2800 rpm @ 1000bar	1250 - 2100 rpm @ 1400bar	Belt
SsangYong	0.9	4	2	5/8	3000 rpm @1000bar	1000 - 2500 rpm @ 1400bar	Chain

HP PUMP

3.3 DFP3 COMMON RAIL PUMP

3.3.1 DESCRIPTION

The DFP3 high pressure pump marks a change from the DFP1 concept. The transmission drive shaft and cam assembly for this pump are replaced by a shaft with an eccentric part connected to push rods.

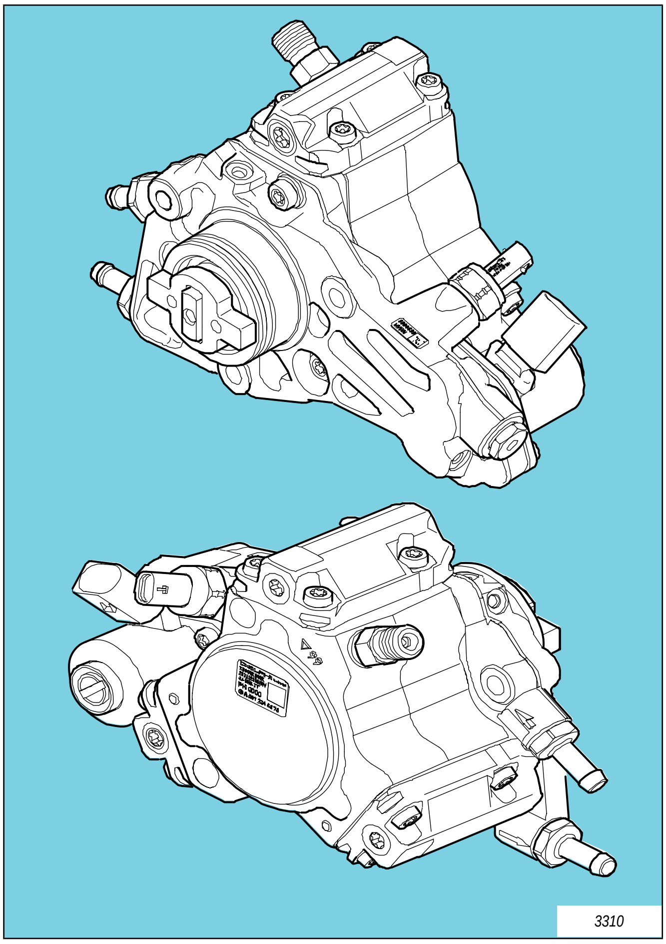
This eccentric is rotated by the pump transmission shaft. Its specific rounded form is designed to drive the push rod movement and generate high pressure.

For engines needing substantial flow rates, the pump is fitted with three plungers angularly placed at 120 degrees to each other. For engines needing a less substantial flow rate, a 2-plunger solution has been adopted, with the plungers angularly placed at 180 degrees.

Since the pump no longer sets the injection procedure - in the same way as for the DFP1 - it is possible to extend the pumping phase so as to reduce drive torque, vibration and noise.

The most significant differences from the DFP1 are:

- The eccentric
- The transmission shaft shape.
- The number of plungers.
- Roller bearings replaced by plain bearings.
- Greater pumping capacity per revolution.
- Higher rotation speed.
- Reduced pump overall dimensions.
- Transfer pump as an option.



3-piston DFP3 pump

HP PUMP

3.3.2 OPERATION

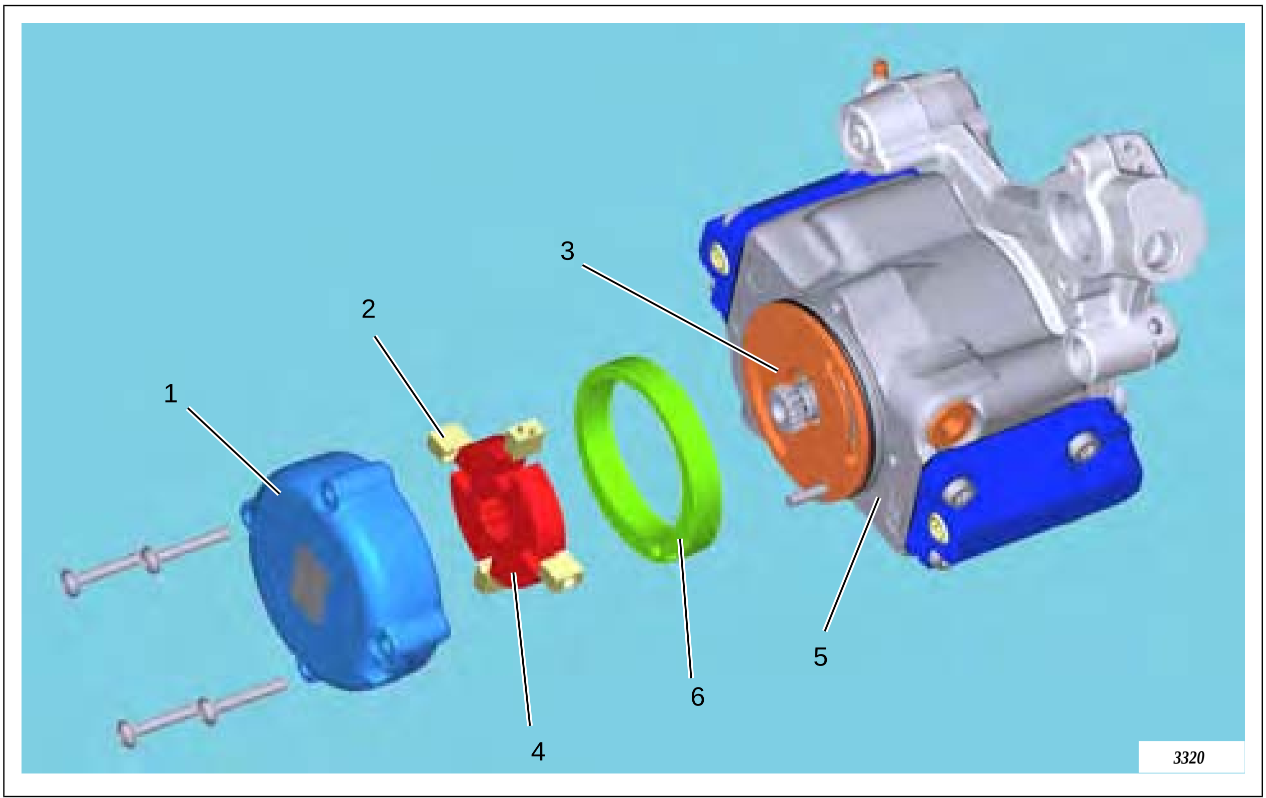
A) PUMP FEED WITH OR WITHOUT TRANSFER PUMP

A transfer pump draws diesel through the filter, or a feeder pump in the fuel tank puts the fuel under pressure. In the first case, the pumping principle employs the DFP1 transfer pump concept. See Paragraph 3.1: DFP1 Transfer pump

Operation and characteristics are almost the same as for the DFP1. The only major difference is in it being placed on the front and no longer directly inside the pump housing itself.

A feed pressure regulator internal to the pump is needed when using a transfer pump.

1	Transfer pump body	4	Rotor
2	Blades (x4)	5	High pressure pump body
3	Distribution plate	6	Liner



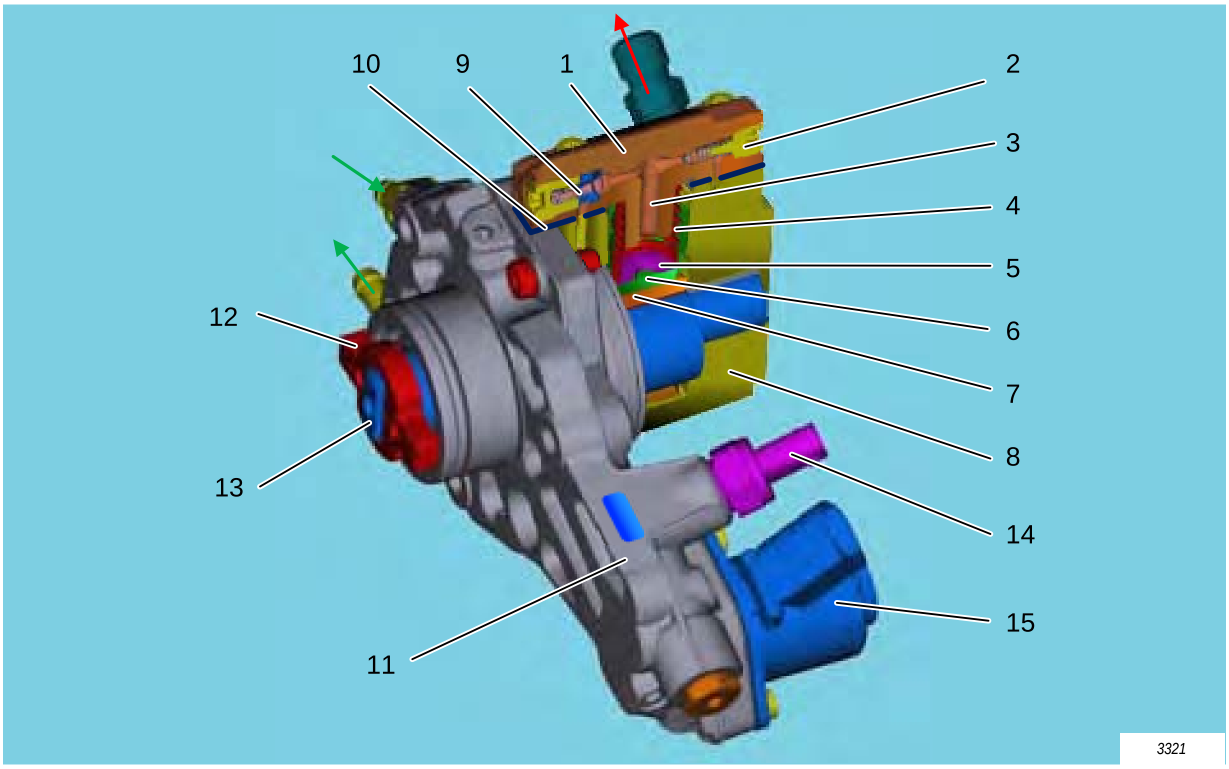
Section view of optional transfer pump for DFP3

HP PUMP

B) PUMPING PRINCIPLE

The pump is driven by belt, chain or Oldham drive as shown in diagram below *(12)* . The transmission torque is sent via drive shaft *(13)* to the eccentric, or cam *(7)* . In the diagram the cam *(7)* is in rest position with its flat faces touching the push rods *(6)* . The cam is considered to be in a working position when one of the curved faces is acting on one of the push rods. This push rod drives plunger piston *(3)* and compresses spring *(4)* . The amount of fuel compressed at piston travel is represented by figure 2 on the hydraulic head diagram.

1	Cylinder head	8	Pump body
2	Discharge valve	9	Inlet valve
3	Plunger Piston	10	Cylinder head gasket
4	Piston spring	11	Identification plate
5	Spring retaining cup	12	Oldham drive
6	Push rod	13	Drive shaft
7	Cam		

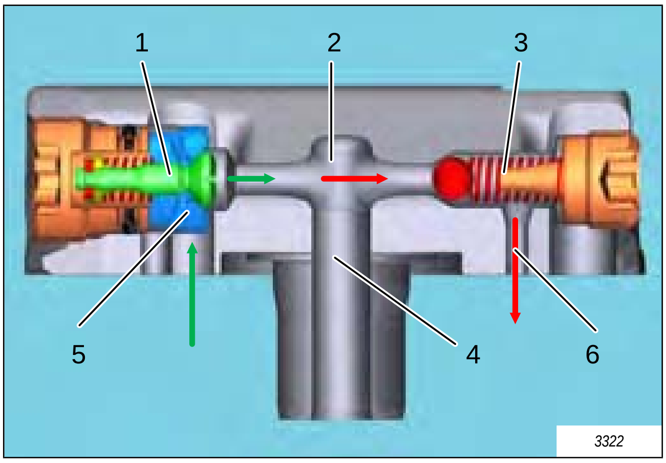


Section view of the 3-plunger version of the DFP3

HP PUMP

C) HYDRAULIC HEAD

Diesel at transfer pressure goes to the hydraulic head via orifice **(5)** and then passes through the inlet valve. This amount of fuel is then compressed in chamber **(2)** at each piston rise. This amount then moves at high pressure through the outlet valve before being sent through orifice **(6)**. This orifice is itself linked to the other HP hydraulic head exits so as to centralise all high pressure fuel.

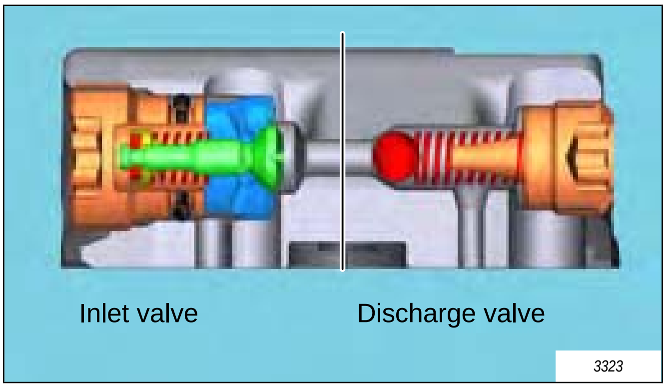


Section view of a hydraulic head

D) INLET AND OUTLET VALVES

The opening and closing of the valves depend on the movements of the plunger pistons, as follows:

- In the expansion phase, the descending piston generates a vacuum that causes the inlet valve to open thus filling the compression chamber. On the return, the outlet valve remains in its seating since the actual pressure behind it is equal to the rail pressure.
- In the compression phase, the inlet valve closes as the rising piston puts the fuel in the chamber under pressure and thus pushes the valve into its seating. The discharge valve opens when the chamber pressure becomes greater than the rail pressure.



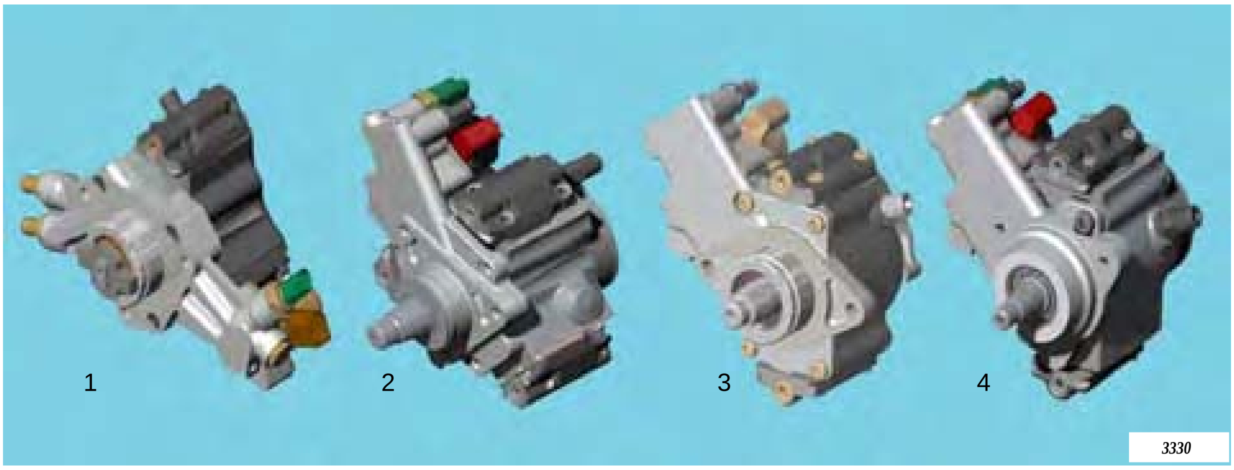
Close-up of hydraulic head valves

Note: *The inlet and outlet valve springs are only there to help their movement. The loading of these springs is light and does not constitute an obstacle in terms of the pressures operating in the hydraulic head.*

HP PUMP

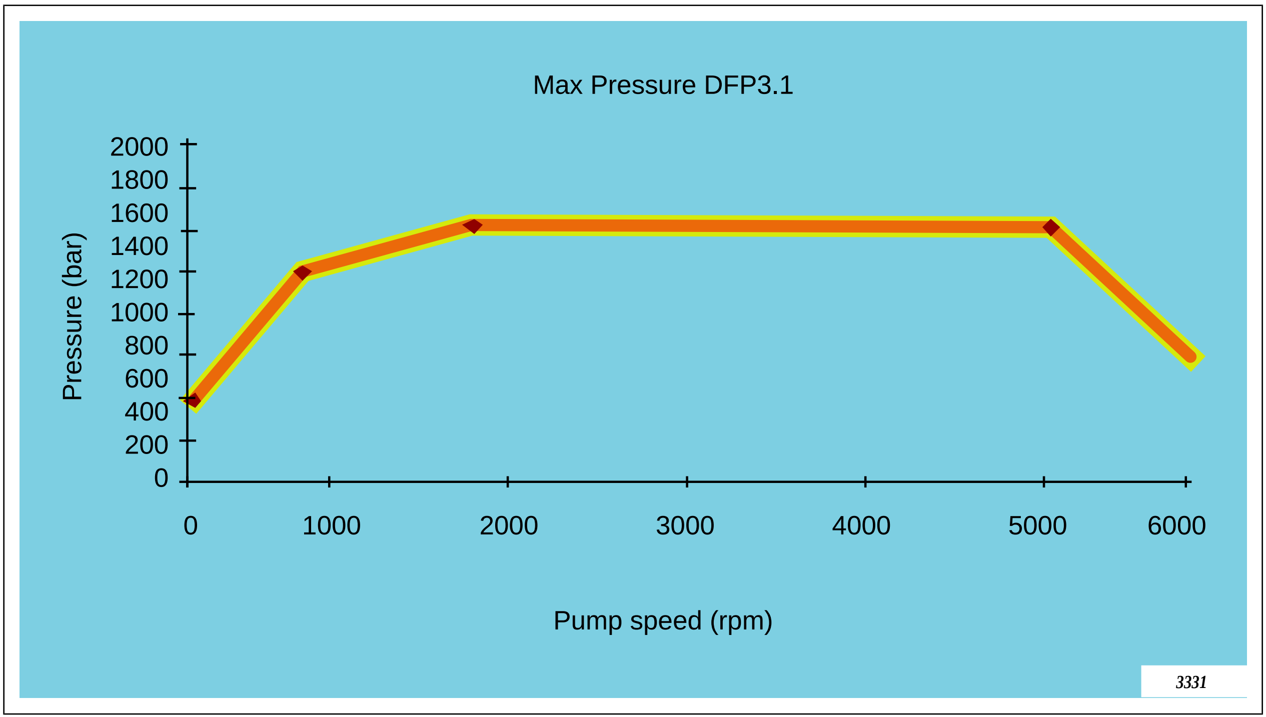
3.3.3 SPECIFICATIONS

1	DFP3.1	3	DFP3.3
2	DFP3.2	4	DFP3.4



Specifications	DFP3.1	DFP3.2	DFP3.3	DFP3.4
Number of plungers	3	3	2	2
Capacity (cm^3/rev)	0.75 to 1.05	1 to 1.05	0.8 to 1	0.5 to 0.7
Max pressure (bar)	1600 to 2000	1600 to 2000	1600 to 2000	1600 to 2000
Drives	Belt/Chain/Oldham	Belt/Chain/Oldham	Belt/Chain/Oldham	Belt/Chain/Oldham
Speed ratio in relation to engine speed	1/2 to 4/3	1/2 to 4/3	1/2 to 1	1/2 to 1
Max speed (pump rpm)	5000	4000	4000	5000
Transfer pump	Integrated as an option	Integrated as an option	Integrated as an option	Integrated as an option

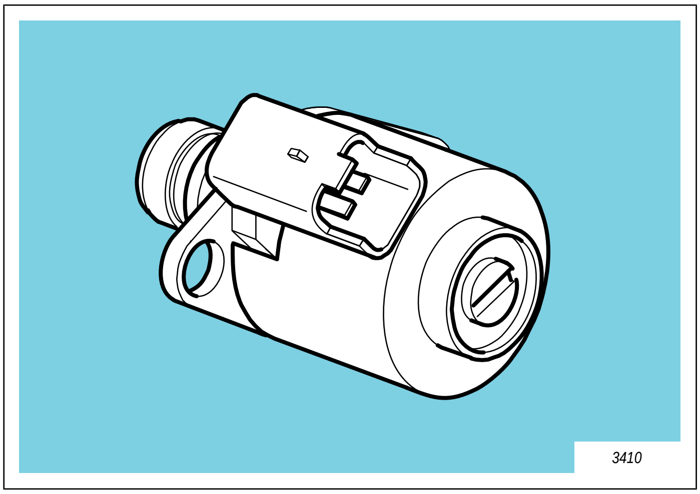
HP PUMP



DFP3.1 max pressure graph

3.4 IMV

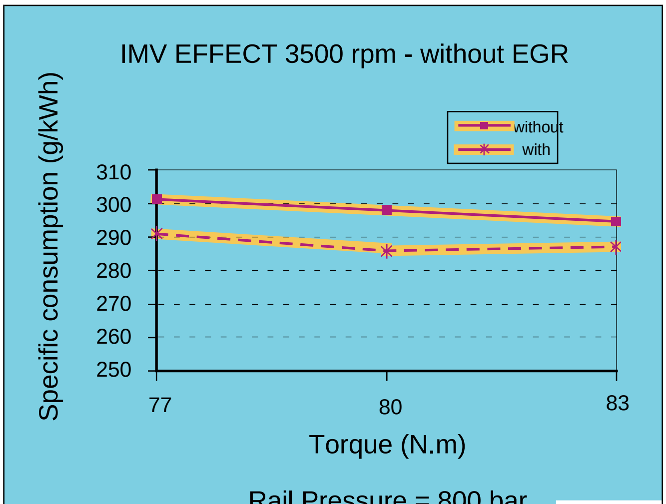
3.4.1 OPERATION



HP PUMP

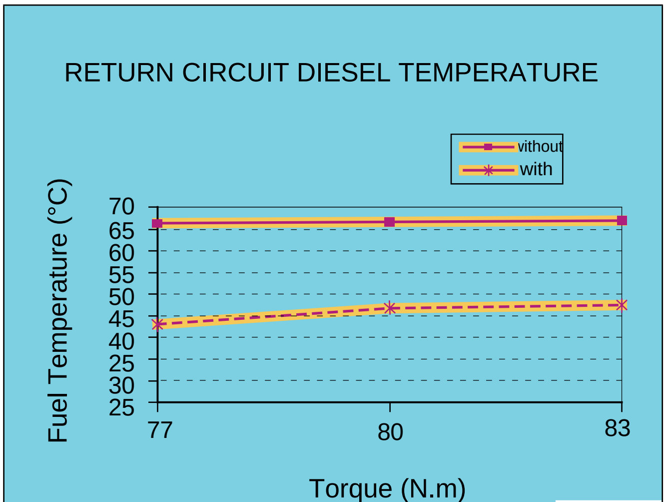
The low pressure actuator also called the Inlet Metering Valve controls rail pressure by regulating the amount of fuel sent to the pumping components of the HP pump. This actuator has a double role as follows:

- First it improves injection system output since the HP pump only compresses the amount of fuel needed to maintain the rail pressure required by the system.



3411

- Secondly it reduces the temperature in the fuel tank. In fact when excess fuel is sent to the return circuit, the expansion of the fluid *(from rail pressure to atmospheric pressure)* involves a large amount of heat. This generates an increase in temperature of the fuel sent back to the tank. To avoid generating too high a temperature, it is necessary to do the following:
  - Cool the diesel in the exchanger *(a costly, cumbersome and not very efficient solution)*.
  - Limit the amount of heat generated by fuel expansion by reducing the rate of discharge. To reduce the rate of discharge, it is enough to adapt the HP pump output to engine needs within the whole operating range. This is what the IMV does.

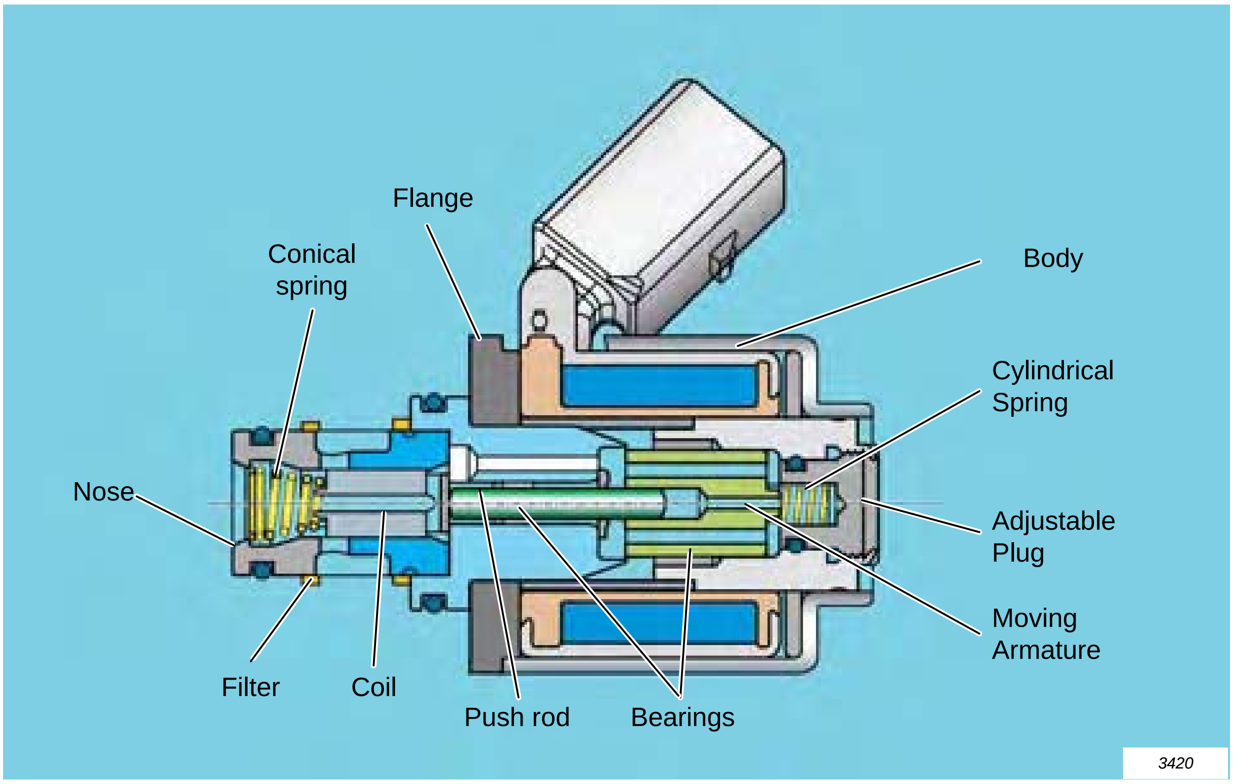


3412

3.4.2 DESCRIPTION

The IMV is fitted to the pump hydraulic head. The transfer pump feeds fuel to it via two radial drill holes. A cylindrical filter is fitted to the IMV feed orifices. This not only protects the low pressure actuator but also protects all the injection system components downstream of the IMV. It is made up of the following elementsin Fig. 3420:

HP PUMP



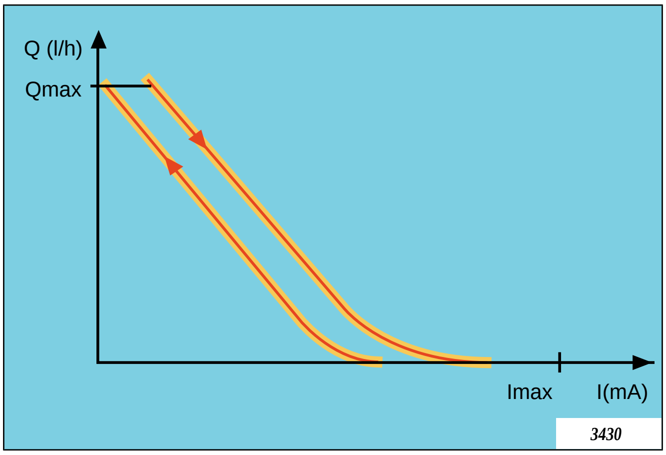
3.4.3 OPERATION

The IMV is used to measure out the amount of fuel sent to the HP pump pumping elements in such a way that the pressure measured by the HP sensor is equal to the pressure level demanded by the DCU.

Each operating point should have the following condition: Amount introduced into the HP pump = amounted injected + injector discharge amount + injector control amount.

The IMV is normally open when it is not being fed: it is made up of two springs of different stiffnesses and loadings. The hydraulic head conical spring being stronger than the coil cylindrical spring keeps the piston item 1 on the IMV section diagram in the fully open position.

It cannot thus be used as a safety device to cut the engine if needed. The IMV is current-controlled. The flow / current curve is shown in the graph opposite.



HP PUMP

The DCU determines the value of the current to be sent to the IMV as a function of:

- Engine speed.
- Flow demanded
- Rail pressure demanded.
- Measured rail pressure.
- Fuel temperature
- Combustion mode

3.4.4 SPECIFICATIONS

Specifications	DFP3
Piston travel	1.4mm
Diameter of orifices	3.5mm
Coil inductance	7.5mH
Coil resistance	5.4 Ω at 25°C
Supply voltage	10.5 to 16V
I maximum	1.3A
Weight	270g
Operating temperatures	minus 40°C to +125°C
Max flow	130 l/h
RCO control	300 to 2000Hz

A new generation of IMVs have been developed to be fitted to the following:

- the latest DFP1s
- all DFP3s

Note: *However whilst the DFP1 & DFP3 IMVs look like each other they are not interchangeable because of hydraulic upgrade reasons.*

The main changes between the old and new generation IMVs are as follows:

- Orifices reduced from 3.5 to 3.0 mm dia.
- Orifices moved.
- Maximum current increased from 1.3 to 1.6 A.
- Springs changed.

Despite these changes the IMV flow characteristics remain the same: the orifice size change is compensated for by increasing the range of control current settings.

HP PUMP

3.5 Pressure limiter

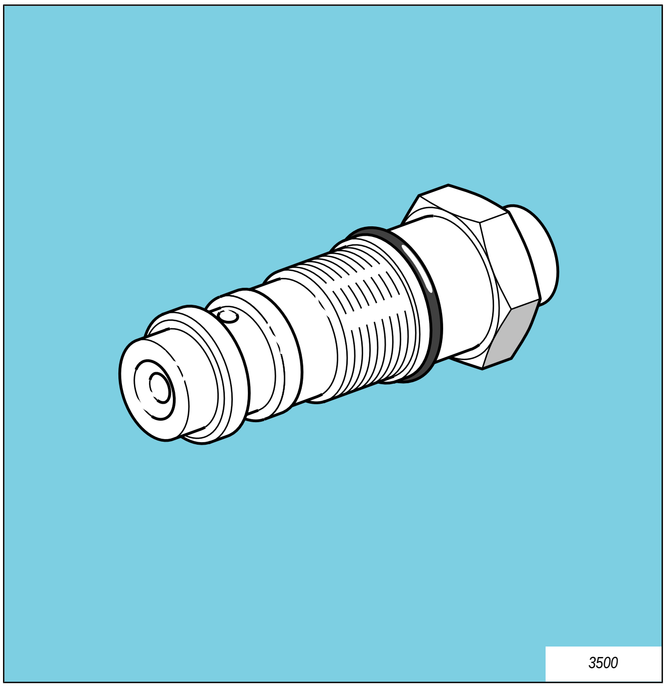
This PLV - Pressure Limiter Valve - component mechanically limits the pressure *(between 1850 and 2250 bar)* in the high pressure pump.

It discharges the pressure on an ad hoc basis if IMV regulation is no longer active or if discharge via the injectors is not being facilitated.

The fuel is recycled to the pump inlet.

This component does not require any network intervention.

Note: *This pressure limiter is not fitted to pumps that have a rail-fitted discharge actuator since this actuator performs a limiter function.*



3.6 Venturi

The Venturiis covered separately because the Venturi is not a major pump element: See chapter on 7.1 Venturi

INJECTOR DFI 1.X

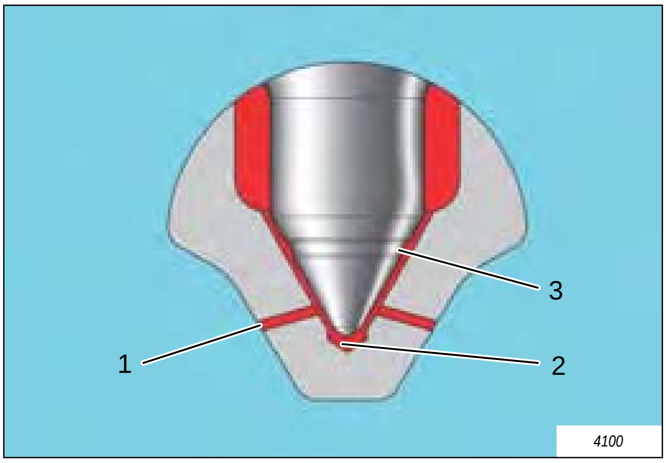
4.1 OPERATION

The Common Rail system injector has been designed to comply with the new depollution standards. It has to do the following to do this:

- Enable multiple injections.*(Up to 5 injections per cycle)*
- Enable small quantities to be injected *(0.5mg/cp)*
- Enable injection at high pressures *(1800bar)*
- Accommodate low-level hydraulic interaction between two successive injections
- Homogeneously distribute the amount injected

The following developments have made these recommendations possible:

- Improvements in the hydraulic system
  - Injector seal diameter modified.
  - Crosspiece orifices modified.
- Modifications made to the injector as follows:
  - Number of holes increased.
  - Conical holes.
- The development of new valves, in particular developments in the materials used for manufacture and in their heat treatment.



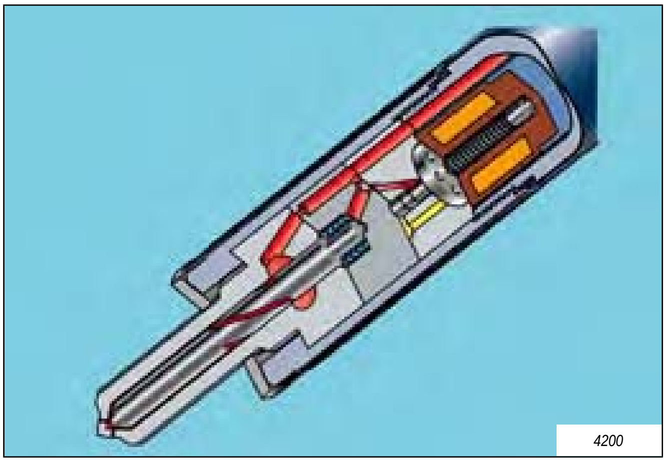
Injector needle - 1: Conical injection hole / 2: Optimised µsac volume / 3: Injector needle geometry

4.2 TECHNOLOGY

Depending on the generation of the injector, maximum injector pressures are of the order of 1800 bar. This means that the forces needed to lift the injector needle are very large. Because of this it is impossible to use an electomagnetic actuator directly to operate the injector needle without using very high currents - and the growth time for establishing such currents would be incompatible with the required reaction times needed for multiple injections. Furthermore using such high currents would require such a lot of electronic power that it would engender substantial heating in the actuator and DCU.

So a valve sited above the needle manages the control chamber pressure rise/discharge by indirectly operating the injector needle in the following way:

- When the needle has to lift *(at injection beginning)*, the valve opens to discharge the control chamber into the return circuit.
- When the needle has to close *(at injection end)*, the valve closes in such a way that the control chamber pressure resets.



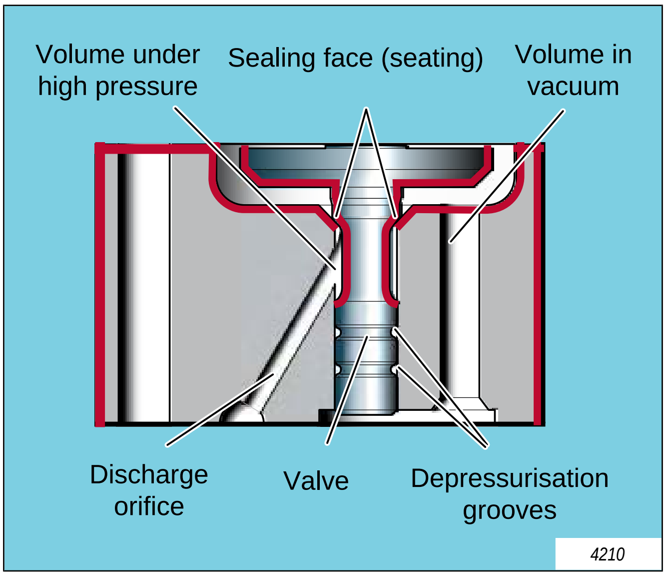
Injector nose

INJECTOR DFI 1.X

4.2.1 Valve

The following design features ensure an acceptable response time along with minimum energy consumption:

- The valve is as light in weight as possible.
- The travel of the valve is as small as possible.
- The force required to move the valve is a minimum. This means that valve has to be in hydraulic balance in the closed position. This balance is obtained through using identical geometry in the valve pressure chamber sections, as well as ensuring that the pressure to each part of the valve is identical. This means only a lightly-loaded spring is needed to hold the valve in its seating. This is then enough to energise the coil to compress the spring and lift the valve.



Valve

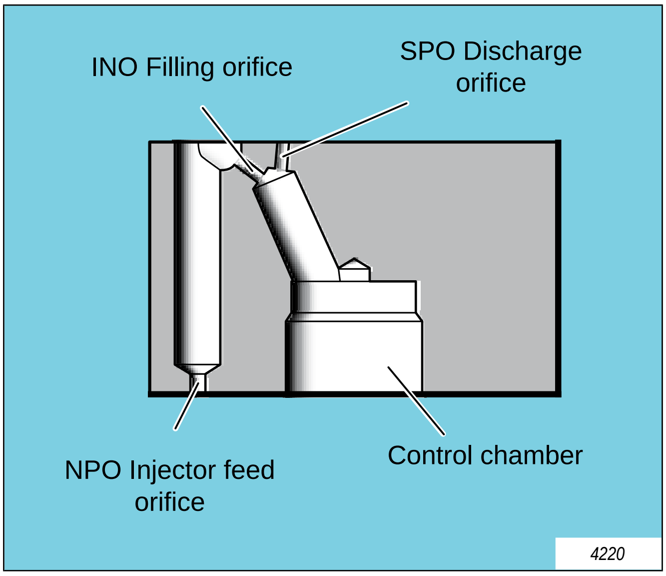
The sensitivity of the valve to polluted fuels has led to developments in heat treatment and in the materials used for valve design.

The new generation of DLC *(Diamond Like Carbon)* valves is the result of these design developments. Applying a DLC lining *(in red in diagram above)* prevents any valve seating deformation or erosion and yet has no operational effect.

4.2.2 Crosspiece

The crosspiece is sited below the valve support bracket. It links the control chamber with the three calibrated orifices used during injector operation. These orifices are as follows:

- Injector feed *(Nozzle Path Orifice: NPO)*.
- Injector discharge from control chamber *(Spill Orifice: SPO)*.
- Fill from control chamber *(Inlet Orifice: INO)*.



INJECTOR DFI 1.X

4.2.3 Specifications

Specifications	DFI 1.2	DFI 1.3	DFI 1.3_1800	DFI 1.4
Operating pressure (bar)	1400	1600	1800	1800
Number of Injections	2	3	3 to 5	3 to 5
Number of electric bank cycle validations (millions of cycles)	200	800	1200	1200
Vehicle Km	250 000	250 000	400 000	400 000

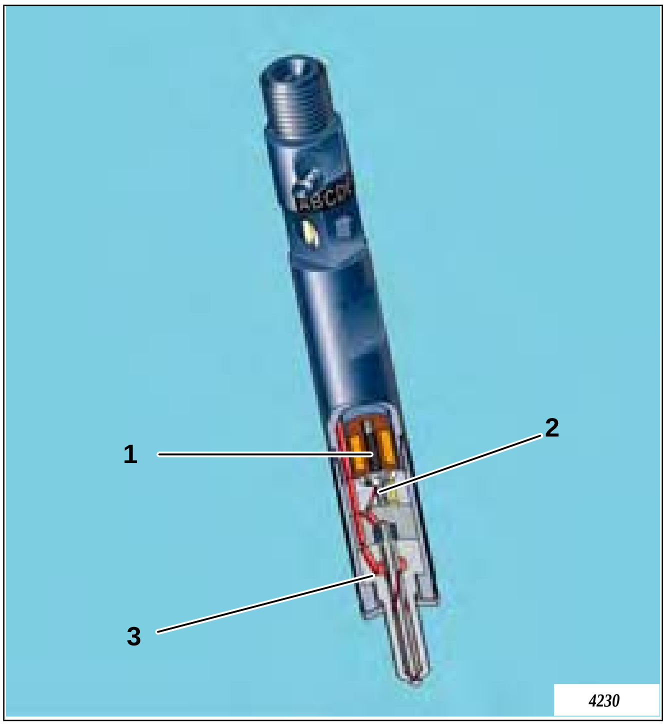
Note: *The kilometrage mentioned in the above table is to be considered in relation to the mode of rail pressure discharge. In fact if the injectors are used to discharge rail pressure, the valves will be more stressed than in a system fitted with an HPV. In the case shown, the valves are only used for injection.*

DFI 1.4 injectors have been developed to do the following:

- Reduce sensitivity to variations in discharge return circuit vacuum levels.
- Reduce drift by using new surface treatments. See DLC on preceding page
- Operate at higher pressure.

The technical developments made in response to these criteria were as follows:

- To increase valve return spring stiffness. *(1)*
- To modify valve internal return circuit. *(2)*
- To change DLC valve surface treatment. *(2)* See DLC on preceding page
- To modify feed conduit and injector gallery. *(3)*

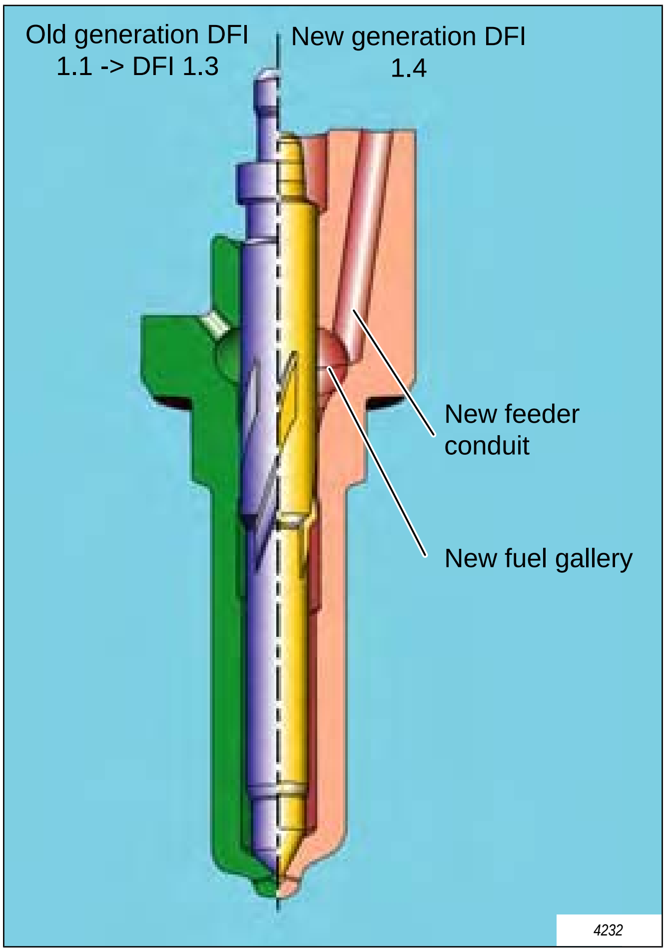


INJECTOR DFI 1.X

The diagram opposite shows the overview of the DFI 1.4 injector development (to right of centre line) in comparison with the old DFI 1. generation of injectors (to left of centre line)

The main changes can be seen as follows:

- At the feed conduit
- At the fuel gallery



INJECTOR DFI 1.X

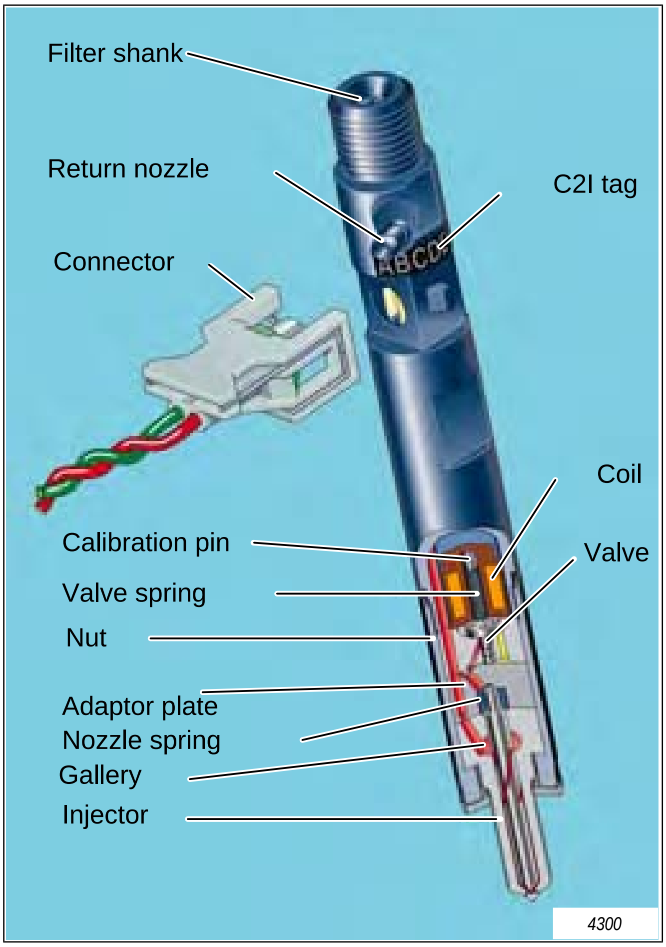
4.3 DESCRIPTION

The Common Rail system injector holder is made up of the following parts:

- A injector nozzle and needle.
- A injector body fitted with feed and return orifices.
- A coil integrated into injector body.
- A connector fitted to injector top.
- A filter shank fitted to fuel feed orifice.
- A crosspiece with control chamber and calibrated jets for operating the needle.
- A valve and support bracket.
- Cap nut.

Eccentric pegs are used to ensure correct angular positioning when assembling injector; crosspiece, valve support bracket and injector holder.

Adjusting valve spring pre-loading is done by inserting a calibration pin between coil and spring.



4.4 OPERATING PRINCIPLE

4.4.1 Pressure propagation

Propagating the pressure in the injector breaks down into several stages, as follows:

- Fuel under high pressure first passes through the injector body before feeding the crosspiece by traversing these jets in the following order:
  - INO: Feed to control chamber.
  - NPO: Feed to injector fuel gallery.
  - SPO: Feed to valve chamber.
- Fuel under high pressure progressively fills valve chamber, crosspiece control chamber and needle helical grooves.

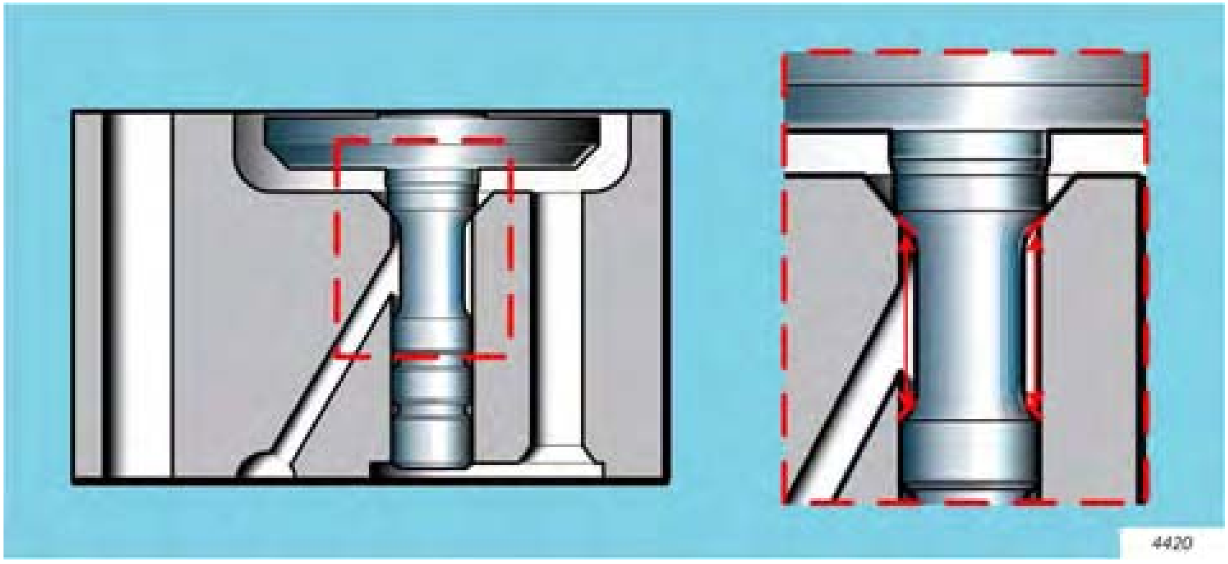
Pressures are balanced across all injectors at this stage.

INJECTOR DFI 1.X

4.4.2 Injector at rest

Pressures balanced keeping injector closed, or at rest. See diagram: Injection fig 4450/1

Identical geometry of sections in bold allows valve to remain closed. Valve is held in equilibrium because the pressures in these two sections are equal.



4.4.3 Coil control

When the DCU activates the coil, the valve opens when the coil force is greater than the spring force. Opening the valve creates fuel discharge to injector return and engenders a pressure fall in the following:

- The valve chamber
- The SPO
- The INO

Needle remains in seating despite this fall in pressure because the fall has not yet reached the control chamber, **so there is no injection.** See diagram: Injection fig. 4450/2

4.4.4 Injection start

Injection start happens when the pressure fall has spread throughout the crosspiece control chamber. In fact the pressure difference across the two ends of the needle creates its imbalance. This translates into the needle rising as the needle nose pressure becomes greater than the crosspiece control chamber pressure.

Fuel goes through NPO to feed injector. See diagram: Injection fig. 4450/3

Note: *Fuel passing through injector feed orifice (NPO) creates a load loss related to the rail pressure. When rail pressure is at a maximum (1600 bar), this load loss exceeds 100 bar. The pressure at the needle cone (injector pressure) is thus less than rail pressure.*

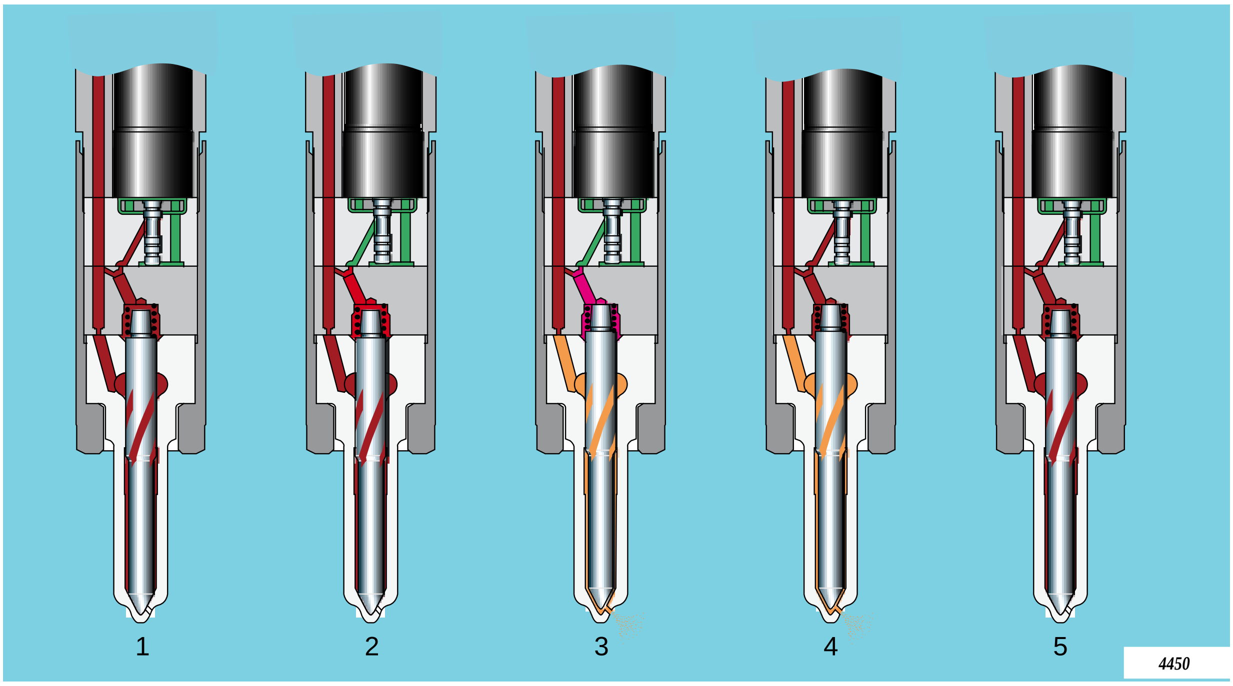
4.4.5 Injection end

When the DCU cuts current to the coil, the valve closes since the coil force becomes less than the spring force.

Following valve closure the circuit regains pressure. However the needle remains out of its seating. See diagram: Injection fig. 4450/4 The only way to reclose it, is to apply a pressure different from that at each of its ends. This pressure difference that will cause the injector to close is created by the load loss across the NPO filling jet, which resists the control chamber pressure that is roughly equal to the rail pressure.

INJECTOR DFI 1.X

When the control chamber pressure becomes higher than the pressure at needle nose, **injection stops.** See diagram: Injection fig. 4450/5



Injection - Red: High pressure (Rail pressure) / Green: Low Pressure / Orange: Injection pressure (Rail pressure - NPO load loss)

Key:

Injector N°	Valve	Needle	Injection
1	Closed	Closed	No injection
2	Opening	Closed	No injection
3	Open	Opening	Injection start
4	Closing	Open	Injection end
5	Closed	Closed	No injection

INJECTOR DFI 1.X

4.5 INJECTOR OPERATION

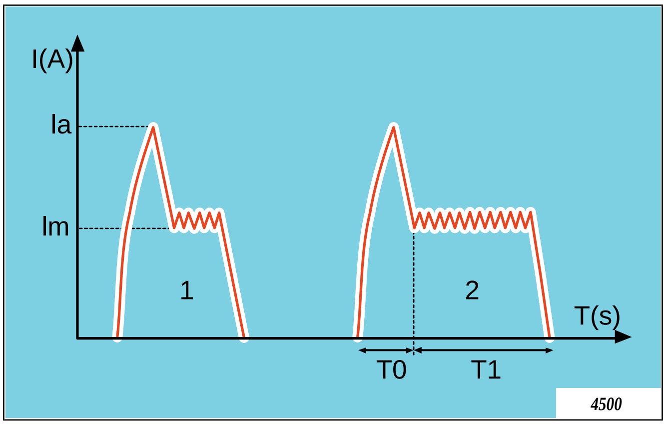
The coil command current takes the form shown in the *Injector pulse* graph.

A staccato-style current reduces loss because of the effect of the electrical energy changes on the DCU and injector.

The start current (Ia) is greater than the maintain current (Im), during the maintain phase:

- With the air-gap between coil and valve reduced *(by valve travel amount, about 30 µm)* the electromagnetic force to be applied to the valve can thus be reduced.
- It is no longer necessary to overcome valve inertia.

1	Pilot Injection	Im	Maintain current
2	Main Injection	T0	Start Current duration
Ia	Start current	T1	Maintain Current duration



Injection pulse

4.6 DISCHARGE THROUGH INJECTORS

Note: *This chapter does not concern HPV-fitted systems.*

Then rail pressure demand falls sharply (if pedal sensor demand goes to 0 (foot lifted) or a fault causes rapid rail discharge for example), IMV closure prevents any new DCU-initiated pressure requirement to be reached sufficiently quickly. The system thus uses the injectors to discharge the rail. This operating mode depends on being able to control the injector response times. In fact, in order to discharge the HP circuit without risking fuel getting into the cylinders, the coil has to receive pulses that are long enough to lift the valve and put the rail directly into communication with the injector return circuit, and yet short enough to avoid the injector needle lifting and causing fuel to enter the combustion chamber unexpectedly.

This way of operating is only possible if the injector response time - that is to say the time between the start of solenoid excitation and the instant when the injector needle lifts - is calibrated perfectly. This time period is obviously different for each injector as it depends on the initial characteristics of the injector *(C2I)* and also on its level of wear *(running in periods)* . It is therefore essential to know the initial characteristics and drift of each injector exactly.

INJECTOR DFI 1.X

4.7 C2I: INJECTOR INDIVIDUAL CORRECTION

Note: *The C2I abbreviation comes from "**C**orrection **I**ndividuelle **I**njecteur" with the number 2 symbolising the two **I**s*

4.7.1 Description

The amount injected is proportional to the injection time *(pulse)* and rail pressure. The flow graphs in relation to pulse time and rail pressure are called the injector characteristics.

Common Rail system injectors are very high precision parts. They are capable of injecting amounts varying from 0.5 to 100 mg/cp under pressures from 150 to 1800 bar. The precision needed requires very small manufacturing tolerances *(µm)* on jet diameters and on the operating play between the different moving parts. However, machining variations, load losses, any contact between moving parts and magnetic forces cause variances between one injector and another. Because of this, flow variations can reach 5 mg/cp. In other words, that means that the same pulse applied to two injectors could produce a difference of 5 mg/cp.

It is impossible to control an engine effectively with such a variance between injectors. So it is necessary to apply a correction so that the required amount of diesel is injected whatever may be the initial characteristics of the injector. For this to happen, it is necessary to know the injector characteristic and correct the pulse applied to the injector as a function of the difference between this characteristic and that used in the DCU.

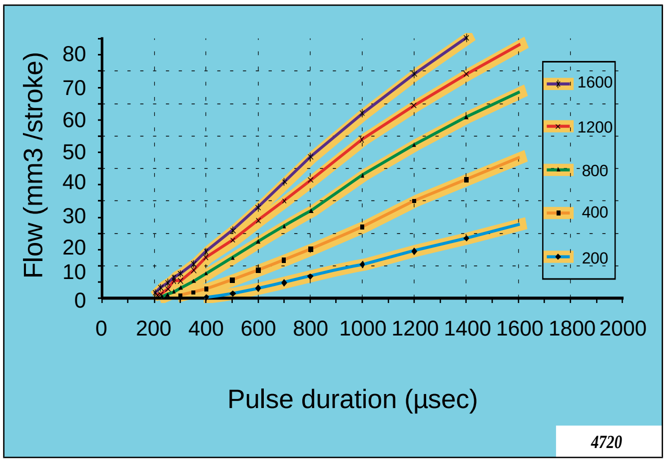
The characteristic recorded in the DCU is called the target. It is the mean characteristic of flows measured from a representative batch of injectors. This target is used to convert the flow demand Q in pulse time T. However this pulse cannot be applied directly to the injector since the characteristics of this latter are different from the target. It is therefore necessary to correct the pulse time T using the particular injector characteristic. This characteristic is determined by measuring the flows for different pressure values. The C2I is a modelling procedure for these characteristics.

4.7.2 Procedure

The injectors are tested at the end of the manufacturing line. The measurements are processed to work out correction coefficients. These coefficients are written on the injector in two forms, as follows: in a data matrix code and in alphanumeric characters.

To correct the flow differences between injectors and the target, each injector is marked with the flow difference between the actual pulse time and the target pulse time as a function of flow, for a given pressure.

- The corresponding corrections be then determined for pilot and principal flows from the graph, for four pressures *(200, 800, 1200 and 1600 bar)*. That produces **eight coefficients.**
- From this we get a *(Pressure, Flow and Correction)* card that gives us the correction to apply to the target pulse to obtain the required flow.



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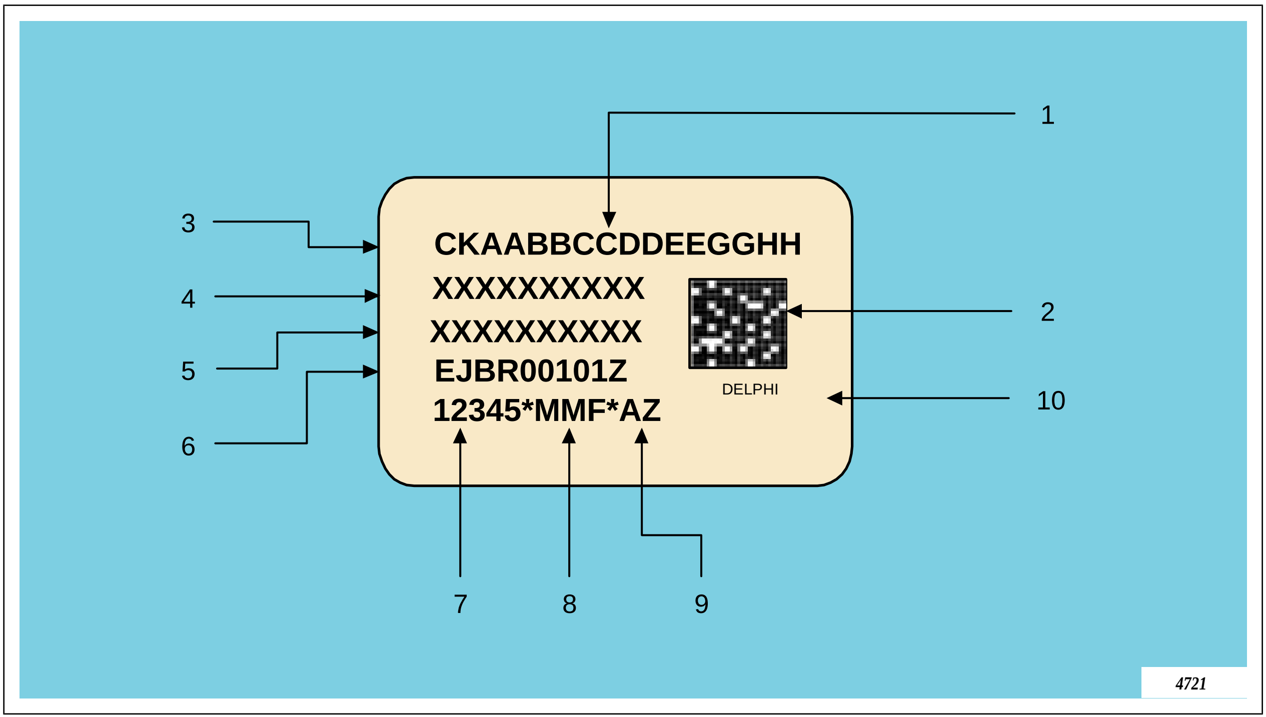
INJECTOR DFI 1.X

Label encryption is a complex operation, since we have to employ the level of resolution that is strictly necessary to optimise this method *(and limit label size)*. Each coefficient has been coded into a number of bits that is unique to that coefficient.

1	Label	6	Injector Delphi Diesel reference
2	Code data matrix (Factory reading)	7	Chronological serial number
3	Correction factors (C2I)	8	Date and place of manufacture
4	Vehicle builder reference	9	Injector day of manufacture
5	Builder approval number	10	Delphi logo



C2I label

Note: *Code Data Matrix Information:*

- *Correction factors*
- *Injector holder Delphi reference*
- *Injector holder vehicle builder reference*
- *Date*
- *Site code*

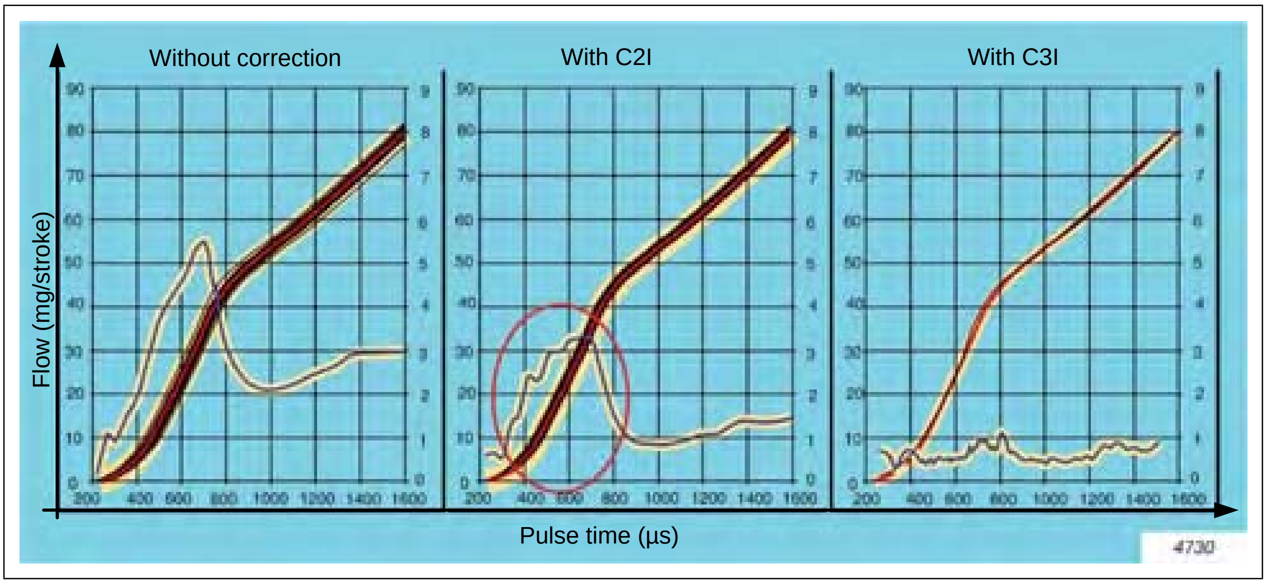
4.7.3 Development: C3I

To reduce the very small deviations that remain still after C2I correction and to get as close as possible to the target, a new type of injector correction procedure has been developed, and this is known as C3I.

C3I comes from the name in English, Correction Improved Individual Injector.

C3I has been introduced to increase the accuracy of the C2I correction procedure. In fact, if we take the following diagram as an example, we can see the significant gain brought about by using C3I.

INJECTOR DFI 1.X



Flow curve study for 1600bar rail pressure; Red: Target; Black: Injectors measured: Blue: Typical difference between target and measured injectors: Encircled: C2I inaccuracy zone

The two major differences between C3I and C2I are the following:

- A three-part linear correction is possible with C3I whilst C2I only allows a single linear correction.
- A different encoding method as follows:
  - C2I: 16 Hexadecimal characters.
  - C3I: 20 Alphanumerical characters.

INJECTOR DFI 1.X

4.7.4 Read/Write

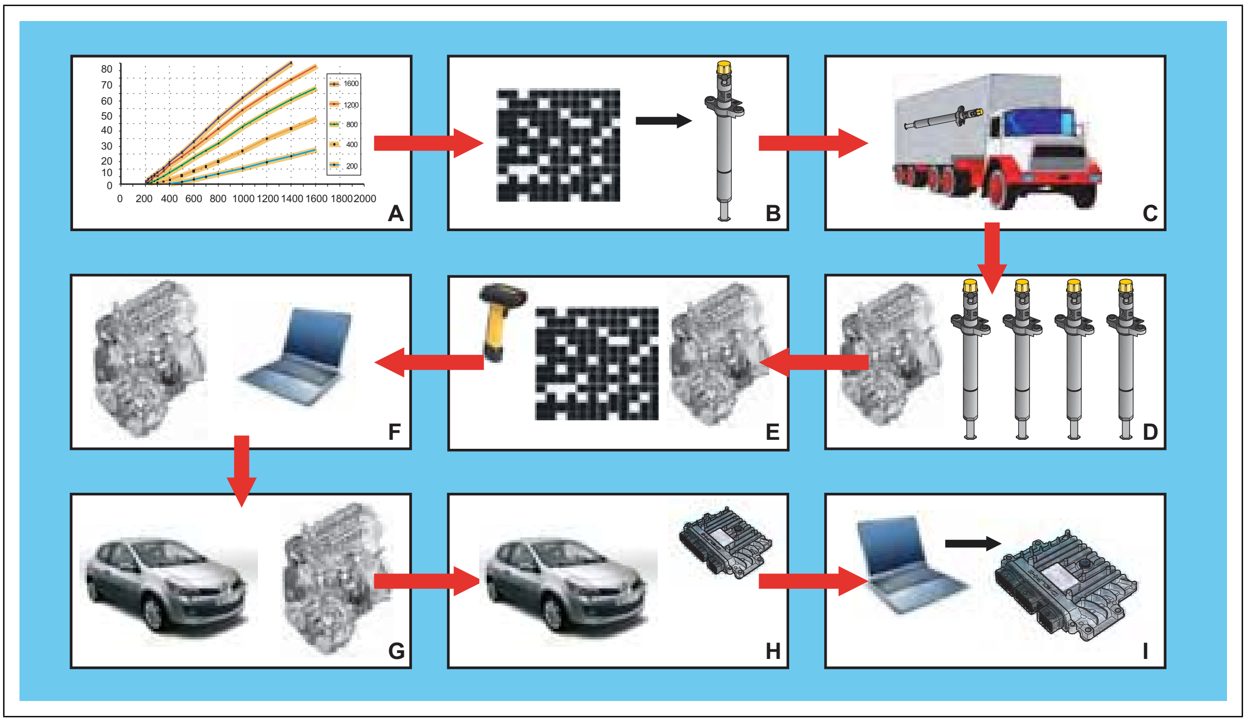
Matrix data is read and stored on an intermediary medium in the engine factory. This intermediary medium contains C2I *(or C3I)* data and the cylinder number on which the particular injector has been fitted. The C2I *(or C3I)* data on the four injectors is read before the injectors are fitted on the engine so as to facilitate using a laser reader on the matrix code data. Through this process the client can thus guarantee that there is no risk of any reversal of the order of reading codes and the order of the cylinders on which the injectors are going to be fitted. In the vehicle factory, the contents of the intermediary medium are read than dowloaded to the injection system DCU.

In after-sales, if one or more injectors need replacement, it is necessary to load their C2I data into the DCU. This operation automatically re-intialises the back data linked to the old injectors.

When replacing the DCU, it is necessary to load the C2I (or C3I) data and vehicle settings into the new DCU.

Note: *Other stages such as programming the DCU and saving the back data from the old DCU into the new DCU have to be done following any C2I downloading, but the method is often specific to each builder and cannot thus be described in a generic workshop manual.*

A	Characterisation	F	Temporary saving
B	Encoding	G	Engine/Vehicle assembly
C	Delivery	H	DCU/Vehicle assembly
D	Fitting to engine	I	Loading C2I into vehicle
E	Read C2I for each injector		



C2I/C3I loading method

RAIL ASSEMBLY

5.1 RAIL

The rail is a pressure reservoir downstream of the high pressure pump. It forms a reserve of diesel under high pressure ready to be used by the injectors.

The rail assembly is made up of the following:

- Body
- Rail pressure sensor
- The following end pieces: 1 pump inlet and X injector outlets
- HPV as an option

4741

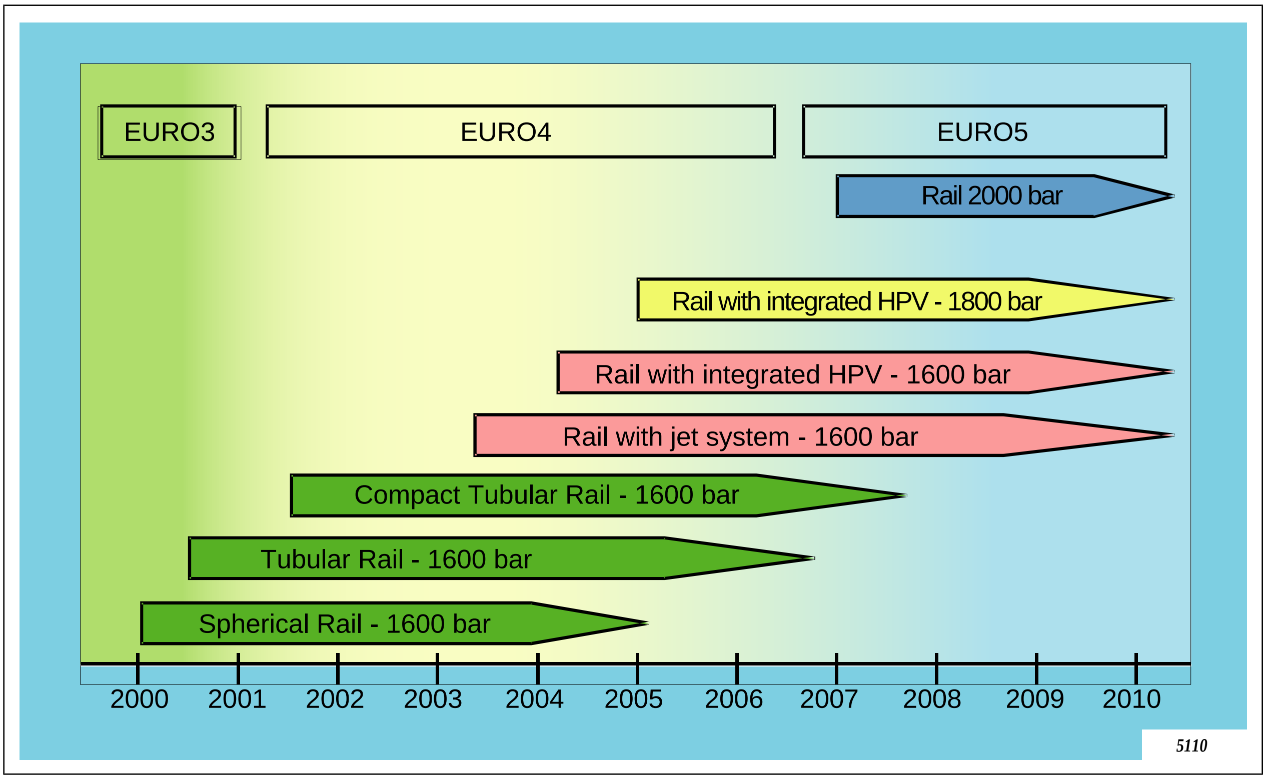
Fitted rail assembly:

- HPV to left.
- At bottom: Four injector outlet end-pieces.
- To the right: Rail pressure sensor
- Second end-piece coming from the right: high pressure entry end-piece

RAIL ASSEMBLY

5.1.1 GENERAL

The diagram below shows the development stages of the rail in relation to the pollution standards EURO3, 4 & 5.



Generations	Types	Applications	Volumes (cm^3)
DFR 1	Spherical rail	Ford Lynx, Renault K9	18
DFR 1D	Spherical rail with jet system	Renault K9 Euro4	18
DFR 2.1	Tubular ring rail	Ford Puma, SsangYong	18.7
DFR 2.1D	Tubular ring rail + jet	/	/
DFR 2.2	Tubular rail	Kia, SsangYong	19.5
DFR 2.2D	Tubular rail + jet	/	/
DFR 3	Tubular rail with HPV	Cummins	19.5
DFR 3D	Tubular rail with HPV and jet system	Daimler Chrysler	26.5

RAIL ASSEMBLY

5.1.2 RAIL CHOICE

Choosing rail type:

The spherical rail represents an advantage because of its low bulk, but can only be used on relatively small engines since its use means having to use rail/injector tubes that are longer than those used with a tubular rail. Using these longer tubes provokes greater load loss. However the sperical rail offers a significant advantage in hydraulic terms since all paths to the injectors have the same length. The tubular rail has the advantage of having identical rail/injector tubes.

Rails	Spherical rail	Tubular rail
Hydraulic path	+	-
Possibility of having identical rail/injector tubes	-	+
Impact of tube length in terms of load loss	-	+
Weight	+	-
Cost	+	-

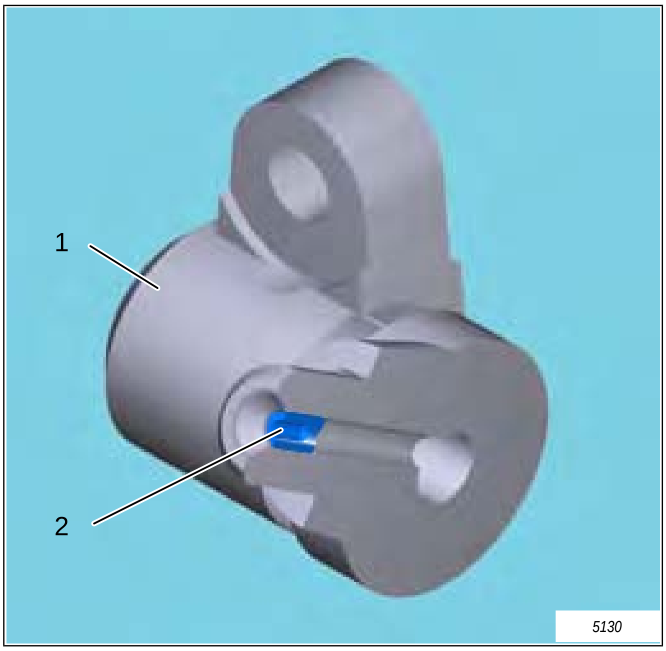
Volume choice:

The smaller the rail internal volume, the easier it is to fill and empty and thus to increase and decrease pressure. These advantages are gained at the expense of the stability of pressure control stability and the rate of introduction at injection end. The choice of rail volume thus involves a compromise between the duration of any transitory phases, the size of any pressure fall during injection, and the degree of stability of control.

5.1.3 JET

Fitting jet pieces to the injector outlets is meant to limit rail pressure oscillations caused by the injection process and any pump pressure variations. This system alllows more precise injection control.

1. Rail
2. Jet



Installing jet

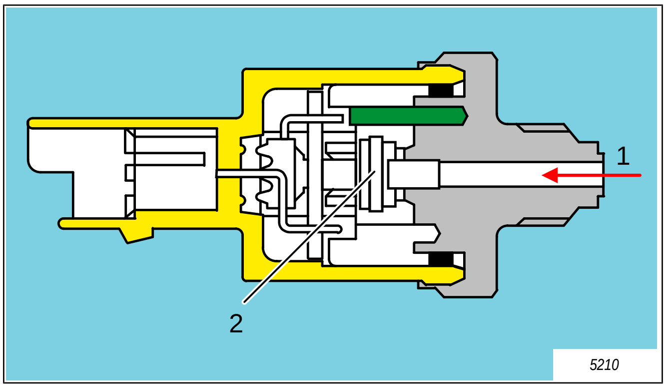
RAIL ASSEMBLY

5.2 RAIL PRESSURE SENSOR

5.2.1 OPERATION

The pressure sensor is essentially made up of a metallic membrane that deforms under pressure. The membrane has a fitted piezo-resistant element whose resistance varies in relation to membrane deformation. This deformation thus represents the amount of pressure in the rail.

1. Diesel under high pressure
2. Membrane



Rail pressure sensor

5.2.2 INSTALLATION

The sensor is screwed to the rail. A soft steel washer ensures sealing at high pressure. Using a pre-defined torque and angle that makes the best use of the axial force ensures complete sealing.

The latest versions do not use a sealing washer. The sensor/rail contact is direct, as for the HPV.

5.2.3 SPECIFICATIONS

There are several versions of this sensor that allow measurements up to 1600, 1800 and 2000 bar.

1800 bar sensor	Specifications	
Accuracy	+/- 1% between 0 and 1000 bar for diesel temperatures between 20°C and 100°C +/- 1.6% between 1000 and 1800 bar for diesel temperatures between 20°C and 100°C	
Max pressure without significant degradation	2200 bar	
Max pressure that could lead to significant degradation	> 2500 bar.	
Body	Machined body	Mechanically welded body
Connection system	Type SIGMA 2	Type KOSTAL

RAIL ASSEMBLY

5.3 HPV

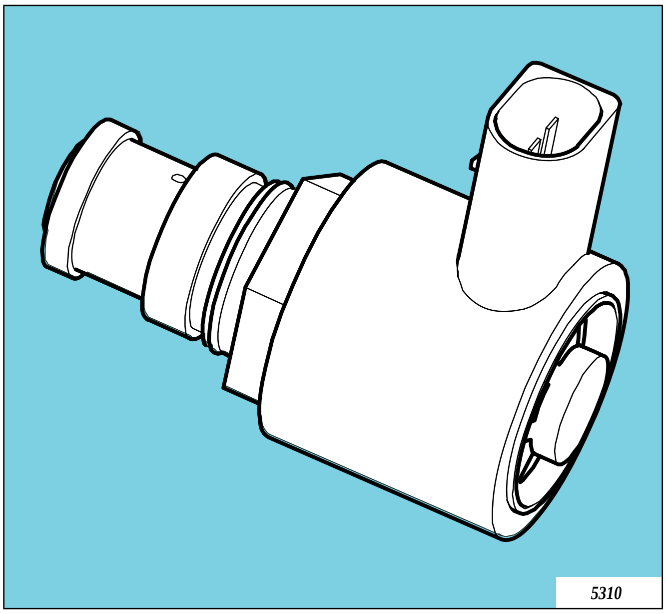
5.3.1 OPERATION

This High Pressure Valve (HPV) actuator is fitted to the rail and is designed to control rail pressure.

Note: *An HPV-fitted Common Rail system no longer programmes injector discharges. The HPV actuator in the system takes over this function.*

The HPV does the following:

- Reduces high pressure circuit pressure when discharging diesel.
- Accurately controls rail pressure oscillation peaks.
- Limits pressure in case of system overpressure. The HPV thus protects the Common Rail system, in particular the rail and injectors.
- Controls rail pressure when:
  - The IMV is no longer electrically controlled.
  - There is a pressure sensor fault.
  - The system is not fitted with an IMV.



HPV overall view

Note: *The HPV should also maintain sufficient pressure to start and turn over when a circuit is open electrically (HPV disconnected).*

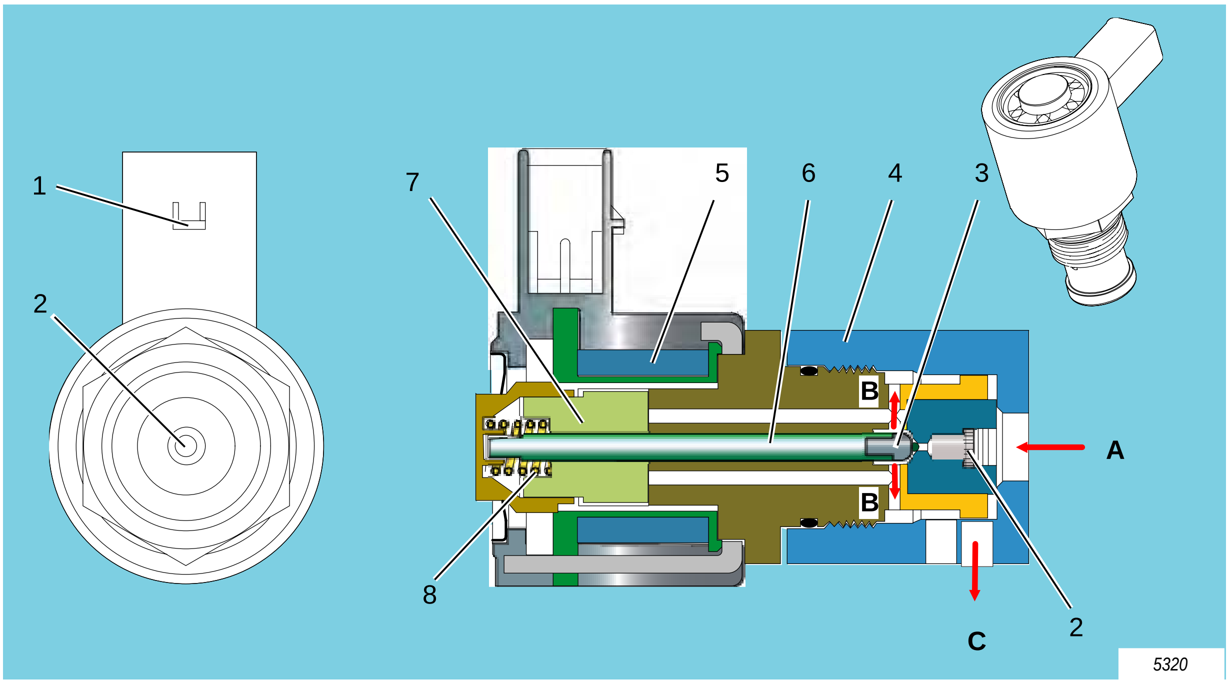
RAIL ASSEMBLY

5.3.2 DESCRIPTION

The HPV is fitted to the rail. It is made up of the following elements:

- A piston held in full closed position by a spring.
- A electrical connector
- A current-controlled coil.
- A piston-linked pin for opening and closing the HPV via a ball follower.
- A body with axial feed orifice and two discharge orifices.
- A cylindrical filter fitted to feed orifice.

1	Electric connector	5	Coil
2	Filter	6	Pin
3	Ball follower	7	Piston
4	Rail end-piece	8	Spring



HPV section view

A. Diesel under high pressure coming to rail.
B. Diesel discharged from rail.
C. Diesel fed to discharge return.

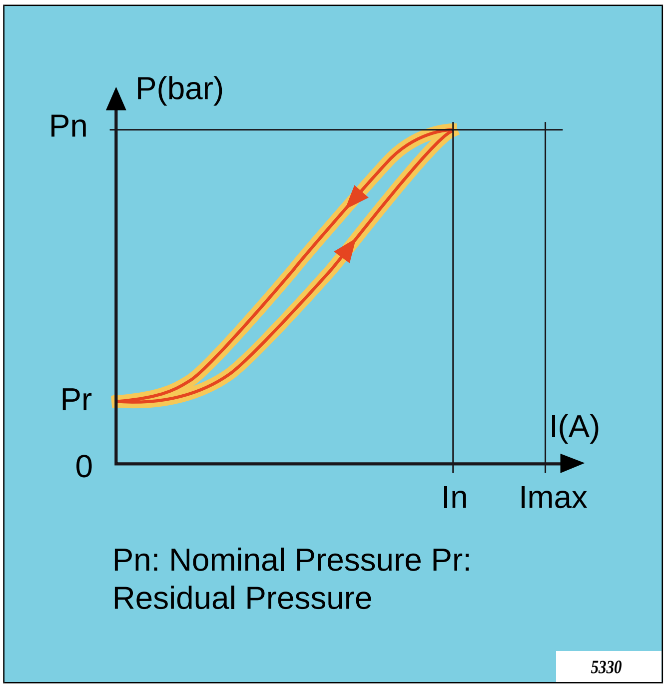
RAIL ASSEMBLY

5.3.3 OPERATION

The HPV is normally closed when not powered. It can be used as a safety device to cut engine if needed. The IMV is current-controlled. The flow / current curve is shown in the graph opposite.

The DCU determines the value of the current to be sent to the IMV as a function of:

- Engine speed.
- Rail pressure demanded.
- Measured rail pressure.
- Fuel temperature.
- Combustion mode.



Relation between rail pressure and current

RAIL ASSEMBLY

FILTER

6.1 DESCRIPTION

The filter protects the Common Rail system by:

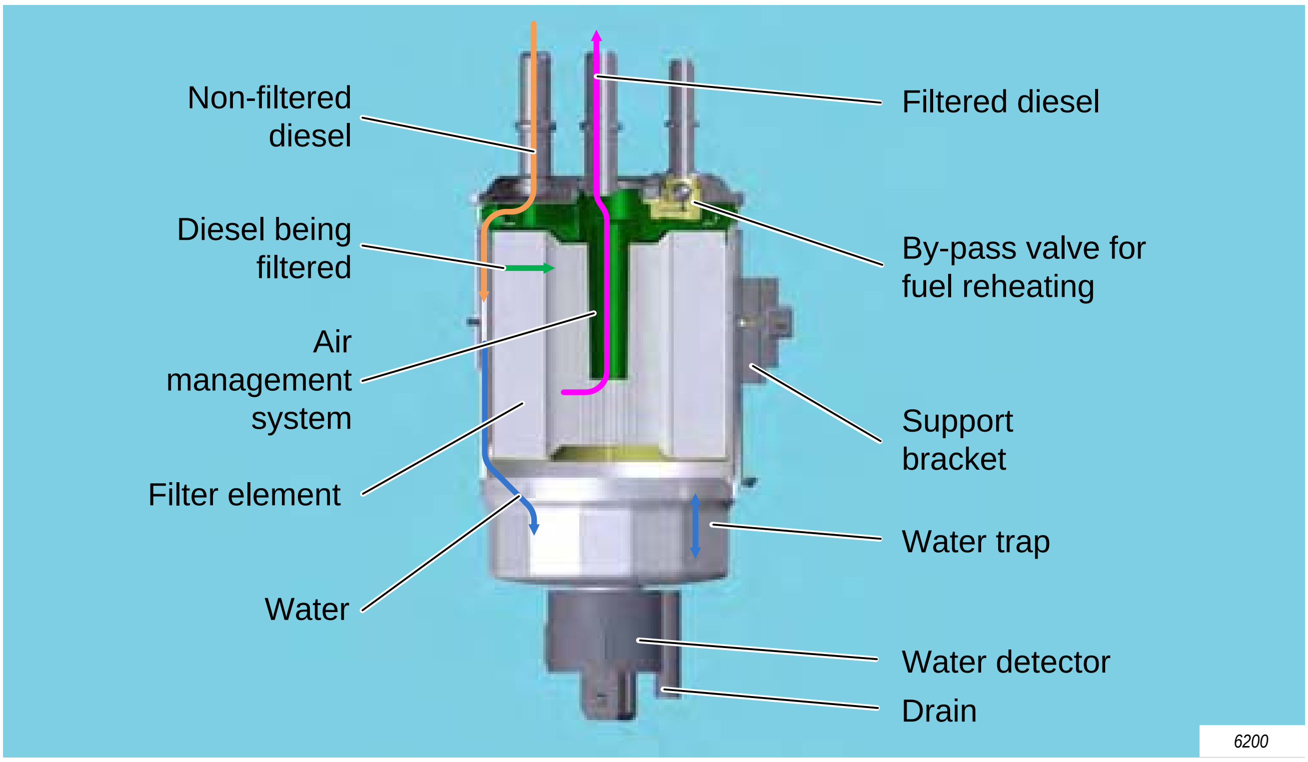
- Separating out and storing diesel impurities so as to avoid any pollution of the Common Rail system.
- Separating and storing any water naturally present in the diesel fuel.
- Evacuating any air in the fuel circuit.

The filter should be able to adapt to all configurations by operating both under pressure and in a vacuum.

Specifications	Vacuum	Pressure
Vehicle consumption	12l/100km	12l/100km
Mean flow	130 l/h	180 l/h
Max flow	160 l/h	230 l/h
Critical Conditions	Max vacuum: 700 mb	Max pressure at filter entry: 400 mb

Note: *In the table above, "critical conditions" are the maximum acceptable conditions for the system before any rail pressure regulation problems appear.*

6.2 TECHNOLOGY



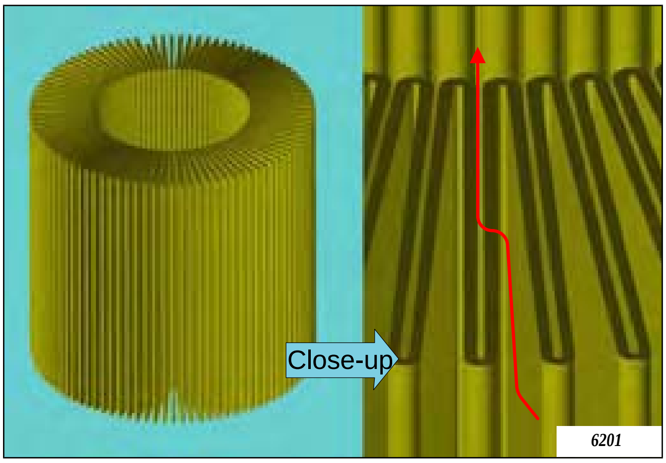
FILTER

The filter element could have two types of structure as follows:

- Rolled
- Crinkled

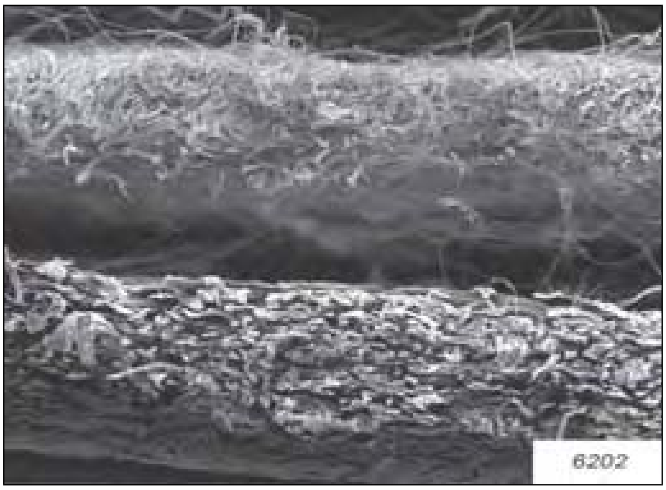
Rolled-type filters are made up of flat elements arranged in a roll. Diesel passes through the tube wall and penetrates the porous fibre, and any particles are held in stored on the tube surface. This technology is no longer used because of the limited element life for this type of filter. The sensitivity of common rail systems has led to a new design of filter element in the form of a crinkled structure.

Crinkled structure filters are arranged in spirals to improve filtration capacity. Diesel is filtered as it passes through the filter from one part to another. The filter element is made up of a combination of cellulose and artificial fibres.



6201

The photo opposite shows a blown up view of a crinkled filter element. The fibre at the top is made of Polymer. It filters out large particles and stops any water in the fuel. The second fibre at the bottom of the photo is made of cellulose and filters out small particles.


6202

FILTER

6.2.1 FILTERING OUT IMPURITIES

The designation for 2 & 5µm filters is a commercial categorisation. Standard Filter means "5 µm" and High Efficiency Filter means "2 µm".

Two measuring procedures can determine the 2 µm or 5 µm categorisation.

- The Beta ratio (ß) procedure measures the ratio of particles stopped by the filter between the clean part and the dirty part, for a given size.
- The Differential (Diff) procedure measures the percentage of particles stopped by the filter for two given sizes.

Filters	2µm	5µm
Beta	ß (4µm)>96% ß (4µm)>99.6% ß (14µm) not measurable as it is too close to 100%	ß (4µm)>93% ß (14µm)>99.2%
Differential	Diff (3-5µm & 5-6µm) >95%	Diff (3-5µm & 5-6µm) >90%

6.2.2 SEPARATING OUT THE WATER

Water is filtered through the polymer in the filter element See Filter Element Photo above fig. 6201. The water is unable to pass through the element because of its polymer-repelling properties and spore dimensions.

Depending on the quality of fuel being used, Delphi recommends using a filter in the following ways:

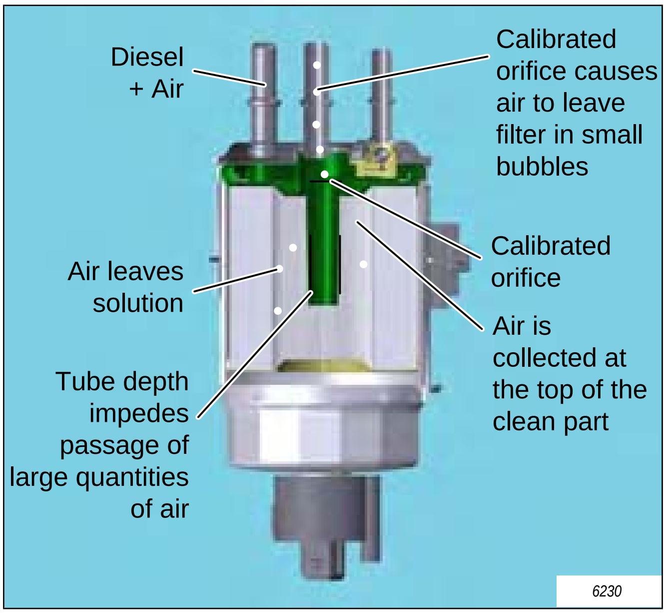
- For good quality fuels, use a collector to separate out the water;
- For average quality fuels, use a collector and water sensor to separate out the water;
- For low quality fuels, use an independent water separator with collector and water sensor to separate out the water.

Filters	2 µm	5 µm
Efficiency	95% of water stopped for a 130 l/h flow with 2% water in the fuel.	80% of water stopped for a 80 l/h flow with 2% water in the fuel.

FILTER

6.2.3 AIR MANAGEMENT

The filter should be able to handle any air in the fuel circuit. The purpose is to protect the HP pump by limiting the air in the circuit. This is done using filter storage and converting the residual air into bubbles small enough (<3mm) for the common rail system to handle.

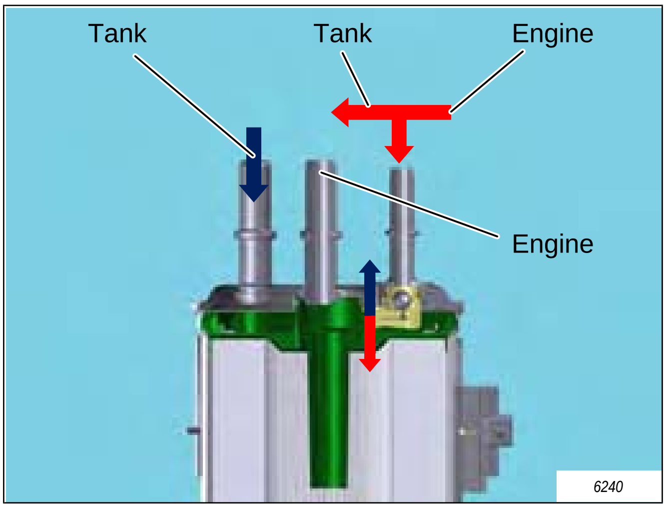


6.2.4 REHEATER (OPTION)

Its purpose is to raise the temperature of the fuel in the system. It is used mainly for cold start conditions. It can be fitted directly into the filter or placed in the fuel line *(as is the case for Kia with an electric reheater outside the filter)*.

In this case we are interested in systems integrated into the filter, as follows:

- **Hydraulic/thermal with bimetal strip and recirculation** *(Renault K9)*. In this particular case, the fuel temperature is measured by two metallic strips. Below the low temperature threshold, a quantity of fuel from the return circuit is reheated then re-routed to the intake circuit after filtering. Above this threshold, the valve progressively closes as a consequence of the amount of reheated fuel diminishing - as this table shows:



- **Thermal switch** *(Peugeot DV4)*. This type of reheater is directly clipped to the filter. The thermal switch ensures reheating for fuel temperatures between 0 and 5+/- 5°C. This type of thermal switch has a negative temperature cooefficient *(reistance diminishes as temperature rises)*.

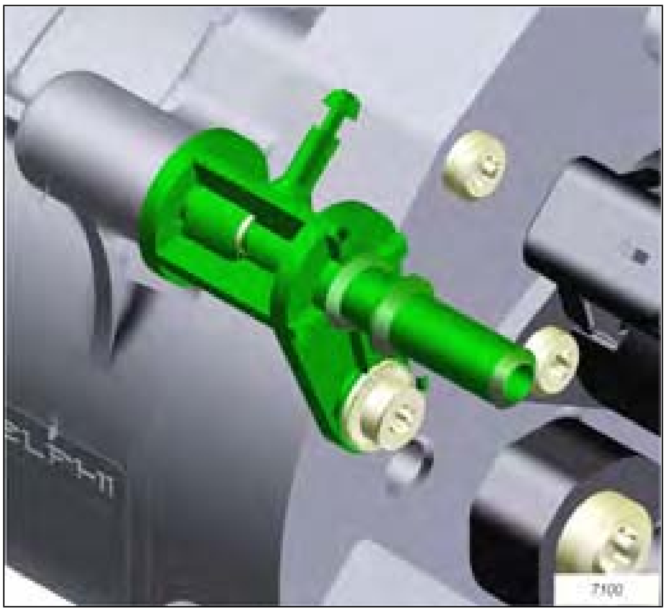
Fuel Temperature (°C)	T°<0	0<T°<50	T°>50
Reheated fuel flow (litres/hour)	45 - 55	Progressive lowering	< 5

VENTURI

7.1 DESCRIPTION

The purpose of the venturi is to create a vacuum in the injector return circuit to avoid injector control chamber pressure fluctuations as far as possible. This has the end purpose of avoiding any injection control disturbance.

Whilst the venturi is commonly placed on the pump, it can also be placed independently of the pump. (*(Example: PSA DV4TED4 & DAIMLER OM646)*



7.2 OPERATION

The Venturi principle is where a reduction in fuel pressure is induced at points where the speed of fuel flow is increased. Passing through the narrow part the fuel speed of flow increases at the expense of pressure. The internal architecture of the venturi defines its prevailing pressures and flows in the venturi.

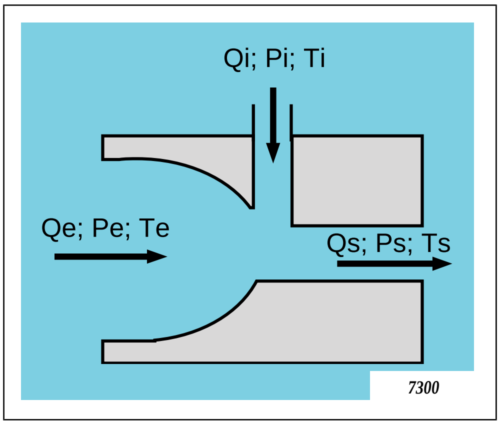
In the case of the common rail low pressure circuit, the pressure at venturi entry is greater than atmospheric pressure (Pe), the suction value at the discharge return point (Pi) results in a Pe-Pi>O vacuum.

VENTURI

7.3 SPECIFICATIONS

This is an example of Entry/Exit characteristics for a venturi fitted in a Delphi common rail system

Abbreviations	Descriptions	Specifications	Diagrams
Qe	Entry flow of fuel coming from pump	70<Qe<120l/h	
Pe	Entry pressure of fuel coming from pump	200<Pe<350mb	
Te	Entry temperature of fuel coming from pump	-40<Te<95°C	
Qi	Intake flow of fuel coming from injector return	0<Qi<25l/h	
Pi	Intake pressure of fuel coming from injector return	Pi<-10mb	
Ti	Intake temperature of fuel coming from injector return	-40<Ti<140°C	
Qs	Flow of fuel exiting to tank	70<Qs<140l/h	
Ps	Pressure of fuel exiting to tank	40<Ps<80mb	
Ts	Temperature of fuel exiting to tank	-40<Ts<130°C	



Note: *In the case of a force-feed pump, a by-pass system in parallel with the HP pump ensures continuing hydraulic operation. A vacuum is thus present from the time of ignition switch-on before starting engine.*

THE DCU

8.1 OPERATION

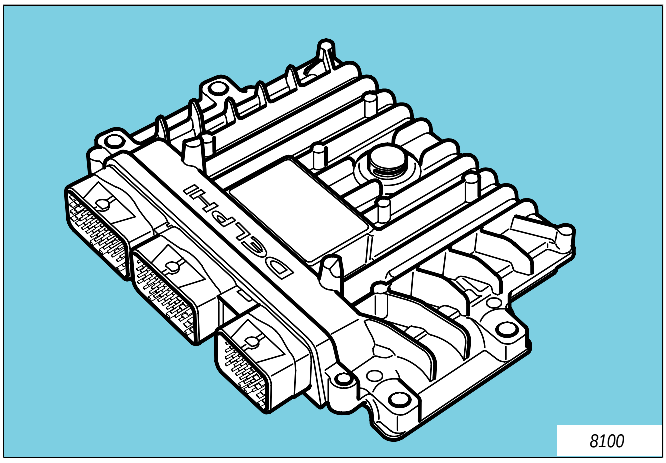
The DCU can have several descriptions, as follows:

- ECU as in Electronic Control Unit,
- Diesel Control Unit (DCU)
- DCM as in Diesel Control Module.

This unit is the heart of the injection control system. It ensures the injection system functions correctly and can also ensure satisfactory management of the engine, indeed the vehicle.

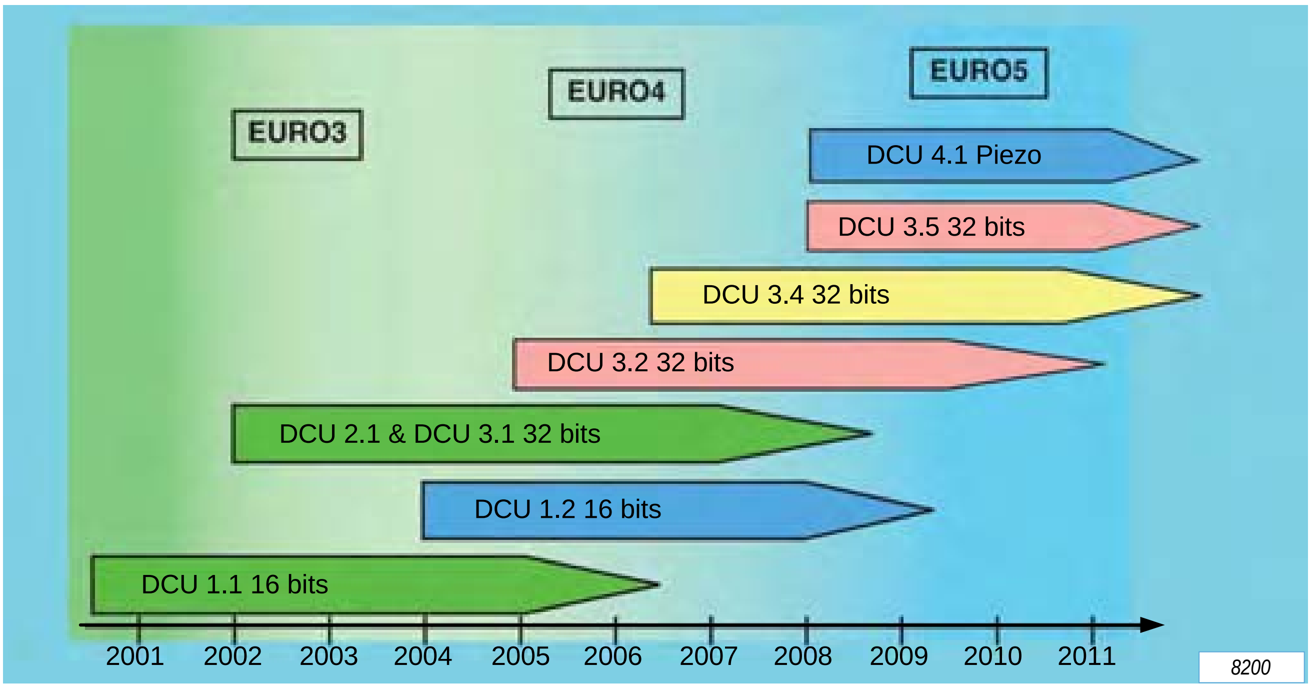
The DCU manages the following:

- Connection with sensors *(Example, rail pressure sensor)* and actuators
- Connection with actuators *(Example, Fans)*
- Control of actuators *(Example, EGR valve)*
- Processing of sensor and actuator signals *(Examples: Accelerometer sensor signal and Turbo position)*
- Strategy control.
- Communication with other ECUs



DCU Delphi DELCO 3.4 PSA

8.2 SPECIFICATIONS



Developing DCUs as a function of depollution standards

THE DCU

Generations	Number of paths Number of connectors	Types	Standards	Applications
1.1	112 paths / 3 connectors	TRW 16bits	EURO3	Renault K9/Kia/Ford Lynx
1.2	112 paths / 3 connectors	TRW 16bits	EURO4	Renault K9
2.1	112 paths / 3 connectors	TRW 32bits	EURO3	PSA DV4TED4
3.1	121 paths / 1 connectors	Delco 32bits	Advanced EURO3 and EURO4 programmes	Ford/SsangYong
3.2	154 paths / 2 connectors	Delco 32bits	EURO4	Daimler Chrysler OM646
3.3	124 paths / 2 connectors	Delco 32bits	TIER3	JCB
3.4	128 paths / 3 connectors	Delco 32bits	EURO4 & 5	PSA DW10B / Renault K9 €5
3.5	154 paths / 3 connectors	Delco 32bits	EURO 5	PSA DW10C / Daimler Chrysler OM651 Solénoïde
4.1	154 paths / 2 connectors	Delco 32bits	EURO 5 Piezo injector	Daimler Chrysler OM651 Piezo

RAIL PRESSURE CONTROL

Pressure control uses two main modules as follows:

- The first determines rail pressure demand as a function of the engine operating conditions.
- The second guides the IMV so that the rail pressure reaches the required value.

Note: *Another regulation unit has been developed for HPV control on new applications.* *See section 5.3 HPV*

9.1 PRESSURE REQUEST

The request for pressure is determined as a function of engine speed and loading. The objective is to adapt injection pressure to engine needs, as follows:

- When speed and loading are high, turbulence is very high and fuel can be injected under very high pressure to ensure optimum combustion.
- Under low loading and low speeds, filling rates and turbulence are low.

Pressure demand is corrected as a function of air temperature, water temperature and atmospheric pressure so as to take into account the increase in burn time provoked by particular conditions such as cold starting or high altitude running.

A specific pressure demand is needed to be able to obtain the surcharge flow required for starting. This demand is determined as a function of the amount injected and the external conditions *(mainly the fluid temperatures)*

The pressure demand is limited as a function of the fuel temperature. In fact not all the diesel compressed by the HP pump is injected into the engine. The return circuit sends a part of the compressed diesel liquid to the fuel tank. The diesel discharge from rail pressure to atmospheric pressure provokes a subsantial release of heat into the fuel tank.

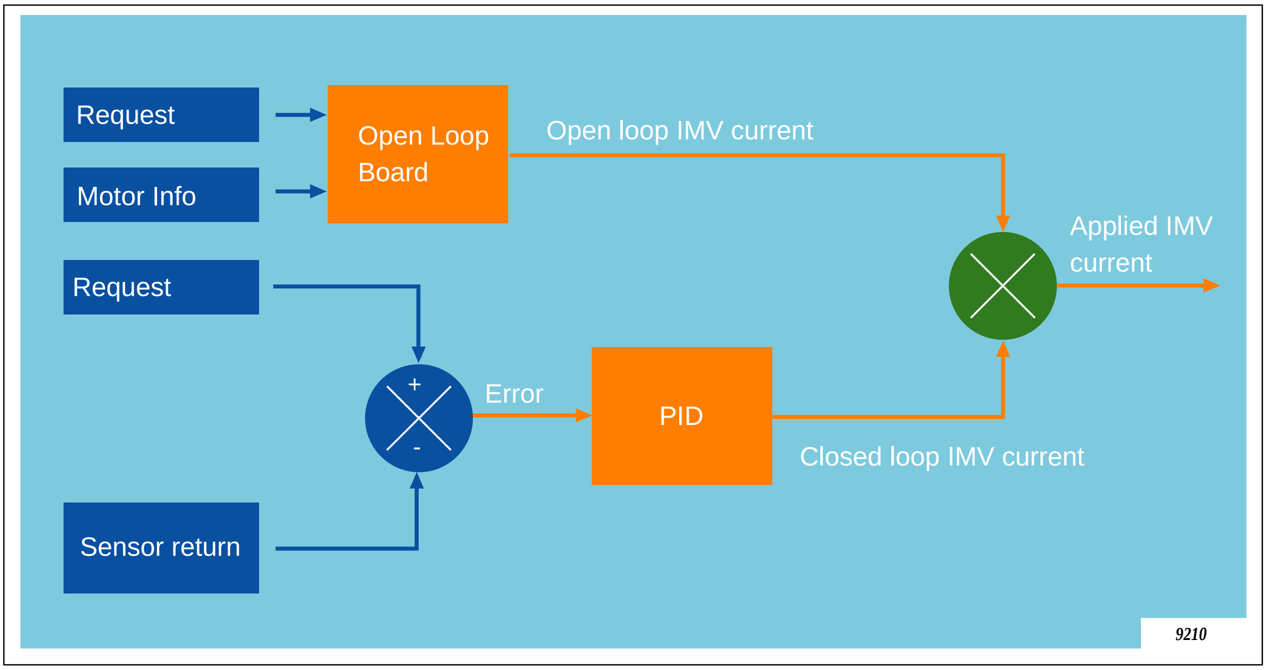
RAIL PRESSURE CONTROL

9.2 PRESSURE CONTROL

9.2.1 WITH IMV ALONE

Rail pressure control is done by closed loop regulation of the filling actuator. A cartograph *(called open loop)* determines the current that should be sent to the actuator to obtain the flow requested by the DCU. A closed loop is in a position to correct the current value as a function of the distance between the value requested and the pressure value as follows:

- When the pressure is less than that requested, the current is reduced so that the amount sent to the HP pump is increased.
- When the pressure is greater than that requested, the current is increased so that the amount sent to the HP pump is reduced.



The principle of rail pressure regulation using an IMV

9.2.2 WITH HPV

The principle of rail pressure regulation using an HPV is the same as that for using an IMV. The current applied to the HPV is calculated by adding the open loop current to the closed loop current. *(PID)*

When the common rail system is fitted with an HPV, several types of rail pressure regulation are possible, as follows:

- HPV alone: IMV fully open: the HPV exclusively controls rail pressure.
- IMV alone: HPV closed: the IMV exclusively controls rail pressure.
- HPV+IMV: Both actuators simultaneously control rail pressure.

INJECTION CONTROL

This strategy in the first instance manages injection demand, secondly controls injectors by translating driver requests into command signals to the injectors, and finally corrects any injector drift.

Its main functions are the following:
- Managing injector phasing
- Managing flow
- Converting these two above points into injection pulses.
- Accelerometer correction

10.1 PHASING THE INJECTIONS

10.1.1 PILOT INJECTIONS

These injections reduce combustion noise, effectively by burning a small quantity of diesel before the main injection takes place. This procedure makes the combustion pressures less harsh. See section 1.1 Reducing Noise

Note: *In the new common rail systems, it is now possible to have two pilot injections and a pre-injection very close to the main injection.*

Pilot injection timing is determined as a function of engine speed and total fuel flow. During the starting procedure this can be calculated in relation to engine speed and water temperature.

Pilot injections are also subject to correction factors - similar to the main injection procedure.
- The first correction is made as a function of air and water temperatures. This correction modifies pilot injection timing in relation to the engine operating temperature.
- The second correction is determined as a function of the atmospheric pressure. This correction is used to modify pilot injection timing in relation to atmospheric pressure.

10.1.2 MAIN INJECTION

The main injection timing request is determined as a function of engine speed and amount injected (which represents engine loading).

Injection timing advance should be reduced at start up so as to place combustion beginning near TDC (top dead centre), that is to say the point where temperatures are highest in the absence of combustion. For this to happen, a specific starter phase cartograph determines injection timing as a function of engine speed and water temperature. Once the engine has started, the system should reuse the cartographs and corrections described below:
- The first correction is made as a function of **air and engine water temperatures**. This correction adapts phasing to the engine operating temperature. When the engine is hot, timing can be retarded to reduce combustion temperature and thus polluting emissions *(mainly NOx)*. When the engine is cold, timing advance should be sufficiently large to ensure combustion starts correctly.
- The second correction is determined as a function of **atmospheric pressure**.
- The third correction is made as a function of water temperature and **time lapsed from starting**. This correction can increase injection timing advance during the engine heating phase, that is to say during the 30 seconds following starting. This correction is designed to reduce the combusion rate and any instabilities that might appear just after a cold start.
- The fourth correction is determined as a function of any **rail pressure error**. This correction is used to reduce injection timing advance when the rail pressure is greater than the pressure demanded. In this case combustion can become noisy. It is possible to compensate for this by slightly reducing the timing advance.
- A fifth correction is determined as a function of the **exhaust gas recirculation rate (EGR)**. This is used to correct injection timing advance as a function of the exhaust gas recirculation rate. When the EGR increases, injection timing advance should be increased to compensate for the temperature drop in the cylinder.

INJECTION CONTROL

10.1.3 POST MAIN INJECTION

The injections that follow the main injection are designed to heat up the exhaust line.

- These can be used more rapidly to start the catalyser.
- On those vehicles equipped with a particle filter, post injections are used rapidly to raise filter temperature to the regeneration temperature and to stabilise it. *(>650°C)*

These injections also are subject to corrections but in these case the biggest corrective factors are as follows:

- The pre-turbo temperature.
- Catalyser temperature.
- Particle filter temperature.

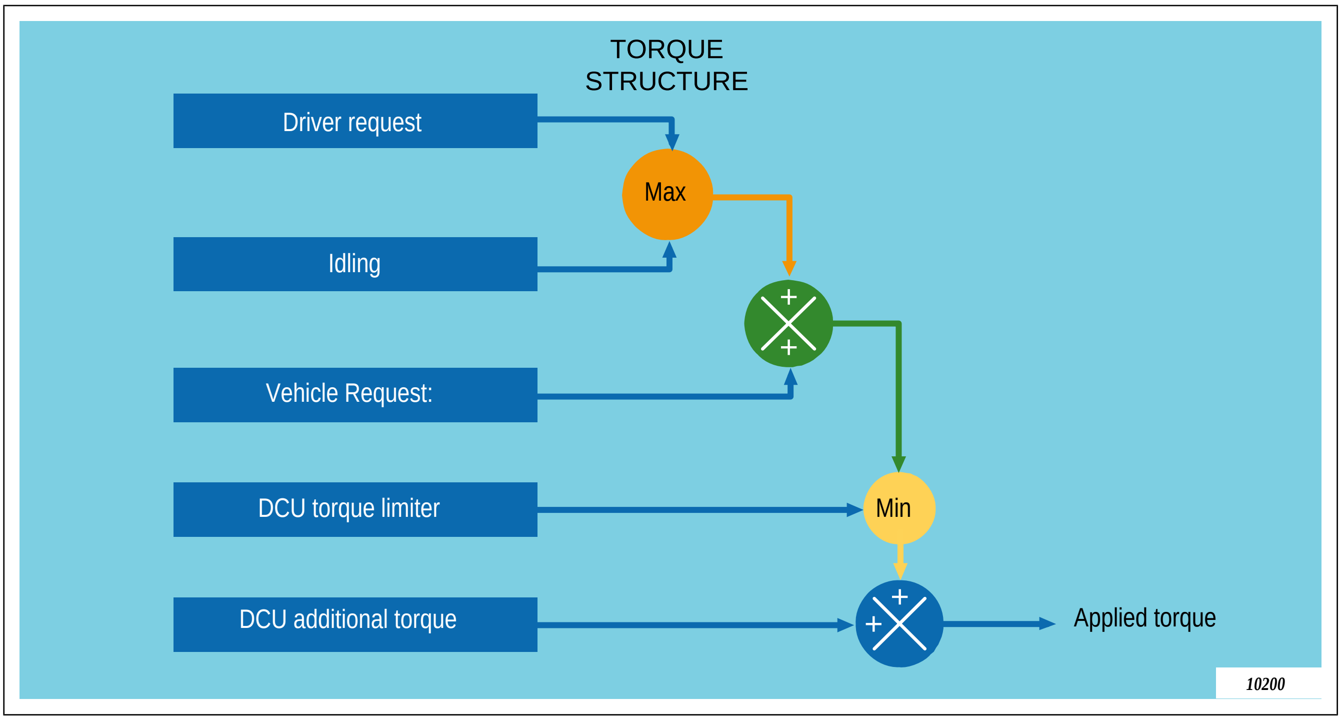
10.2 TORQUE STRUCTURE

All driver demands are translated into a torque demand as follows:

- Push on accelerator pedal
- Manipulate speed limiter
- Manipulate cruise control

These driver actions are first converted into torque so as to be able to be considered by the various torque users as follows:

Putting this into schematic form, the torque structure can be summarised as follows:



INJECTION CONTROL

Each of the segments above is made up a sub-module as follows:

- **Driver Request**:
  - Accelerator pedal
  - Speed limiter
  - Cruise control
- **Idling**
- **Vehicle Request**:
  - Electronic Stability Program (ESP)
  - Anti-lock Braking System
  - ...
- **DCU torque limiter**:
  - Anti-fume Strategy
  - Reduced flow mode
  - Electronic System Monitoring (ESM)
  - ...
- **Additional DCU torque**
  - Anti-Oscillation Strategy
  - Additional torque for high acceleration

The idling controller compares the driver request with the idling speed flow value.

- When the driver pushes on the accelerator pedal, the system notes the request and determines the amount to be injected.
- When the driver releases the pedal, the idling controller takes over at around 1200 rpm to determine the minimum fuel flow needed to be injected to keep the engine running in a stable condition.

Thus the sytem retains the greater of these two values.

The maximum torque required is then noted by other torque users such as the ABS and ESP systems, and any other user operating outside the DCU-managed strategies.

This torque under consideration can then be limited using DCU strategies:

- **Anti-fume Strategy**: This is simiply a limit on torque as a function of air flow and engine speed. It is particularly used at high altitude to reduce the injected amount when the atmospheric pressure is low.
- **Reduced flow mode**: This mode becomes active when a fault arises that could damage mechanisms.
- **Electronic System Monitoring:**: This complex strategy is an inverse torque structure. On receiving an actual pulse this strategy recalculates a requested torque and then compares it with the driver request. If the difference is outside the limit, the DCU allows only a reduced flow. In worse cases the DCU can shut down injection completely.

The DCU can apply torque inversely using the following:

- **Anti-oscillation Strategy**: this compensates for engine speed fluctuations during transitory phases.
- **Additional Torque**: This strategy allows the application of a greater-than-normal-maximum torque peak during difficult transitory phases.

At completion of this torque cascade, the final torque is calculated so as to determine the fuel amount to be injected.

10.3 INJECTION AMOUNTS

The torque calculated using the torque structure is thus translated into fuel amounts then into pulses.

The amount to be injected is shared among several injections. The main amount represents the amount of fuel injected into the cylinder during the main injection sequence. The total amount injected in one cycle is thus the sum of the main injection amount and the other injections (pilot, pre, post).

These amounts are calculated as a function of engine speed and indicated torque. As for injection phasing, correction factors are applied to the main demands.

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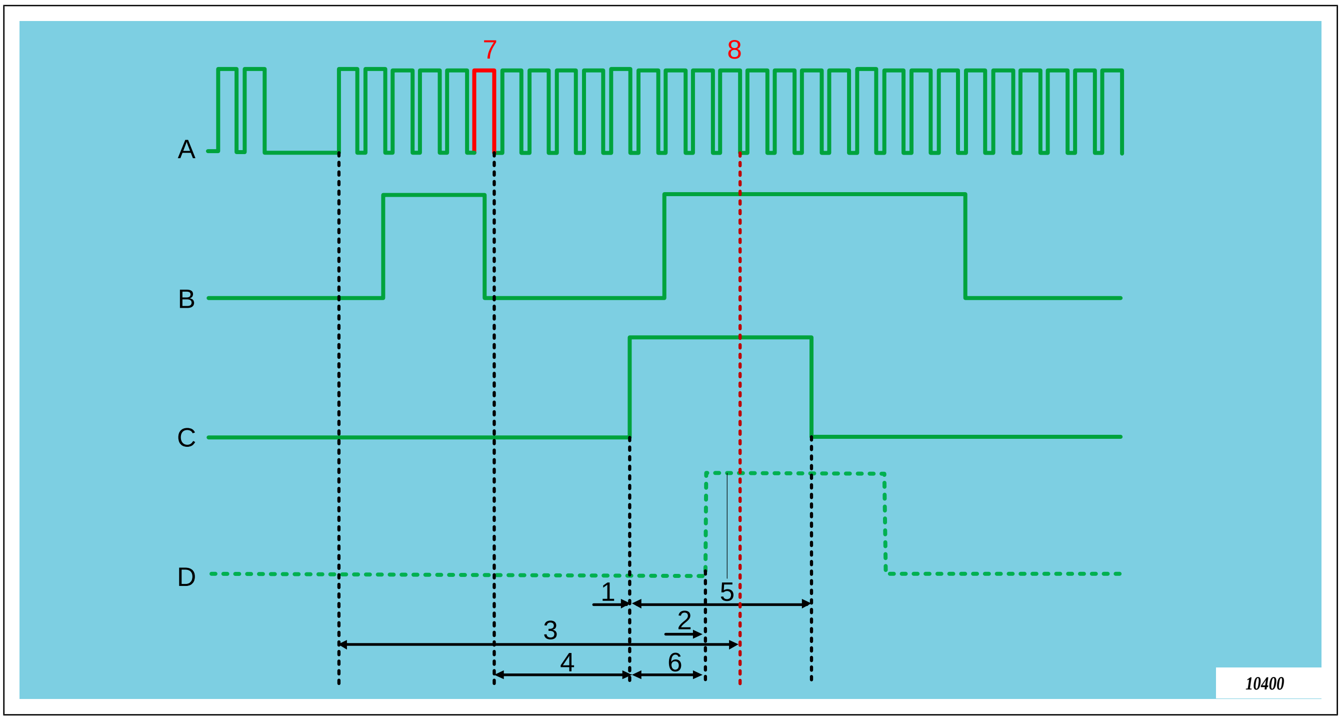
Concerning pilot fuel amounts:

- The first correction is made as a function of air and water temperatures. This correction adapts the pilot amounts to the engine operating temperature. When the engine is hot, the burn time diminishes since the temperature at the end of compression increases. The pilot fuel flow can thus be reduced since the combustion noise is naturally less when the engine is hot.
- The second correction is determined as a function of the atmospheric pressure. This correction is used to adapt pilot fuel flow as a function of atmospheric pressure.

10.4 PULSE DETERMINATION

The system knows at this point when injections should begin *(timing)* and it also knows the amounts of fuel that have to be injected into the cylinders for each injection *(fuel flow)*. It remains for the system to determine the number of pulses, their duration and their position in the engine cycle.

A	Engine flywheel sensor signal	3	Reference angle
B	Camshaft sensor signal	4	T off
C	Injection command pulse	5	T on
D	Measured injection current	6	Opening period
1	Pulse start	7	Reference tooth
2	Injection start	8	Top Dead Centre (PMH)



Injection pulse command

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- **The reference tooth** helps synchronise engine flywheel signals and phase sensor to determine engine condition and to start injection in the appropriate cylinder.
- **The reference angle** is the angle between the engine flywheel gap and top dead centre.
- **T off** is the time lapse between reference tooth and pulse start. This time helps calculations on pulse start particularly the processing of the angular data from the engine flywheel signal.
- **T on** symbolises pulse duration. Its value is determined as a function of fuel demand and rail pressure. The result of this calculation is then corrected by the following:
  - C2I to take injector initial characteristics into account.
  - Battery Resistance Compensation (BRC) strategy See section 10.7 Electrical Effect Correction
  - Strategy of balancing post-to-post fuel injection amounts
- **The Open Time** depends on the characteristics of the specific injector (C2I), injector drift (MDP resetting by accelerometer) and rail pressure.

Note: *Other phenomena such as battery voltage and harness resistance can disturb injector open time. The BRC strategy can correct any ill-effects brought on by these two parameters. The open time can also be disturbed by HP tube and rail pressure waves provoked by the preceding injections. The PMC strategy seeks to quantify these disturbances and correct the open time. This strategy had the initial purpose of compensating for the hydraulic effects of the pilot on the main injection process. Now the strategy is used on all injections in the same cycle.*

10.5 CYLINDER BALANCING STRATEGY

10.5.1 POST TO POST FUEL FLOW BALANCING

This strategy is also known as Cylinder Balancing and balances fuel flows post to post. The pulse of each injector is corrected as a function of the difference in instantaneous speed as measured between two successive injections as follows:

- First the instantaneous speeds are calculated on two successive injections.
- Then the difference between these two instantaneous speed readings is calculated.
- Finally the time amount to be added to the main injection pulse for each of the injectors is determined. This time amount is calculated as a function of the C2I for each injector and the differences in the instantaneous speeds.

10.5.2 CLOSED BLOCK INJECTOR DETECTION

The cylinder balancing strategy also facilitates detecting a closed block injector. The difference in instantaneous speed between two successive injections then crosses a pre-defined threshold. In such a case the system detects a fault.

10.6 ACCELEROMETER STRATEGY

10.6.1 RE-SETTING PILOT INJECTION

The accelerometer is used to reset pilot injection flow in closed loop for each injector. This auto-adaptive method can correct any injector drift over time.

The principle for using the accelerometer lies in detecting combustion noise. The sensor is placed on the engine block where it is best placed to receive a good signal from all cylinders. In order to get the same response from a cylinder near to as from one far from the accelerometer, the noise signals from the latter are processed to obtain a variable that quantifies combustion intensity. This variable, called the ratio, is the ratio between background

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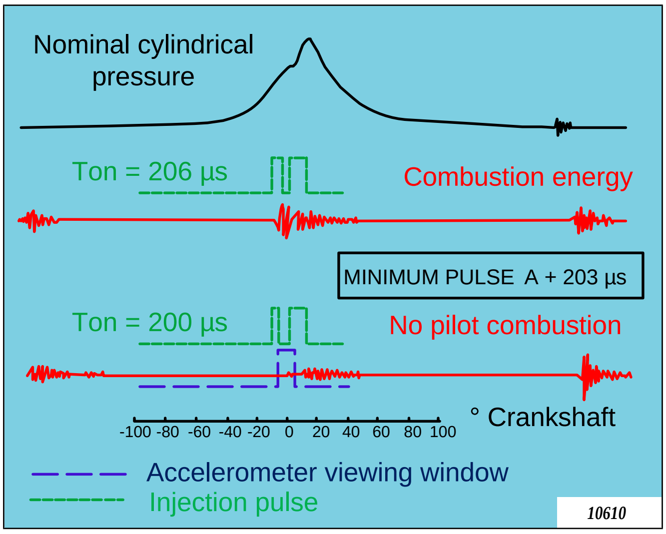
noise and combustion noise. Using a ratio that takes background noise into account deals with the differences in noise intensity resulting from the central location of the accelerometer.

- The first window serves to fix the accelerometer signal background noise level for each cylinder. This window should thus be set up at a time when there cannot be any combustion.
- The second window measures the intensity of pilot combustion. Its position is such that only combustion noise from pilot injections is measured. It is thus placed just before the main injection.

Here we are considering the minimum drive pulse (MDP), the minimum from which combustion can be produced. Any pulse that is less than the MDP causes no combustion since the coil excitation time is too short to lift the needle. To find this MDP, the strategy is incrementally to increase the pilot injection pulse bit by bit (in steps of some µs) from 0µs until the pulse provokes combustion from the pilot injection. Once this pulse value is found, it is deducted from the C2I physical value and saved in the DCU. This strategy is called applications-related resetting. There could be between two and six resetting values per injector. They are applied as a function of the prevailing rail pressure. These correction values are then added to the pulse request so as to compensate for system drift.



The principle of pilot injection resetting thus consists of determining the MDP. It is periodically carried out under certain operating conditions. Following any resetting procedure, the new minimum pulse value replaces the value obtained from the preceding resetting. The C2I procedure provides the first MDP value. The strategy that determines the new MDP provides each following value and applies it by adding the difference between the pulse measured and the (C2I-obtained) nominal pulse. Each resetting then allows MDP closed-loop updating as a function of injector drift. This update is saved in the Non Volatile Memory (NVM).

On the other hand the accelerometer does not allow evaluation of the amount injected. It only allows access to the exact pulse value from whichever injector is beginning to inject.

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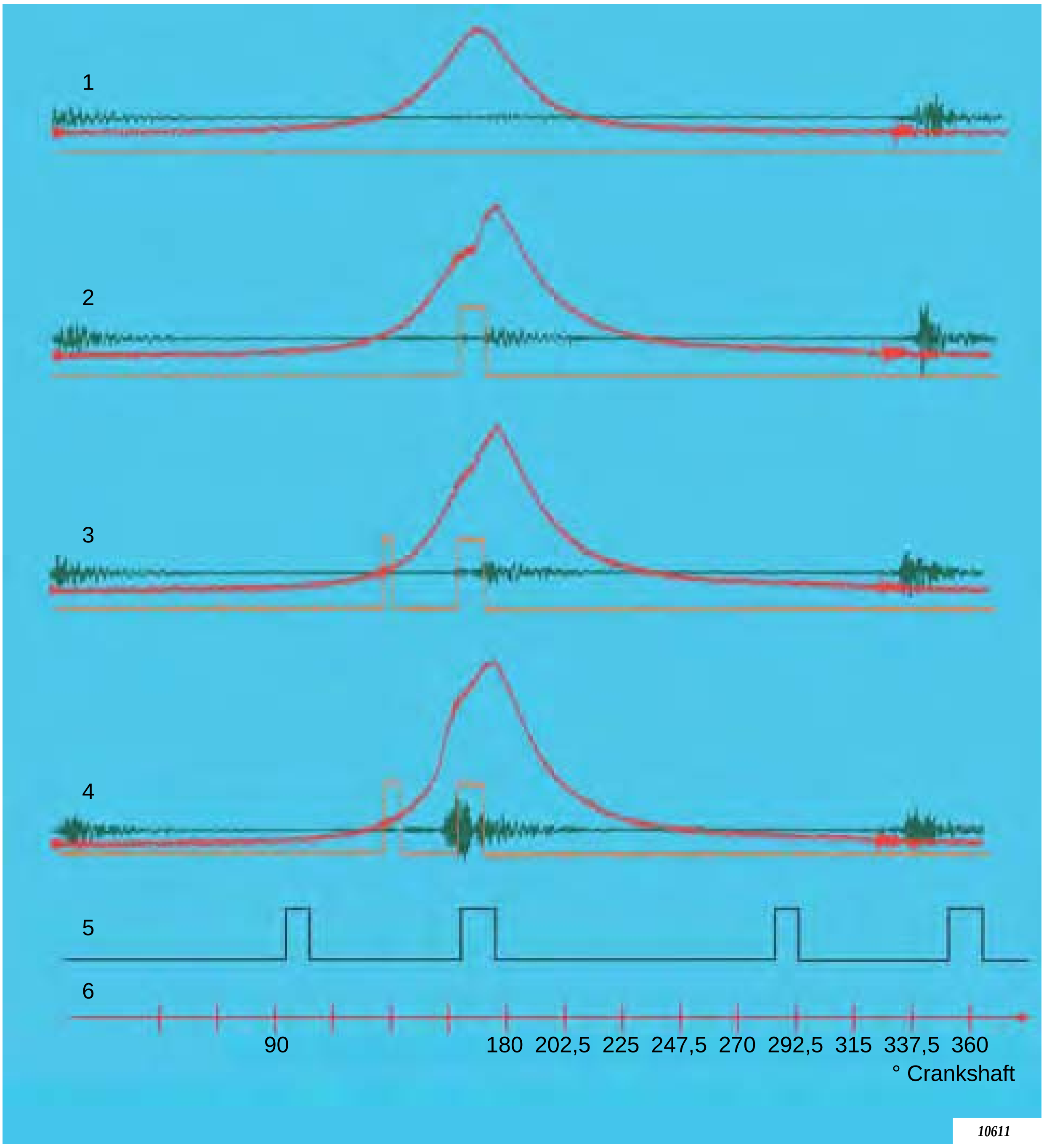

Accelerometer response to the pilot quantity injected. Red: Cylinder pressure; Orange: Injection pulse; Green: Accelerometric response (Ratio)

The graph 5 noise-measuring windows are configured in such a way that the first window measures background noise and the second window measures pilot injection combustion noise.

Case N°1: The cylinder pressure in red comes from natural compression since there is no injection. Consequently we see no change in ratio.

Case N°2: There is no main injection. Main injection combustion is not visible within the degree interval on the noise-measuring window. It occurs just after that.

Case N°3: The pilot quantity injected is low, so the ratio is low.

Case N°4: The pilot quantity injected is high, so the ratio is very high.

Note: *Using two accelerometers is going to be standard for future Euro5 applications. On a four-cylinder engine, one accelerometer will be dedicated to two posts. The idea is to more accurately detect combustion noise and avoid disturbance from other posts, in order to make any corrections as accurate as possible.*

10.6.2 DETECTING CYLINDER LEAKS

The accelerometer is also used to detect an open blocked injector. The detection principle is to monitor the ratio. If there is a leak in a cylinder, the accumulated fuel automatically burns when the temperature and pressure conditions are right (at high speed, heavy load and slight leaking). This combustion starts approximately 20 degrees before TDC. This is well in advance of any main injection combustion. The ratio thus substantially increases in the detection window. This increase thus shows up any leaks. The threshold for detecting a fault is set at a percentage of the maximum value that the ratio can take.

Because of the severity of recovery at engine shut-down, detection should be extremely robust. Now there are several causes that could provoke a ratio increase, as follows:

- Pilot injection too big.
- Main combustion shifted to detection window (too far advanced or window shifted).
- Fuel leak into cylinder because of bad injector sealing.

When the ratio becomes too big, in the first instance the strategy limits pilot injection flow and delays the main injection. If the ratio remains high despite these actions, it indicates that there is a real leak, a fault is registered and the engine is shut down.

10.6.3 DETECTING AN ACCELEROMETER FAULT

This strategy can detect a fault in the sensor or harness linking the sensor to the DCU. It relies on detecting combustion. At idling speed the detection window is set too low in the combustion caused by the main injection. If the ratio increases it means the accelerometer is operating correctly. If not a fault code indicates a faulty sensor. The recovery modes associated with this fault are to inhibit pilot injection and injector discharge.

10.7 ELECTRICAL EFFECT CORRECTION

This strategy called BRC (Battery Resistance Compensation) compensates when battery voltage and harness resistance diminish.

10.7.1 SENSITIVITY TO BATTERY VOLTAGE

When battery voltage goes down, the speed at which the current rises in the injector coil diminishes to the same degree.

The lower the voltage, the later injection begins. This means injection time is less. The principle behind correcting this phenomenon is simple. The strategy notes the battery voltage and corrects the pulse by time-shifting it and/ or increasing it if needed. The amount of correction is calculated using a reference voltage *(14 volts)*.

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10.7.2 SENSITIVITY TO HARNESS RESISTANCE

Harness resistance tends to increase with age. Consequently the control current - as also the amount injected - is lower.

The principle behind correcting this phenomenon is simple. Electric current and battery voltage are measured at an exact moment, providing the means to calculate the total resistance. This figure is then used to calculate the corrections to be applied both to pulse start time and to pulse duration.

10.8 VLC STRATEGY

The combination of parameters such as fuel temperature, internal part wear, filter condition, etc., means that the injection system may reach its limit during operation. In this case, system under-capacity prevents sustaining the demanded rail pressure, so the DCU generates a fault. The diagnosis of such a system then becomes very difficult. It may lead to components being replaced without good reason.

The changes in most of the parameters mentioned above are not known, and the DCU has difficulty in evaluating them. In order to avoid a fault being generated, the DCU will reduce the fuel amount requested to a value that can maintain and control rail pressure. In other words it will dynamically regulate injection system demands - within certain limits - in relation to the operating readings *(fuel temperature, engine speed, etc)* at the particular point.

This strategy is known as VLC *(Variable Limit Capacity)*.

In practice, this strategy translates into calculating two offsets

The VLC offsets can be read using the diagnostic tool.

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ABBREVIATIONS / DESCRIPTIONS

ABS	Anti-lock Braking System
AOS	Anti Oscillation System
LP	Low pressure
BRC	Battery Resistance Compensation
C2I	Individual Injector Correction
C3I	Improved Individual Injector Correction
CO	Carbon Monoxide
Check-Sum	C2I validation
Data Matrix	C2I coding tag
DCU	Diesel Control Unit
EGR	Exhaust Gas Recirculation
Hexadecimal	16-character digital base from 0 to F
ECU	Diesel Control Unit (DCU)
ESP	Electronic Stability Program
ESM	Electronic System Monitoring *(Pulse monitoring)*
EURO 1/2/3/4/ etc	European pollution standards designations
HC	Hydrocarbon
HP	High pressure
HPV	High Pressure Valve (Rail discharge actuator)
Imax	Maximum current
IMV	Inlet Metering Valve *(Filling actuator)*
INO	Inlet Orifice *(Injector crosspiece filling orifice)*
l/h	litres per hour
Main	Main injection
Max	Maximum
MDP	Minimum Drive Pulse *(minimum pulse required for injection)*.
mg/str	milligrammes per stroke
Min	Minimum
N°	Number
NPO	Nozzle Path Orifice *(Injector Feed Orifice)*
NOx	Oxides of Nitrogen
NVM	Non Volatile Memory
PM	Particle
PID	PID regulator
PLV	Pressure Limiter Valve (Limiteur de pression)
PMC	Pilot Main Compensation (Compensating for the effect of pilot injection on main injection)
Post	Injection following main injection
Prail	Rail pressure
Pulse	Electrical impulse to control injectors
PWM	Pulse Width Modulation
Q	Flow:
Qmax	Max flow
RCO	Rapport Cyclique d'Ouverture (%) (Open Cycle Ratio % - OCR - in English)
RPM	Revolutions per minute *(= rpm)*
SAV	Service Après Vente (After Sales Service in English)
SPO	Spill Orifice *(Discharge orifice)*

ABBREVIATIONS / DESCRIPTIONS

TDC	Top Dead Centre
T or T°	Temperature
Temp.	Temperature
VCO	Valve Cover Orifice
VLC	Variable Limit Capacity

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