Fuel System

COMMON RAIL ACCUMUALTOR FUEL-INJECTION SYSTEM

Field of application

The in-line fuel-injection pump's main area of application is still in all sizes of commercial-vehicle diesel engines, stationary diesel engines, locomotives and ships. Injection pressures of up to approx. 1600 bar are used to generate output powers of up to about 160 kW per cylinder.
Over the years, a wide variety of different requirements, such as the installation of direct-injection (DI) engines in small delivery vans and passenger cars, have led to the development of various diesel fuel-injection systems which are aligned to the requirements of a particular application. Of major importance in these developments are not only the increase in specific power, but also the demand for reduced fuel consumption, and the call for lower noise and exhaust-gas emissions. Compared to conventional cam-driven systems, the Delphi "Common Rail" fuel-injection system for direct-injection (DI) diesel engines provides for considerably higher flexibility in the adaptation of the injection system to the engine, for instance:

- Extensive area of application (for passenger cars and light commercial vehicles with output powers of up to 30kW/cylinder, as well as for heavy-duty vehicles, locomotives, and ships with outputs of up to approx. 200kW/cylinder,
- High injection pressures of up to approx. 1400 bar.
- Variable start of injection,
- Possibility of pilot injection, main injection, and post injection,
- Matching of injection pressure to the operating mode.

Funtions

Pressure generation and fuel injection are completely decoupled from each other in the "Common Rail" accumulator injection system. The injection pressure is generated independent of engine speed and injected fuel quantity. The fuel is stored under pressure in the high-pressure accumulator (the "Rail") ready for injection. The injected fuel quantity is defined by the driver, and the start of injection and injection pressure are calculated by the ECU on the basis of the stored maps. The ECU then triggers the solenoid valves so that the injector (injection unit) at each engine cylinder injects accordingly. The ECU and sensor stages of such a CR fuel-injection system comprise:

- ECU,
- Crankshaft angle sensor,
- Phase sensor,
- Accelerator-pedal sensor,
- Rail-pressure sensor,
- Water temperature sensor and,
- Air-flow sensor.

Using the input signals from the above sensors, the ECU registers the driver's requirements (accelerator-pedal setting) and defines the instantaneous operating performance of the engine and the vehicle as a whole. It processes the signals which have been generated by the sensors and which it receives via data lines. On the basis of this information, it can then intervene with open and closed-loop controlling action at the vehicle and particularly at the engine. The engine speed is measured by the crankshaft-Angle sensor, and the phase sensor and the phase sensor determines the firing sequence (phase length). The electrical signal generated across a potentiometer in the accelerator-pedal module informs the ECU about how far the driver has depressed the pedal, in other words about his (her) torque requirement.
The ari-flow sensor meter provides the ECU with data on the instantaneous air flow in order that combustion can be adapted so as to comply with the emissions regulations.

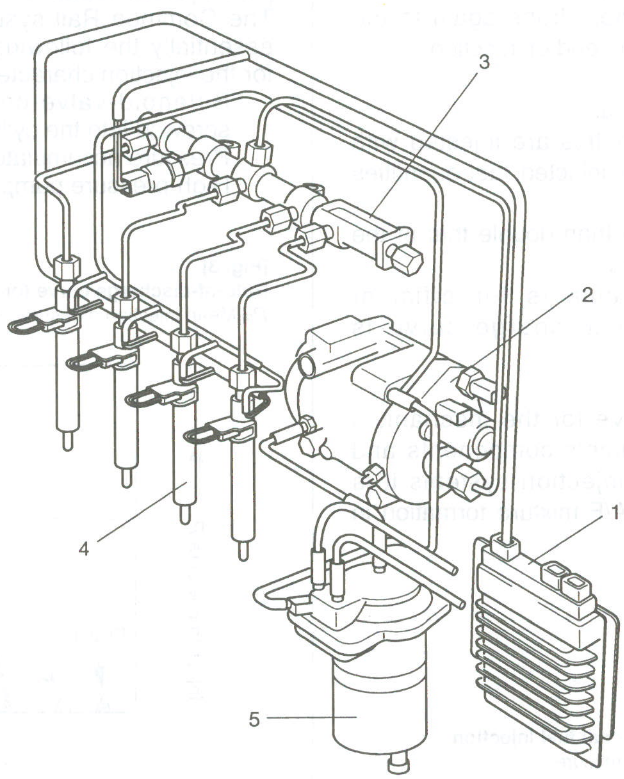
Basic functions

The basic functions control the injection of the diesel fuel at the right moment, in the right quantities, and with the correct injection pressure. They ensure that the diesel engine not only runs smoothly, but also economically.

Auxiliary functions

Auxiliary closed and open-loop control functions serve to improve both the exhaust-gas emission and fuel-consumption figures, or are used for increasing safety, comfort, and convenience. Examples here are Exhaust-Gas Recirculation (EGR), vehicle-speed control, and electronic immobilizer etc.
The CAN bus system permits the exchange of data with other electronic systems in the vehicle. During vehicle inspection in the workshop, a diagnosis interface permits evaluation of the stored system data.

[Fig. 1]
Common Rail accumulator injection system on a 4-cylinder diesel engine



NOTE
This drawing is not exactly same with real lay-out.

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1. ECU
2. High-pressure pump(Lift pump integrated)
3. High-pressure accumulator (rail)
4. Injectors
5. Fuel filter

Injection characteristics

Conventional injection characteristics

With conventional injection systems, using distributor and in-line injection pumps, fuel injection today comprises only the main injection phase - without pilot and post-injection phases (Fig. 2). On the solenoid-valve-controlled distributor pump though, developments are progressing towards the introduction of a pilot-injection phase. In conventional systems, pressure generation and the provision of the injected fuel quantity are coupled to each other by a cam and a pump plunger. This has the following effects upon the injection characteristics:

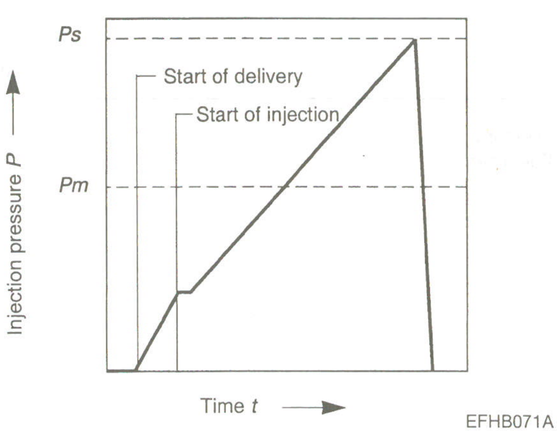
- The injection pressure increases together with increasing speed and injected fuel quantity
- During the actual injection process, the injection pressure increases and then drops again to the nozzle closing pressure a the end of injection

The consequences are as follows:

- Smaller injected fuel quantities are injected with lower pressures than larger injected fuel quantities (refer to Fig. 2)
- The peak pressure is more than double that of the mean injection pressure, and
- In line with the requirements for efficient combustion, the rate-of discharge curve is practically triangular.

The peak pressure is decisive for the mechanical loading of a fuel-injection pump's components and drive. On conventional fuel-injection systems it is decisive for the quality of the A/F mixture formation in the combustion chamber.

[Fig. 2]
Rate-of-discharge curve for conventional fuel injection
Pm Mean injection pressure, *Ps* Peak pressure



Injection characteristics with common rail

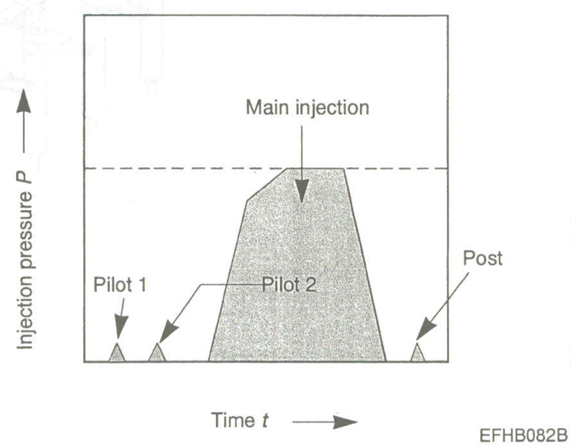
Compared to conventional injection characteristics, the following demands are made upon an ideal injection characteristic:

- Independently of each other, injected fuel quantity and injection pressure should be definable for each and every engine operating condition (provides more freedom for achieving ideal A/F mixture formation)
- At the beginning of the injection process, the injected fuel quantity should be as low as possible (that is, during the ignition lag between the start of injection and the start of combustion).

These requirements are complied with in the Common rail accumulator injection system with its pilot and main, post-injection features (Fig. 3).
The Common Rail system is a modular system, and essentially the following components are responsible for the injection characteristic:

- Solenoid-valve-controlled injectors which are screwed into the cylinder head,
- Pressure accumulator (rail), and
- High-pressure pump

[Fig. 3]
Rate-of-discharge curve for Common Rail fuel injection
Pm Mean injection pressure, *PR* Rail pressure



The following components also required in order to operate the system:

- Electronic control unit (ECU),
- Crankshaft-angle sensor, and
- Phases sensor.

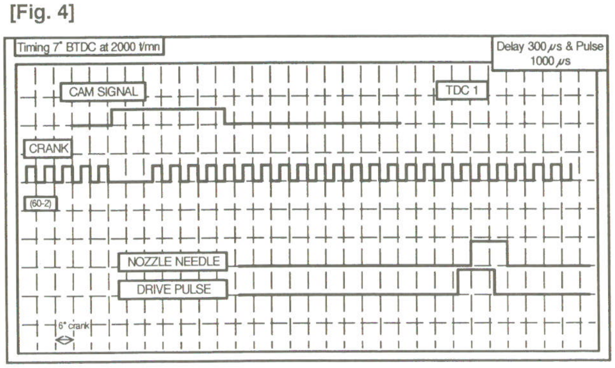
For passenger-car systems, a radial-piston pump is used as the high-pressure pump for pressure generation. Pressure is generated independently of the injection process. The speed of the high-pressure pump is coupled directly to the engine speed with a non-variable transmission ratio. In comparison with conventional injection systems, the fact that delivery is practically uniform, means that not only is the Common Rail high-pressure pump much smaller, but also that its drive is not subject to such high pressure-loading peaks.

The injectors are connected to the rail by short lines and, essentially, comprise a nozzle, and a solenoid valve which is energized by the ECU to switch it on (start of injection). When the solenoid valve is switched off (de-energized) injection ceases. Presuming constant pressure, the injected fuel quantity is directly proportional to the length of time the solenoid valve is energized. It is completely independent of the engine or pump speed (time-controlled fuel injection).
The required high-speed solenoid switching is achieved by using high voltages and currents. This means that the solenoid-valve triggering stage in the ECU must be designed accordingly.
The start of injection is controlled by the angle-time control system of the EDC (Electronic Diesel Control). This uses a sensor on the crankshaft to register engine speed, and a sensor on the camshaft for phase detection (working cycle).

Gerneral principle

This system is a pressure-time injection equipment for which the injected quantity is the result of injection pressure and duration.
Given that each injector is electrically driven by the ECU, and that fuel under pressure is continuously available for injection, the ECU fixes with certitude when and which injector has to be energised. For this purpose a period signal equal to the engine cycle(2 engine revolutions) is considered by the ECU.
The generic system uses a 60-2 events type flywheel (2 consecutive events missing, located at an angle configured in the software between TDC of cylinder n°1 and the previous cylinder in the firing order). It also uses one cam event signal every two engine revolutions in phase with the flywheel signal sungularity.

[Fig. 4]



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For the generic system, the flywheel sensor is a "variable reluctance type" and the cam event sensor is a "Hall effect type".
Special strategies with several cam events can be developed within the context of specific customer demand, likewise other sensor technologies may be used.

The engine speed can vary from:
-0 to 5000 erpm in full load,
-5000 to 6000 erpm with gradual injection cut-off,
-6000 to 7000 erpm accidentally.

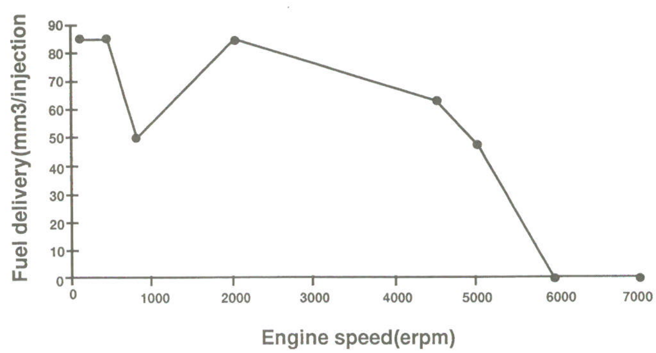
The software module which procdsses cam and flywheel events provides to other system functions the necessary events for tasks scheduling and the injector number data.
Two states exists:
Synchronising state: During this state, no outputs are provided.
Synchronised statd: During this state, the normal and rebuilt (missing teeth) events are provided.
When synchronisation is lost, injections are cut-off until synchronisation is recovered.

There is no general engine state but states per function i.e. cranking and running modes are defined for fuelling and timing control.

Fuelling control

Diesel fuel may be injected into each cylinder 4 times as a maximum: one far pilot injection, one close pilot injection, the main injection and a post injection.
Typical pilot injection amount are from 0.8 mm3/st at idle to 5 mm3/st in full load, any value between these values being possible. The use of pilot injections is possible throughout the whole engine speed and load range.
The sum of the pilot and main injections can be included within the maximum injected delivery mentioned on the follwing graph:

[Fig. 5]



EXHAUST-GAS REDUCTION

Mixture formation and combustion behavior

Compared to SI engines, diesel engines burn low-volatility (high-boiling) fuel, and not only prepare the air/fuel mixture in the period between injection and start of combustion, but also during the actual combustion process. The result is a less homogenous mixture. The diesel engine always operates with excess air (¥> 1). Fuel consumption, and the emissions of soot, CO, and HC increase if there is insufficient excess air.
The A/F mixture formation is defined by the following parameters:

- Injection pressure,
- Rate of discharge (injection time),
- Spray distribution (number of spray jets, spray cross-section, spray direction),
- Start of injection,
- Air movement, and
- Air mass.

These quantities all have an effect upon the engine's emissions and fuel consumption. High combustion temperatures and high levels of oxygen concentration lead to increased NOx generation. Soot emissions rise due to lack of air and poor A/F mixture formation.

Measures at the engine

The configuration of the combustion chamber and air-intake tract can have a positive effect upon the exhaust-gas emissions. If the air movement in the combustion chamber is carefully matched to the fuel jets leaving the nozzle, this promotes efficient mixing of air and fuel and thus complete combustion of the injected fuel. In addition, positive effects are achieved with a homogenous mixture of air and exhaust gas and a cooled EGR tract. Four-valve techniques and turbochargers with variable-turbine geometry (VTG) also contribute to lower emissions and higher power density.

The system is capable of balancing line to line injections over a range of engine speeds, and partly compensating the fuel delivery and engine drifts in the couse of time.

The post injection is used as a reduction agent for exhaust after-treatment in a DeNox catalyst. The post injection is activated when the required fuel amount reach the minimal controllable quantity (function of rail pressure). The post injection can be induced up to once per injection cycle.

Start of logic pulse

The injection start is fixed as being the angle between when the injector starts to inject and the top dead center(TDC) of the cylinder where the injection is made. The TDC position is known thanks to the engine events and data configured in the software.

For far pilot injection, the start of injection may vary between 90° before TDC and 10° before TDC.

The start of close pilot injection may vary from 40° before TDC to TDC.

Main injectionstart may be situated between 25° before TDC and 15° after TDC.

The post injection start may occur between 75° and 220° after TDC.

The separation between the far and close pilots, and between close pilot and main injection, defined as the difference between the end of the first and the start of the second is capable of reaching a limit of 100 §` under stable operation of the injected guantities.

Exhaust-gas recirculation (EGR)

Without EGR, NOx emissions are excessive from the emission-control legislation standpoint, whereas soot emissions are within limits. Exhaust-gas recirculation (EGR) is a method for reducing the emissions of NOx without drastically increasing the engine's soot output. This can be implemented very efficiently with the common rail system thanks to the excellent A/F mixture formation resulting from the high injection pressures. With EGR, a portion of the exhaust gases are diverted into the intake tract during part-load operation. This not only reduces the oxygen content, but also the rate of combustion and the peak temperature at the flme front, with the result that NOx emissions drop. If too much exhaust gas is recirculated though (exceeding 40% of the intake air volume), the soot, CO, and HC emissions, as well as the fuel consumption rise due to the lack of oxygen.

Influence of fuel injection

Start of injection, rate-of discharge curve, and atomization of the fuel also have an influence upon fuel consumption and upon exhaust-gas emissions.

Start of injection

Due to lower process temperatures, retarded fuel-injection reduces the NOx emissions. But if it is too far retarded, HC emissions and fuel consumption increase, as do soot emissions under high loading conditions. If the start of injection deviates by only 1°cks (crankshaft) from the desired value, NOx emissions can increase by as much as 5%. Whereas a deviation of 2°cks in the advance (early) direction can lead to a 10 bar increase in the cylinder peak pressure, a deviation of 2°cks in the retarded (late) direction can increase the exhaust-gas temperature by 20°C. Such high sensitivity demands utmost accuracy when adjusting the start of injection.

Rate-of-discharge curve

The rate-of discharge curve defines the variations in fuel mass flow during a single injection cycle (from start of injection till end of injection). The rate-of-discharge curve determines the mass of fuel delivered during the combustion lag (between start of injection and start of combustion). Furthermore, since it also influences the distribution of the fuel in the combustion chamber it also has an effect upon the efficiency of the air utilization. The rate-of-discharge curve must climb slowly in order that fuel injection during the combustion lag is kept to a minimum. This fuel, namely, combusts suddenly as soon as combustion is initiated with the attendant negative effects upon engine noise and NOx emissions. The rate-of-discharge curve must drop-off sharply in order to prevent poorly atomized fuel leading to high HC and soot emissions, and increased fuel consumption during the final phase of combustion.

Fuel atomization

Finely atomized fuel promotes the efficient mixing of air and fuel. It contributes to a reduction in HC and soot emissions. High injection pressure and optimal geometrical configuration of the nozzle injection orifices lead to good atomization. To prevent visible soot emission, the injected fuel quantity must be limited in accordance with the intake air quantity. This necessitates excess air in the order of at least 10...40% (λ=1.1 ...1.4).

Once the nozzle needle has closed, the fuel in the injection orifices can vaporize (in the case of sac-hole (blind-hole) nozzles the fuel vaporizes in the sac-hole volume) and in the process increase the HC emissions. This means that such (harmful) volumes must be kept to a minimum.

FUEL SYSTEM

The fuel system in a "Common Rail" fuel-injection system (Fig. 1) comprises a low-pressure stage for the low-pressure delivery of fuel, a high-pressure stage for the high-pressure delivery, and the ECU (9).

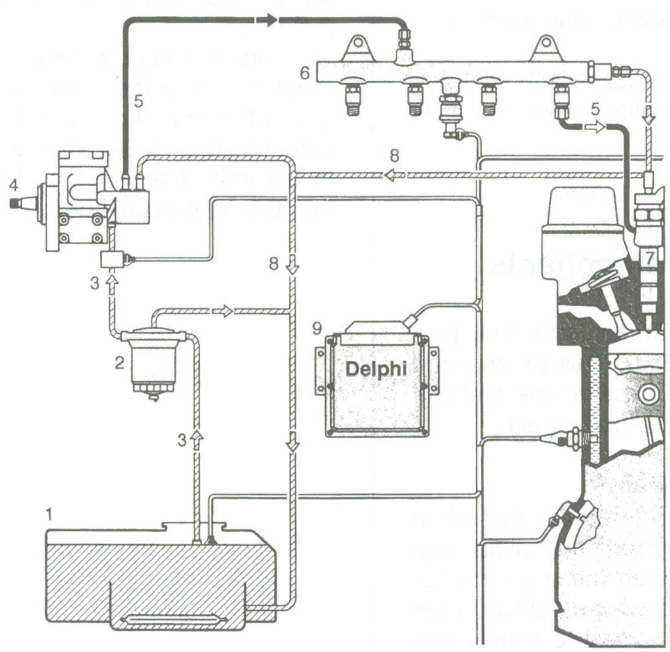
Low-pressure delivery

The low-pressure stage of the Common Rail fuel system incorporates:
- Fuel tank with pre-filter,
- Lift pump(Transfer pump),
- Fuel filter, and
- Low-pressure fuel lines.

Fuel lines for the low-pressure stage

As an alternative to steel pipes, flme-inhibiting steel-braid-armoured flexible fuel lines can be used for the low-pressure stage. They must be routed so that they cannot be damaged mechanically, and fuel which has dripped or evaporated must not be able to accumulate, nor must it be able to ignite.
When the vehicle twists, or the engine moves etc., this must have no derogatory effects upon fuel-line function. All parts which carry fuel must be protected against the effects of heat. In the case of buses, fuel lines must not be located in the passenger compartment or in the driver's cab, nor may fuel be delivered by force of gravity.

[Fig. 1]



Fuel system for a Common Rail fuel-injection system

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1. Fuel tank
2. Fuel filter
3. Low-pressure fuel lines
4. High-pressure pump(Lift pump integrated)
5. HIgh-pressure fuel lines
6. Rail
7. Injector
8. Fuel-return line
9. ECU

Low-pressure system components

Lift pump(Transfer pump)

The lift pump is included in the housing of the HP pump. The lift pump is of the volumetric blade type pump. The pump draws the fuel from the fuel tank and continually delivers the required quantity of fuel in the direction of the high-pressure pump.

Fuel filter

Inadequate filtering can lead to damage at the pump components, delivery valves, and injector nozzles. The fuel filter cleans the fuel before it reaches the lift pump, and thereby prevents premature wear at the pump's sensitive components.

High-pressure delivery

The high-pressure stage of the fuel system in a Common Rail installation comprises:

- High-pressure pump with pressure-control valve,
- High-pressure fuel lines,
- The rail as the high-pressure accumulator with rail-pressure sensor, pressure-limiting valve, and flow limiter, injectors, and
- Fuel-return lines.

High-pressure system components

High-pressure pump

The high-pressure pump pressurises the fuel to a system pressure of up to 1,600bar. This pressurized fuel then passes through a high-pressure line and into the tubular high-pressure fuel accumulator (rail).

High-pressure accumulator (rail)

Even after an injector has taken fuel from the rail in order to inject it, the fuel pressure inside the rail remains practically constant. This is due to the accumulator effect arising from the fuel's inherent elasticity. Fuel pressure is measured by the rail-pressure sensor and maintained at the desired level by the pressure-control valve. It is the job of the pressure-limiter valve to limit the fuel pressure in the rail to maximum 1,600bar. The highly pressurized fuel is directed from the rail to the injectors by a flow limiter, which prevents excess fuel reaching the combustion chamber.

Injectors

The nozzles of these injectors open when the solenoid valve is triggered and permit the flow of fuel. They inject the fuel directly into the engine's combustion chamber. The excess fuel which was needed for opening the injector nozzles flows back to the tank through a collector line. The return fuel from the pressure-control valve and from the low-pressure stage is also led into this collector line together with the fuel used to lubricate the high-pressure pump.

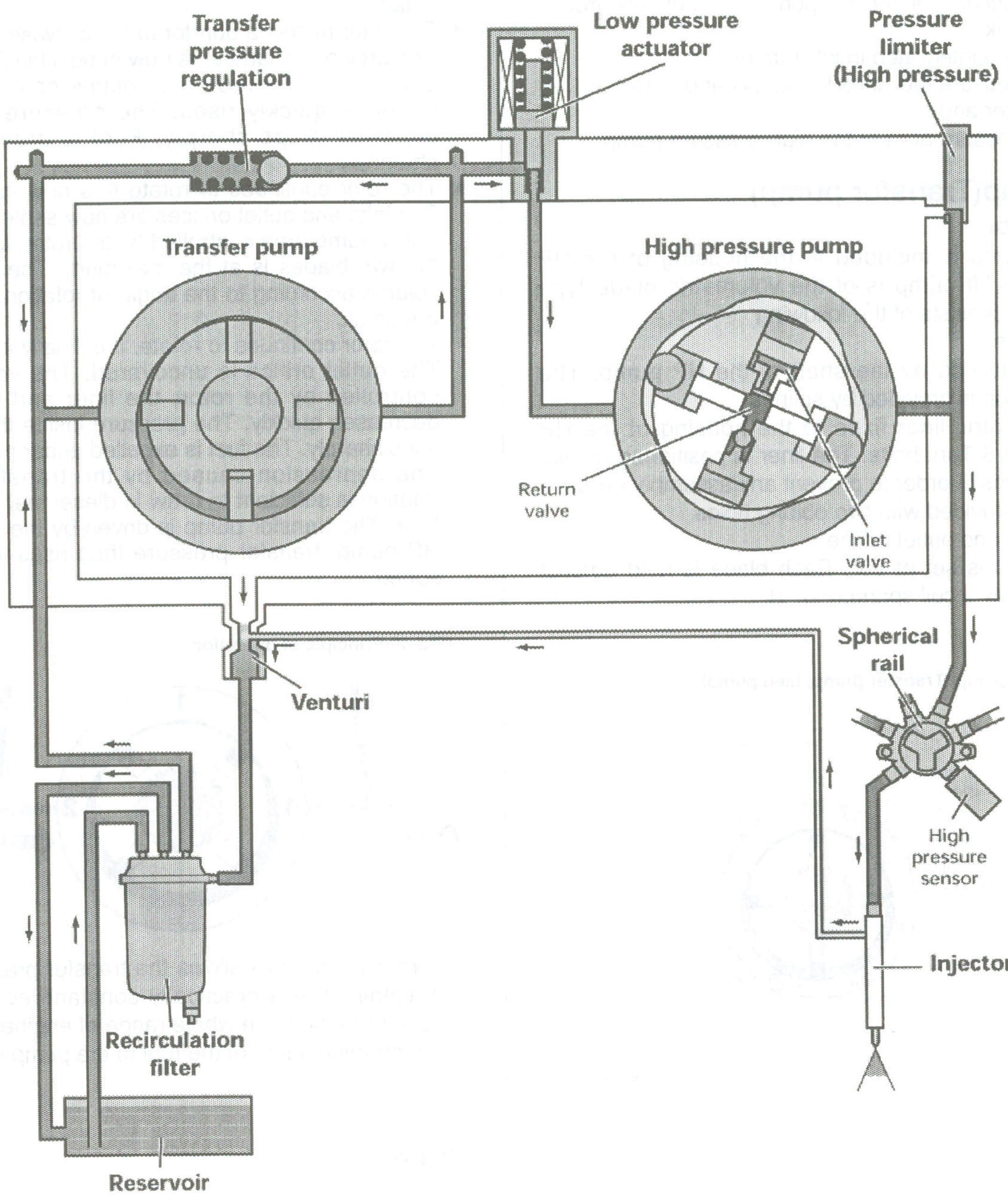
Fuel lines in the high-pressure section

These fuel lines carry the high-pressure fuel. They must therefore be able to permanently withstand the maximum system pressure and, during the pauses in injection, the sometimes high-frequency pressure fluctuations which occur. They are therefore manufactured from steel tubing. Normally, they have an outside diameter of 6 mm and an internal diameter of 2.4 mm.

The injection lines between the rail and the injectors must all be of the same length. The differences in length between the rail and the individual injectors are compensated for by using slight or pronounced bends in the individual lengths of tubing. Nevertheless, the injection lines should be kept as short as possible.

Hydraulic circuit

[Fig. 1] Hydraulic circuit



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DESIGN AND FUNCTION OF THE COMPONENTS

Low-pressure stage

The low-pressure stage provides enough fuel for the high-pressure section. The most important components are:

- Fuel tank,
- Lift pump(integrated in HP-pump),
- Low-pressure fuel lines for supply and return,
- Fuel filter and
- Low-pressure area of the high-pressure pump.

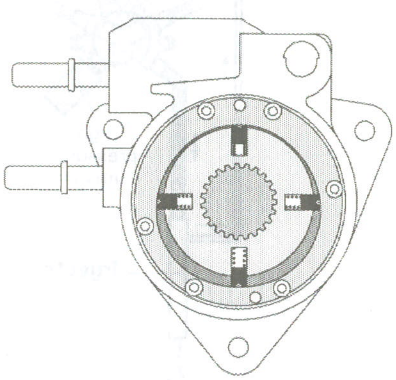
Lift pump(Transfer pump)

Description

The lift pump is included in the housing of the HP pump. The lift pump is of the volumetric blade type pump: and consists of the following components:

- A rotor turned by the shaft of the HP pump. The connection is provided by splines.
- An eccentric liner fixed to the housing of the HP pump by 6 Torx bolts. The liner is positioned by two off-set pins in order to prevent any assembly errors.
- A plate provided with two oblong holes.
- The inlet and outlet orifice.
- Four blades set at 90°. Each blade is held against the liner by a coil spring.(Fig. 1)

[Fig. 1] Lift pump (Transfer pump, feed pump)



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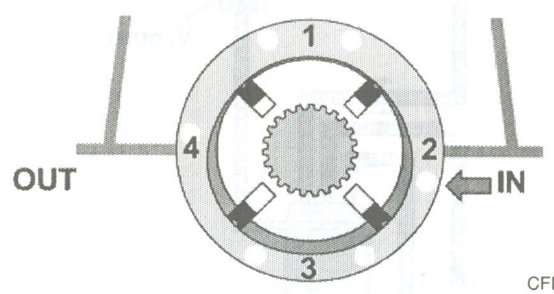
Principle of operation

Consider the chamber between the rotor, the liner and two successive blades. (Fig. 2)

- When the chamber is in position 1, the volume of the chamber is minimal. The changes in volume according to the angle of rotation of the rotor are small.
- The rotor makes a quarter turn clockwise.
  The previous chamber is now in position 2. The inlet orifice is uncovered. The volume contained in the chamber quickly rises. The pressure inside the chamber drops sharply. Fuel is drawn into the chamber.
- The rotor continues to rotate It is now in position 3. The inlet and outlet orifices are now sealed off.
  The volume area controlled by the rotor, the liner and the two blades is at the maximum. The changes in volume according to the angle of rotation of the rotor are small.
- The rotor continues to rotate. It is finally in position 4. The outlet orifice is uncovered. The volume area controlled by the rotor, the liner and the blades decreases quickly. The pressure inside the chamber rises sharply. The fuel is expelled under pressure.
  The depression caused by the transfer pumpís rotation is sufficient to draw in diesel fuel through the filter. The transfer pump is driven by the shaft of the HP pump, transfer pressure thus rises with engine speed.

[Fig. 2] Principle of operation



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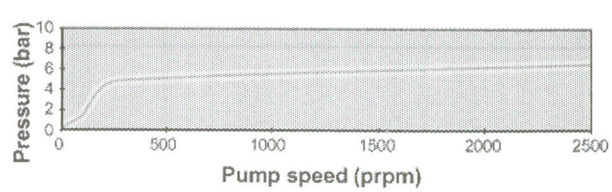
A regulating valve allows the transfer pressure to be maintained at a practically constant level (about 6 bar) throughout the whole range of engine operations by returning some of the fuel to the pump inlet.

[Fig. 3]



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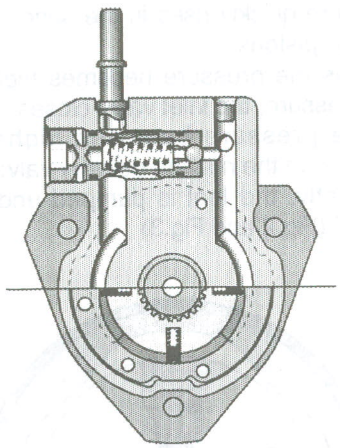
Characteristics of the transfer pump

Regulating pressure:	6 bars
Volume controlled:	5.6 cm^3 / revolution
Flow:	90 l/h at 300 rpm pump. 650 l/h at 2500 rpm pump.
Intake capacity:	65 mbar at 100 rpm pump.

[Fig. 4]



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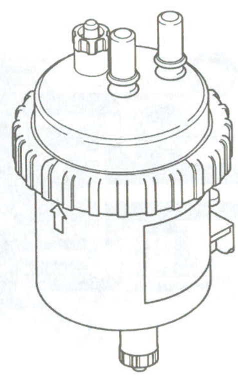
Fuel filter

Contaminants in the fuel can lead to damage at the pump components, delivery valves, and injection nozzles. This, therefore, necessitates the use of a fuel filter which is specifically aligned to the requirements of the particular injection system, otherwise faultless operation and a long service life cannot be guaranteed. Diesel fuel can contain water either in bound form (emulsion) or in free form (e.g. condensation of water due to temperature change). If this water enters the injection system, it can lead to damage as a result of corrosion.
Similar to other injection systems, the Common Rail also needs a fuel filter with water reservoir, from which the water must be drained at regular intervals. The increasing number of diesel engines used in passenger cars, has led to the demand for an automatic water warning device which indicates by means of a warning lamp when water must be drained (this is binding in those countries in which there is a high level of water in the fuel).

[Fig. 5] Fuel filter



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High-pressure stage

In addition to high-pressure generation, fuel distribution and fuel-metering also take place in the high-pressure stage. The most important components are:
- High-pressure pump,
- High-pressure accumulator(rail),
- Rail-pressure sensor,
- Pressure-limiter valve,
- High-pressure pipe,
- Injectors,
- IMV.

High pressure pump

Description

The high pressure pump makes use of the cam and radial plungers principle which has already demonstrated its worth in the rotary pumps. For engines requiring a high flow-rate, the pump has two chambers offset at an angle of 45°

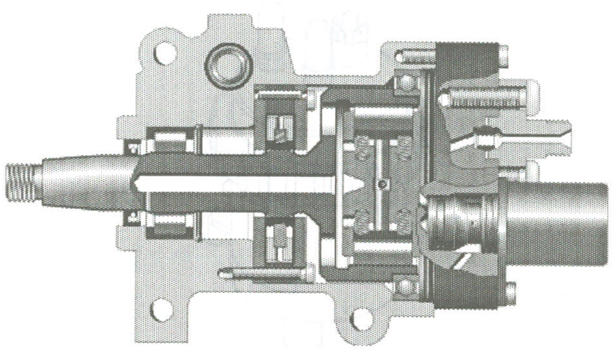
This offset allows peak torques and pressure fluctuations in the rail to be reduced.

The cam with four lobes is identical to that of conventional rotary pumps, but since the pump no longer determines the injection period it is possible to extend the pumping phase in order to considerably reduce drive torque, vibration and noise.

The difference from conventional rotary pumps lies in the fact that it is no longer the hydraulic head rotor which turns inside the cam, but the cam which turns around the hydraulic head.

Thus, any problems of dynamic pressure tightness are eliminated because the high pressure is generated in the fixed part of the pump.(Fig.1)

[Fig. 1] High pressure pump



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Principle of operation

a) Pump feed

The fuel is drawn in through the filter by the transfer pump. Then passed into the intake of the HP pump at a practically constant pressure known as the transfer pressure.

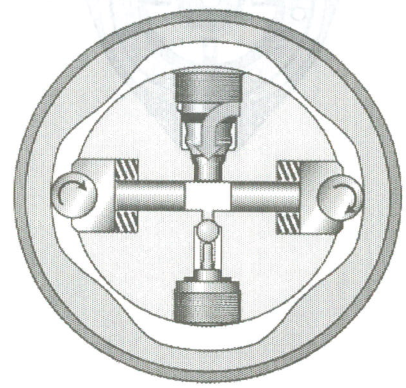
A filling control actuator is located upstream of the HP pump. It controls the amount of fuel sent to the pumping elements by adjusting the cross-section area of the passage. The ECU determines the value of the current sent to the coil in order to obtain the cross-section area of the passage required to reach the pressure demanded according to the engine? operating conditions.

When the pressure demand falls the current rises, and vice-versa.

b) The pumping principle

- During the filling phase, the rollers are kept in contact with the cam by means of coil springs mounted on either side of each shoe. The transferpressure is sufficient to open the inlet valve and to move the pumping plungers apart. Thus, the dead volume between the two plungers fills with fuel.
- When the diametrically opposite rollers simultaneously encounter the leading edge of the cam, the plungers are pushed towards each other. The pressure quickly rises in the space between the two plunger pistons.
- As soon as the pressure becomes higher than the transfer pressure, the inlet valve closes. When the pressure becomes higher than the pressure inside the rail, the delivery valve opens. Consequently, the fuel is pumped under pressure into the rail.(Fig.2 and Fig.3)

[Fig. 2]



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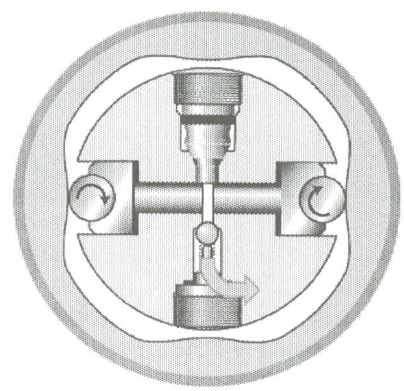
[Fig. 3]



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c) The inlet and delivery valves

During the input phase, transfer pressure the inlet valve. Fuel enters the body of the pumping element. Under the effect of the transfer pressure, the two plungers are forced apart.

When the rollers simultaneously encounter the leading edge of the cam, pressure suddenly rises in the body of the pumping element. The valve closes as soon as the pressure in the pumping element becomes higher than the transfer pressure.

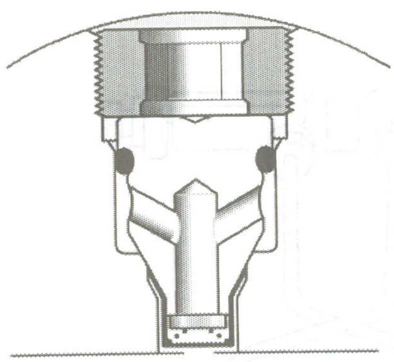
During the input phase, the ball of the delivery valve is subjected to the rail pressure on its outer face and to the transfer pressure on its inner face.

Thus the ball rests on its seat, ensuring the pressure tightness of the body of the pumping element. When the two diametrically opposite rollers encounter the leading edges of the cam, the plungers are forced together and pressure quickly rises in the body of the pumping element.

When the pressure in the element becomes higher than the pressure in the rail, the ball is unbalanced and it opens (spring calibration is negligible compared with the pressure forces).

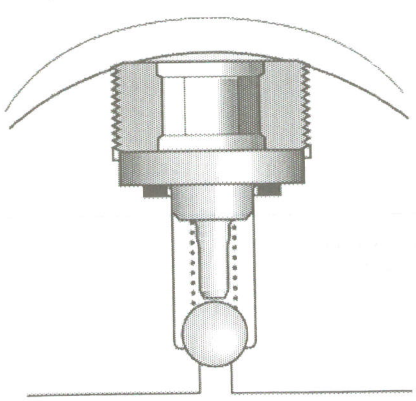
Fuel is then pumped into the rail at high pressure. (Fig.4 and Fig.5)

[Fig. 4] Inlet valve



CFL0FL072

[Fig. 5] Delivery valve



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d) Lubrication and cooling of the pump

Lubrication and cooling of the pump are provided by the fuel circulation. The minimum flow required to ensure adequate operation of the pump is 50 l/h.

e) Phasing of the pump

Conventional fuel injection pumps ensure pressurising and distribution of the fuel to the different injectors. It is essential to set the pump in such a way that the injection occurs at the required place during the cycle. The HP pump of the common rail system is no longer used for the fuel distribution, it is therefore not necessary to set the pump in relation to the engine.

Nevertheless, the setting or phasing of the pump offers two advantages:

- It allows the torque variations of the camshaft and the pump to be synchronised in order to reduce the stresses on the timing belt.
- It allows pressure control to be improved by synchronising peak pressures produced by the pump with pressure-drops caused by each injection. This phasing allows pressure stability to be improved, which helps to reduce the difference in flow between the cylinders (line to line).

The phasing of the pump is acheved by means of a pin located on the pump? drive shaft.

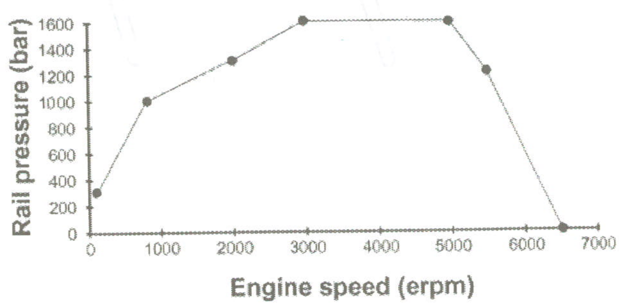
Performance of the HP pump

a) Pressure rise time

The time required to obtain a sufficient pressure in the rail to enable the engine to start depends on the volume of the system (definition of the rail, length of the pipes, ...). The aim is to reach a pressure of 200 bars in 1.5 revolutions (3rd compression). (Fig.6)

b) Max. pressure curve

[Fig. 6]



CFL0FL074

High-pressure accumulator (rail)

Assignments

The high-pressure accumulator (the Rail in Fig. 7) stores the fuel at high pressure. At the same time, the pressure oscillations which are generated due to the high-pressure pump delivery and the injection of fuel are damped by the rail volume.

This high-pressure accumulator is common to all cylinders, hence its name "common rail". Even when large quantities of fuel are extracted, the common rail maintains its inner pressure practically constant. This ensures that the injection pressure remains constant from the moment the injector opens.

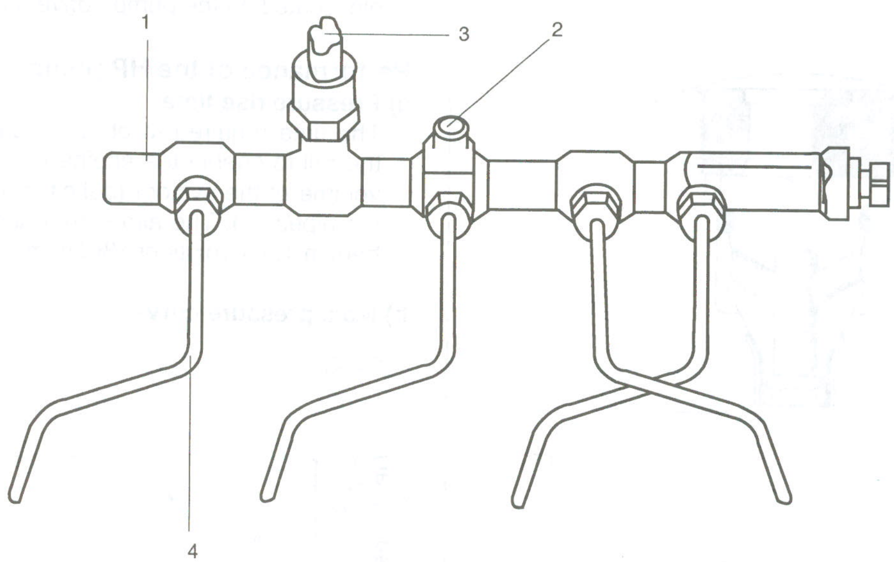
Design and construction

In order to comply with the wide variety of engine installation conditions, the rail with its flow limiters and the provisions for attaching rail-pressure sensor, pressure-control valve, and pressure-limiter valve is available in a number of different designs.

Function

The available rail volume is permanently filled with pressurized fuel. The compressibility of the fuel resulting from the high pressure is utilised to achieve the accumulator effect. When fuel leaves the rail for injection, the pressure in the high-pressure accumulator remains practically constant. Similarly, the pressure variations resulting from the pulsating fuel supply from the high-pressure pump are compensated for.

[Fig.8] High-pressure accumulator (rail)

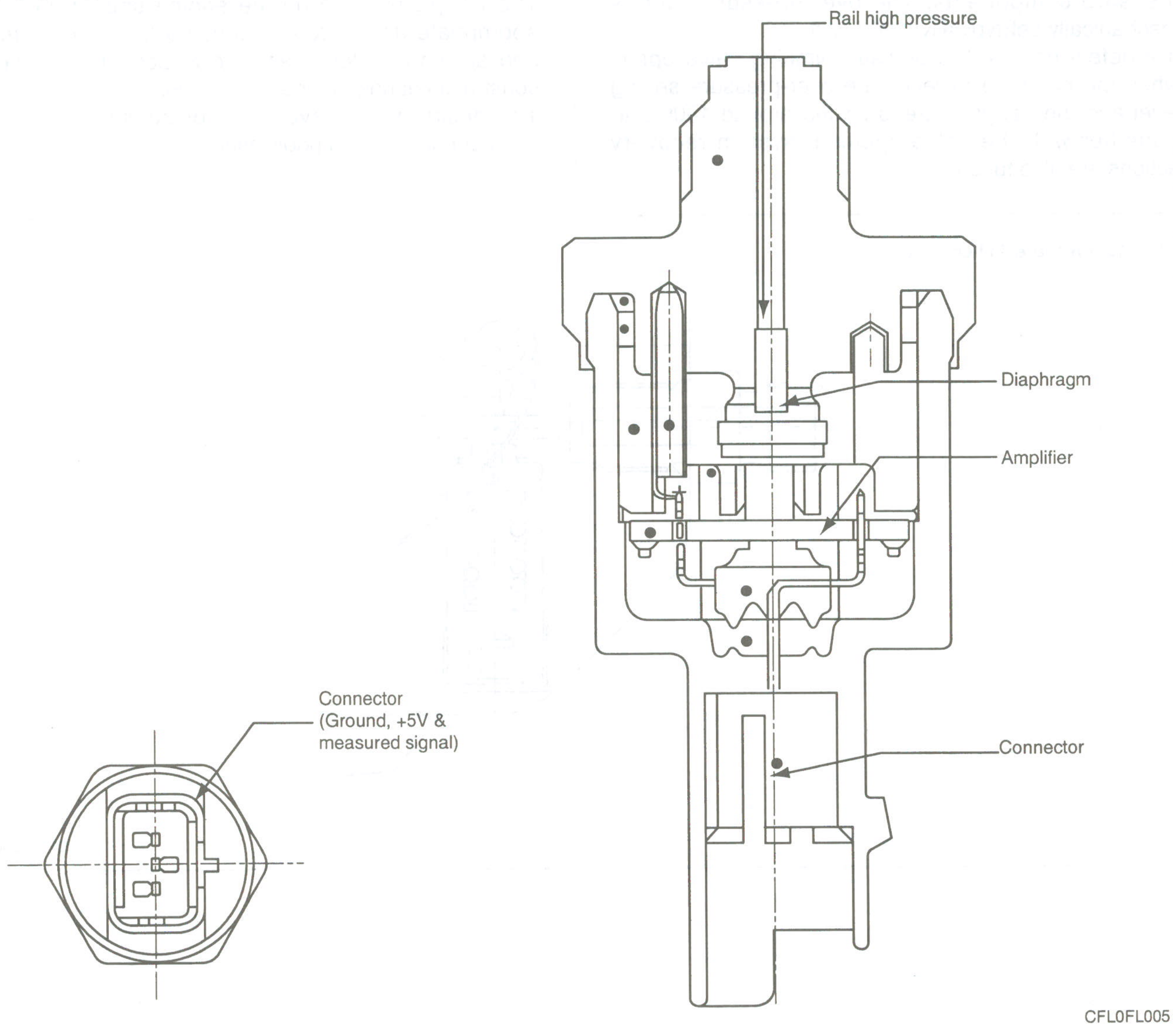


1. Rail
2. Inlet from the high-pressure pump
3. Rail-pressure sensor
4. Line to the injector

Rail-pressure sensor

The high pressure sensor aim is to provide to the ECU the current voltage signal corresponding to fuel high pressure in the HP accumulator (rail pressure). This information is used for fuelling and timing calculations.
It is located on the rail.

[Fig.9] Rail-pressure sensor



Frunctions

The sensor operates as an analog resistor. The change in resistance is proportional to the rail pressure acting upon the diaphragm. A rail pressure change lead to a geometry change. This movement changes the electrical resistance. A bridge circuit on the diaphragm supplies a voltage which is amplified to a range from 0.5V to 4.5V (respectively 0 and 1800 bar).

Pressure limiter valve

When the HP actuator is not used in the system, a pressure limiting valve has to be included in high pressure module.

It is mounted at pump HP outlet.

Its aim is to prevent against over-pressure in the high pressure components. The over-pressure latch is mechanically set(typically: 1800 bar).

If a defect occurs, the pressure limiting valve opens when the pressure exceeds the over-pressure setting level and the rail pressure is limited around 1600 bar. Together with the valve opening, system recovery actions are also taken.

High-pressure pipe

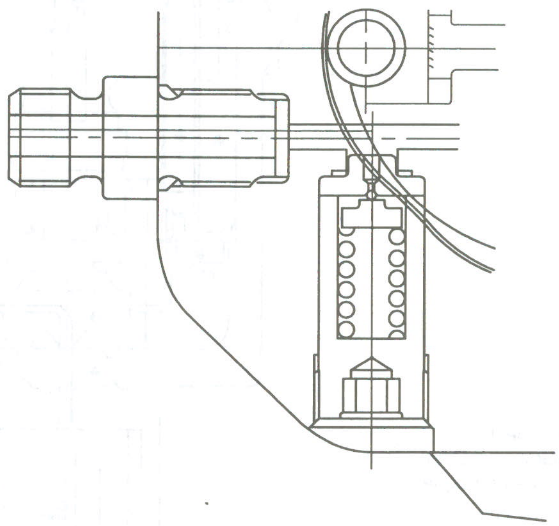
The high pressuer pipes used in the Common Rail system must withstand high pressures up to 2100 bar. They are made with the appropriate steel.

Typical dimensions are 6*2.4 mm with M12 connection nuts.

The HP pipes route on the engine should have the appropriate design to compensate for manufacturing and assembly tolerances, and to accept the specific constraints during engine operations.

The design rules have to be discussed with LVDS engineering for each poolication.

[Fig.10] Pressure limiter valve



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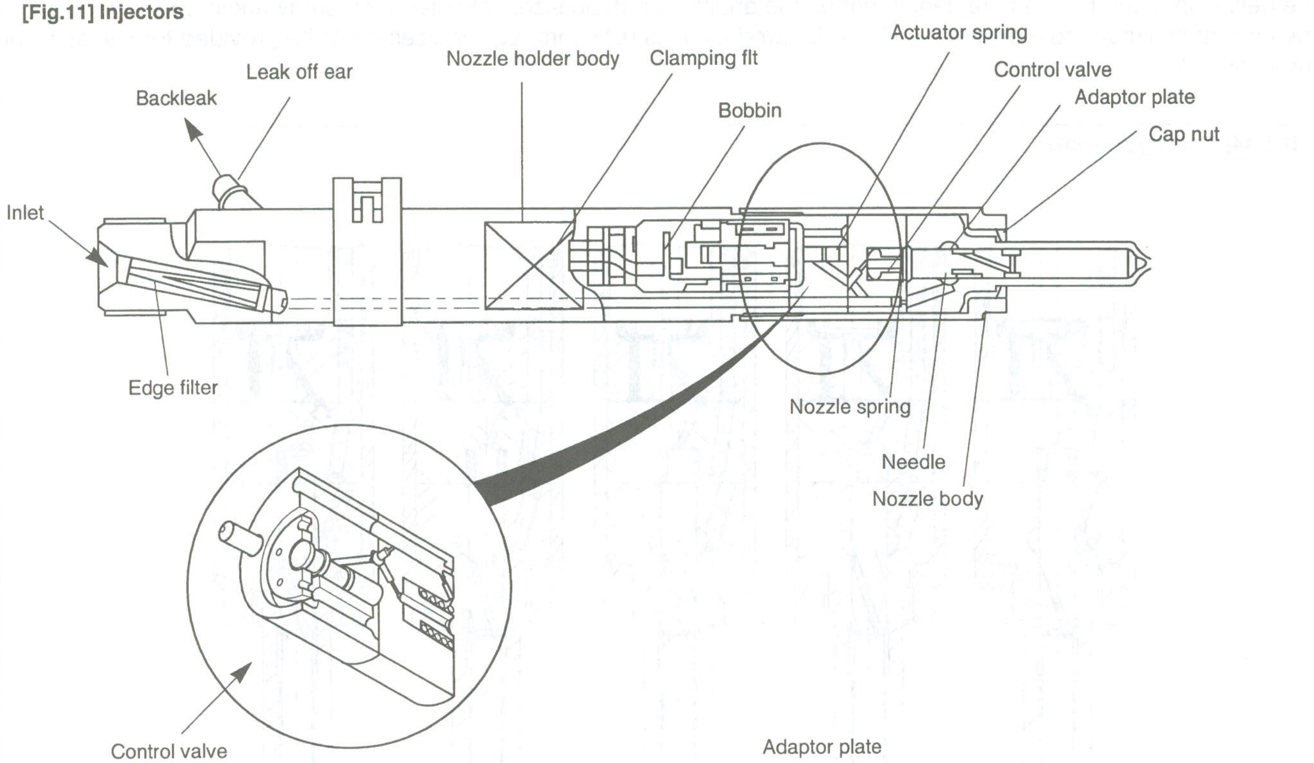
Injectors

The injector of the Common Rail system is electronically controlled. It has been designed:

- To allow multiple injections with short intervals between each injection.
- To be fully electronically controlled.
- To release a small amount of heat.

[Fig.11] Injectors



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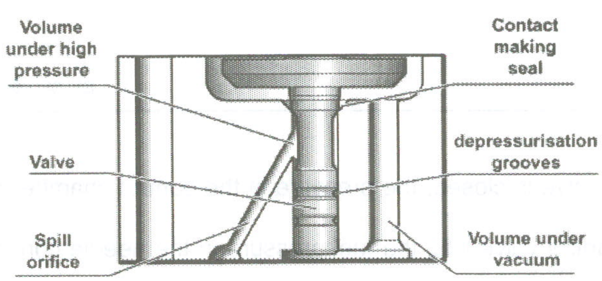
[Fig. 12]



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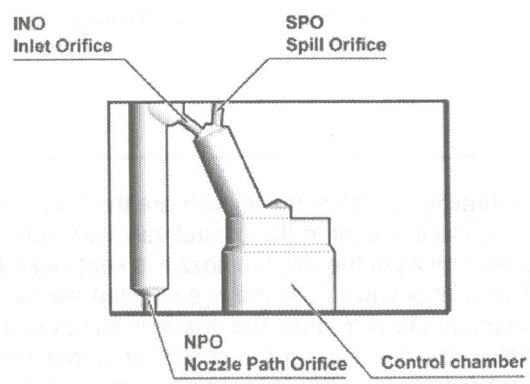
[Fig. 13]

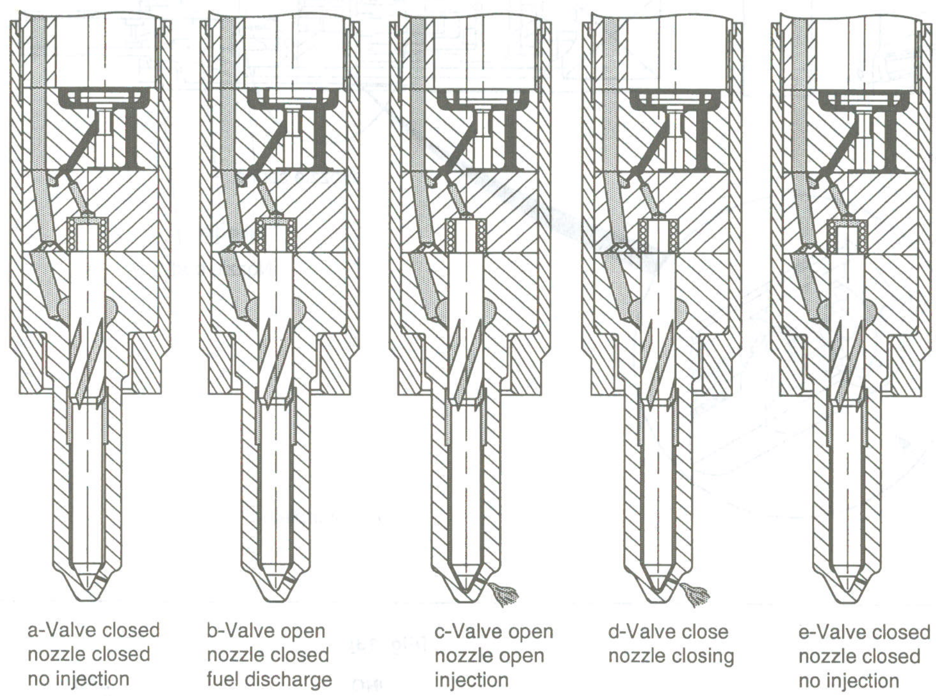


CFL0FL076

Method of operation

The purpose of the injector is to inject the required amount of fuel at the right time with variation of injection and start of injection as small as possible between engine cylinders.
The various orifice diameters in the hydraulic assembly are calibrated to achieve optimal control.
An edge filter is included in the inlet to protect the orifices and injection nozzles from contamination.
To ensure a robust behaviour for small delivery control up to 1600 bar, the pressure in the injectors back leak has be negative(the vacuum permits to avoid perturbations in the control valve chamber which are due to a non consistent diphasic mixture).
The definition of the nozzles are dependent on the application (hole size, hole diameter, spray angle,...).
The current minimum hole diameter suitable for production is 0.14 mm. Lower sizes could be provided for investigation purposes only.

[Fig.14] Working principle



The operating modes of the injector are the following:

a. No current is sent to the control valve solenoid, the control valve is closed, the pressure in the control chamber is the same as in the rail, the nozzle is kept closed.
b. The control valve solenoid is energised via the ECU, the control valve lifts, the fuel pressure in the needle control chamber starts to drop, the nozzle is still closed.
c. When the pressure in the control chamber has sufficiently dropped and as the fuel pressure at the nozzle seat remains equal to the rail pressure, the nozzle needle is unbalanced and moves upwards, the injection holes are open and the injection begins. The energising time on the control valve solenoid will depend on the operating point, it will control the injection quantity for a given rail pressure.
d. The ECU cuts the current on the control valve solenoid, the control valve solenoid, the control valve returns to its seat due to the solenoid spring force, the pressure in the needle control chamber increases and becomes slightly larger than the pressure in the nozzle seat thus closing the needle and stopping the injection.

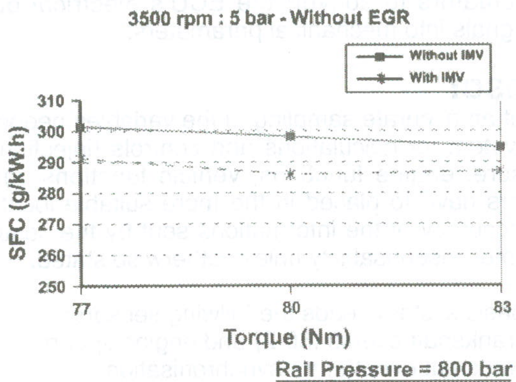
THE IMV(INLET METERING VALVE)

Function

The LP actuator, also called the Inlet Metering Valve, is used to control the rail pressure by regulating the amount of fuel which is sent to the pumping element of the HP pump. This actuator has two purposes:

- Firstly, it allows the efficiency of the injection system to be improved, since the HP pump only compresses the amount of fuel necessary to maintain in the rail the level of pressure required by the system as a function of the engineís operating conditions.(Fig. 15)

[Fig. 15] Inlet metering valve effect



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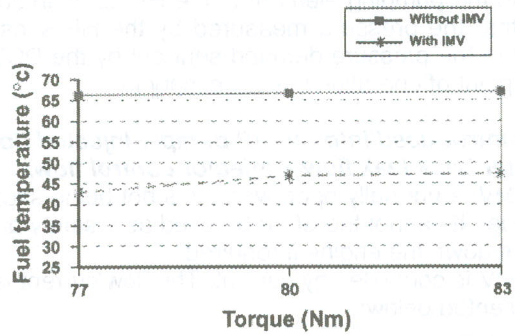
- Secondly, **it allows the temperature to be reduced in the fuel tank.** When the excess fuel is discharged into the back leak circuit, the pressure reduction in the fluid (from rail pressure down to atmospheric pressure) gives off a large amount of heat. This leads to a temperature rise in the fuel entering the tank. In order to prevent too high a temperature being reached, it is necessary to limit the amount of heat generated by the fuel pressure reduction, by reducing the back leak flow. To reduce the back leak flow, it is sufficient to adapt the flow of the HP pump to the engineís requirements throughout its operating range.(Fig. 16)

✱ *Notice*
To cool the fuel in a heat exchanger would be an expensive, bulky and not very effective solution.

[Fig. 16] Fuel temperature at system backleak



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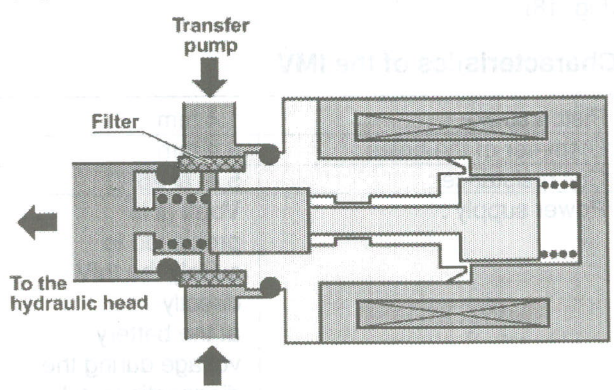
Description

The IMV is located on the hydraulic head of the pump. It is fed with fuel by the transfer pump via two radial holes. A cylindrical filter is fitted over the feed orifices of the IMV. This makes it possible to protect not only the LP actuator, but also all the components of the injection system located downstream of the IMV. The IMV consists of the following components:

- A piston held in the fully open position by a spring.
- A current controlled coil.
- A sleeve held against the piston by a spring whose calibration is set lower than that of the first spring.
- A body provided with two radial inlet holes an axial outlet hole.
- A cylindrical filter positioned on the inlet holes.
- Two O-rings ensuring pressure-tightness between the hydraulic head and the body of the IMV. (Fig. 17)

[Fig. 17]



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Principle of operation

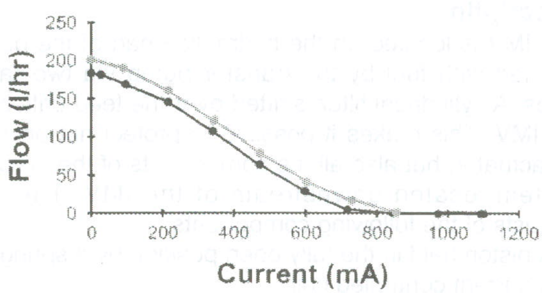
The LP actuator is used to proportion the amount of fuel sent to the pumping element of the HP pump in such a way that the pressure measured by the HP sensor is equal to the pressure demand sent out by the DCU. At each point of operation it is necessary to have:

Flow introduced into the HP pump = Injected flow + Injector back leak flow + Injector control flow.

The IMV is normally open when it is not being supplied with fuel. It cannot therefore be used as a safety device to shut down the engine if required.

The IMV is controlled by current. The flow/current law is represented below:

[Fig. 18] Flow/current law



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The ECU determines the value of the current to be sent to the IMV according to:

- The engine speed.
- The flow demand.
- The rail pressure demand.
- The measured rail pressure.

(Fig. 18)

Characteristics of the IMV

Piston stroke :	1.4 mm
Diameter of the holes :	3.4 mm
Coil resistance :	5.4 at 25°C
Power supply :	Vbatt (it is prohibited to supply the IMV directly at the battery voltage during the diagnostic tests!)
Max. current :	1A
Weight :	260 g
Operating temperatures :	40<T<125°C
Fluid temperatures :	40<T<90°C
Control logic :	Normally open without power. The flow decreases as the current rises.

SYSTEM CONTROL USING EDC

Sysem blocks

The Electronic Diesel Control (EDC) for Common Rail comprises three major system blocks:

1. Sensor and setpoint generators for registration of the operating conditions and the desired values. These convert a variety of physical parameters into electrical signals.
2. The ECU for generating the electrial output signals by processing the information using specified arithmetic operations (control algorithms)
3. Actuators to convert the ECU's electrical output signals into mechanical parameters.

Sensor

To get an accurate sampling of the variables needed by the system for calculations and controls (injection, rail pressure, engine functions, vehicle functions,...), the sensors have to placed in the more suitable locations. The accuracy of the informations sent by the sensor is customer responsability unless otherwise stated.

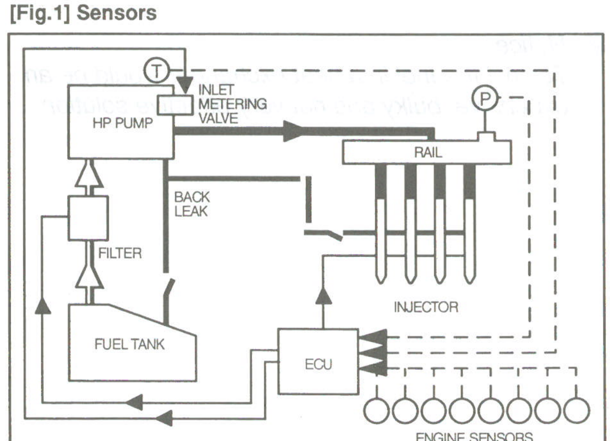
The basic system needs the follwing sensors:

- Crankshaft events (60-2) and engine speed,
- Camshaft event(s) for synchronisation,
- Rain pressure,
- Accelerator pedal,
- Inlet manifold pressure,
- Inlet manifold temperature,
- Coolant temperature,
- Accelerometer (knock sensor),
- Vehicle speed,
- Brake switch,
- Fuel temperature (under LVDS responsability).

Other sensors can also be used depending on the required functionalities:

- Air mass flow or EGR valve lift,
- Clutch,
- Neutral recognition for automatic transmission,
- Kick down,
- Atmospheric pressure,
- ...

[Fig.1] Sensors



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ECU

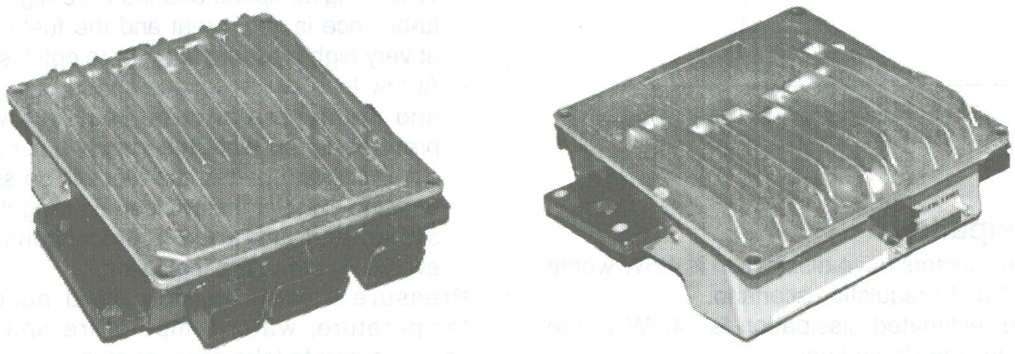
The ECU can be located either in the passenger or in engine compartment.

For each operating point, the Control Unit receives the sensors signals, realises the calculations needed by the functions, controls the rail pressure and the injection (amount, position, multi-injection), drives the actuators associated to the engine and vehicle functions. It also provides system monitoring and diagnosis function;

Generic control unit description

- •ECU with metal + plastic box,
- •The envelope and pin allocations are available,
- •Siemens CS167-32FM processor with intermal Flsh,
- •112 pins, 3 block modular connector,

[Fig.2] ECU



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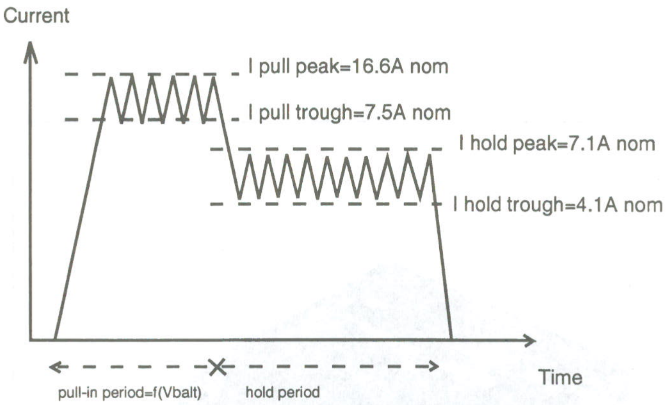
Injector drive current definition

The injector definition allows for low drive currents:

- I pull mean = ~10.5 A at 12V
- I hold mean = ~5A at 12V

[Fig.3]



Power dissipation

•The maximum injectors drive dissipation is 4.5W worse case with a EURO IV regulation scenario.
•The maximum estimated dissipation is 14.2W worse case for the complete Control unit.

Electrical limits

The ECU supply is the voltage between the ECU supply and ground pins.
The voltage drop inside the wires from the battery to the ECU supply must be as low as possible.

Nominal voltage at Control Unit: 12V
Nominal system functionalities: 10 to 16V
Limited system functionnalities: 6 to 10V
Derated functionalities: 16 to 18V (18V for 1 hour max)
No damage: 24V during 2 minutes

INJECTION CONTROL

PRESSURE CONTROL

Pressure control consists of two principal modules:

- The first determines the rail pressure demand value as a function of the engineís operating conditions.
- The second is responsible for controlling the IMV to ensure that the rail pressure reaches the required value.

Pressure demand

Pressure demand is determined according to engine speed and load on the engine. The aim is to adapt the injection pressure to the engineís requirements:

- When engine speed and load are high, the degree of turbulence is very great and the fuel can be injected at very high pressure in order to optimise combustion.
- At low load or low engine speed, the filling is slower and the degree of turbulence is low. If injection pressure is too high, the nozzleís penetration will be excessive and part of the fuel will be sprayed directly onto the sides of the cylinder, causing the formation of smoke and unburned hydrocarbons and perhaps eventually damaging the piston.

Pressure demand is corrected according to air temperature, water temperature and atmospheric pressure and to take account of the added ignition time caused by cold running or by high altitude driving.
A special pressure demand is necessary in order to obtain the additional flow required during starts.
This demand is determined according to injected fuel and water temperature.
The pressure demand is limited as a function of fuel temperature. In fact, not all of the fuel compressed by the HP pump is injected into the engine. Part of the compressed fuel is sent back to the fuel tank through the back leak circuit. The reduction in pressure of the fuel from rail pressure to atmospheric pressure causes a large amount of heat to be released into the fuel tank.

Main flow demand

The main flow represents the amount of fuel injected into the cylinder during the main injection. The pilot flow represents the amount of fuel injected during the pilot injection. The total fuel injected during one cycle (main flow + pilot flow)is determined in the following manner: The driverís demand (which represents the movement of the pedal position in flow demand)is compared with the value of the minimum flow determined by the idle speed controller.

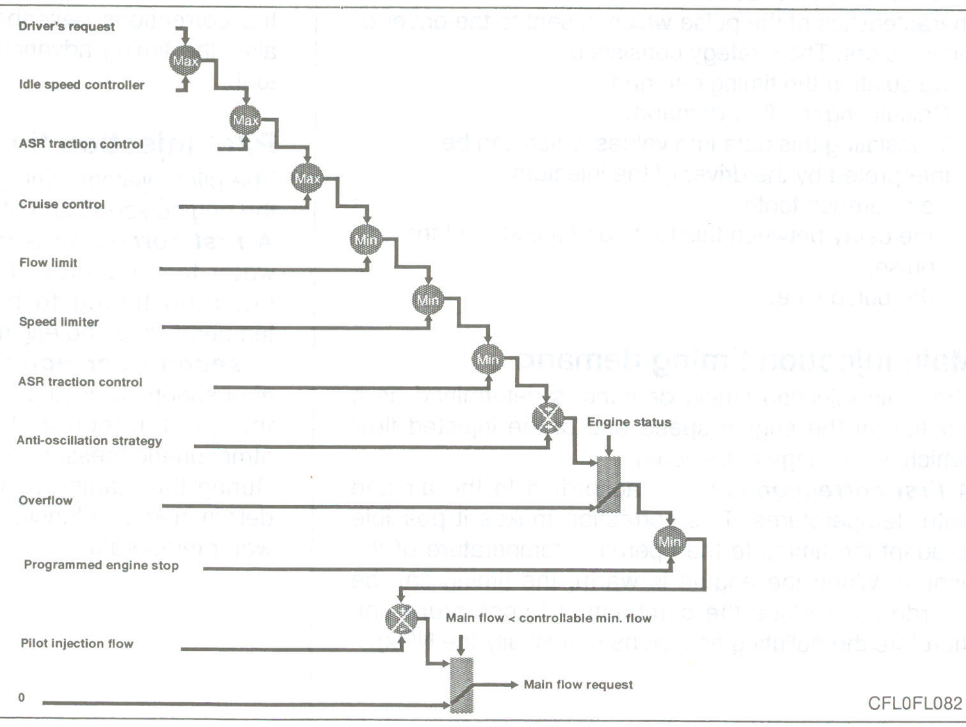
- When the driver depresses the pedal, it is his demand which is taken into account by the system in order to determine the fuel injected.
- When the driver releases the pedal, the idle speed controller takes over to determine the minimum fuel which must be injected into the cylinder to prevent the engine from stalling.

It is therefore the greater of these two values which is retained by the system.
This value is then compared with the lower flow limit determined by the ASR trajectory control system. As soon as the injected fuel becomes lower than the flow limit determined by the ASR trajectory control system, the antagonistic torque (braking torque due to the engine brake)transmitted to the drive wheels exceeds the adherence capacity of the vehicle and there is therefore a risk of the drive wheels locking.
The system thus chooses the greater of these two values in order to prevent any loss of control of the vehicle (due to the locking of the drive wheels) during a sharp deceleration. This value is then compared with the flow limit determined by the cruise control. As soon as the injected fuel becomes lower than the flow limit determined by the cruise control, the vehicle? speed falls below the value required by the driver. The system therefore chooses the greater of these two values in order to maintain the speed at the required level.
This value is then compared with the flow limit determined by the flow limitation strategy. This strategy allows the flow to be limited as a function of the operating conditions of the engine.
The system therefore chooses the smaller of these two values in order to protect the engine.
This value is then compared with the flow limit determined by the speed limiter. As soon as the injected fuel becomes higher than the flow limit determined by the speed limiter, the vehicleís speed exceeds the maximum threshold determined by the driver.The system therefore chooses the smaller of these two values in order to maintain the speed below the maximum threshold determined by the driver.
This value is then compared with the fuel limit determined by the ASR trajectory control system.
As soon as the injected fuel becomes higher than the fuel limit determined by the ASR trajectory control system, the engine torque transmitted to the wheels exceeds the adhesion capacity of the vehicle and there is a risk of the drive wheels skidding.
The system therefore chooses the smaller of the two values in order to avoid any loss of control of the vehicle during accelerations.The anti-oscillation strategy makes it possible to compensate for fluctuations in engine speed during transient conditions. This strategy leads to a fuel correction which is added to the total fuel of each cylinder. The correction is determined before each injection as a function of the instantaneous engine speed and of the gear engaged.
A switch makes it possible to change over from the supercharge fuel to the total fuel according to the state of the engine.

- Until the starting phase has finished, the system uses the supercharge fuel.
- Once the engine changes to normal operation, the system uses the total fuel.

The main fuel is obtained by subtracting the pilot injection fuel from the total fuel. A mapping determines the minimum fuel which can control an injector as a function of the rail pressure.
As soon as the main fuel falls below this value, the fuel demand changes to 0 because in any case the injector is not capable of injecting the quantity demanded. (Fig. 1)

[Fig. 1]



CFLOFL082

a) Driver demand

The driver demand is the translation of the pedal position into the fuel demand. It is calculated as a function of the pedal position and of the engine speed. The driver demand is filtered in order to limit the hesitations caused by rapid changes of the pedal position. A mapping determines the maximum fuel which can be injected as a function of the driver demand and the rail pressure. Since the flow is proportional to the injection time and to the square root of the injection pressure, it is necessary to limit the flow according to the pressure in order to avoid extending the injection for too long into the engine cycle. The system compares the driver demand with this limit and chooses the smaller of the two values. The driver demand is then corrected according to the water temperature. This correction is added to the driver demand.

b) Idle speed controller

The idle speed controller consists of two principal modules:

The first module determines the required idle speed according to:

- The operating conditions of the engine (water temperature and gear engaged).
- Any activation of the electrical consumers (electric windscreen, power assisted steering, air conditioning, thermoplungers).
- The battery voltage.
- The presence of any faults liable to interfere with the rail pressure control or the injection control. In this case, the accelerated idle speed is activated to prevent the engine from stalling when operating in degraded mode.
- It is possible to increase or to reduce the required idle speed with the aid of the diagnostic tool. The second module is responsible for providing closed loop control of the engine? idle speed by adapting the minimum fuel according to the difference between the required idle speed and the engine speed.

c) Flow limitation

The flow limitation strategy is based on the following strategies:

- The flow limitation depending on the filling of the engine with air is determined according to the engine speed and the air flow. This limitation allows smoke emissions to be reduced during tabilised running.
- The flow limitation depending on the atmospheric pressure is determined according to the engine speed and the atmospheric pressure. It allows smoke emissions to be reduced when driving at altitude.
- The full load flow curve is determined according to the gear engaged and the engine speed. It allows the maximum torque delivered by the engine to be limited.
- The flow limitation under transient conditions is determined according to the engine speed and the flow demand. This limitation allows smoke emissions to be avoided under transient conditions.
- A performance limitation is introduced if faults liable to upset the rail pressure control or the injection control are detected by the system. In this case, and depending on the gravity of the fault, the system activates:

  Reduced flow strategy 1 which guarantees 75% of the performance without limiting the engine speed.

  Reduced flow strategy 2 which guarantees 50% of the performance with the engine speed limited to 3000 rpm.

  Reduced flow strategy 3 which limits the engine speed to 2000 rpm.

  The system chooses the lowest of all these values. A correction depending on the water temperature is added to the flow limitation. This correction makes it possible to reduce the mechanical stresses while the engine is warming up. The correction is determined according to the water temperature, the engine speed and the time which has passed since starting.

d) Supercharge flow demand

The supercharge flow is calculated according to the engine speed and the water temperature.

A correction depending on the air temperature and the atmospheric pressure is made in order to increase the supercharge flow during cold starts.

It is possible to alter the supercharge flow value by adding a flow offset with the aid of the diagnostic tool.

Pilot flow demand

The pilot flow represents the amount of fuel injected into the cylinder during the pilot injection. This amount is determined according to the engine speed and the total flow.

A first correction is made according to the air and water temperatures. This correction allows the pilot flow to be adapted to the operating temperature of the engine. When the engine is warm, the ignition time decreases because the end-of-compression temperature is higher. The pilot flow can therefore be reduced because there is obviously less combustion noise when the engine is warm.

A second correction is made according to the atmospheric pressure. This correction is used to adapt the pilot flow according to the atmospheric pressure and therefore the altitude.

During starting, the pilot flow is determined on the basis of the engine speed and the water temperature.

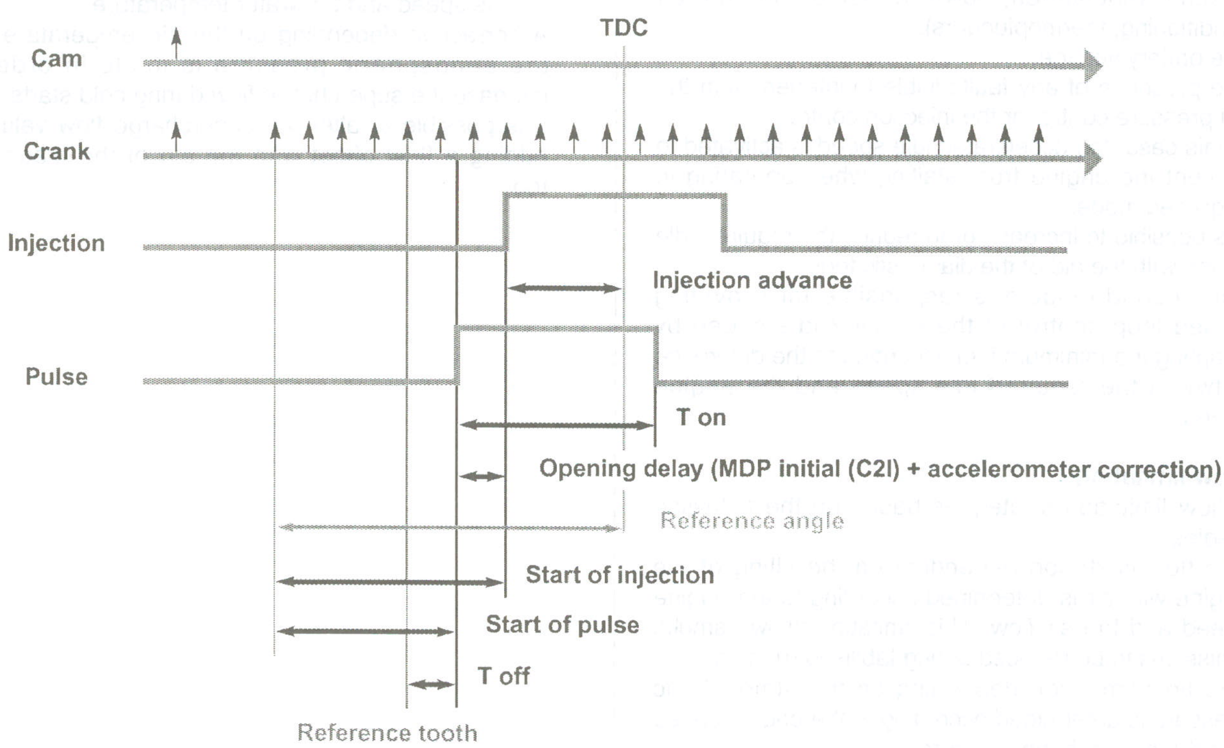
Pulse determination

The system at this point knows when the injections should begin (timing)and it also knows the amount of fuel which must be injected into the cylinders during each injection (flow). It therefore still has to determine for each injector the number of pulses, their time and their position in the engine cycle.

In point of fact, this function allows the previously determined timing advances and flows to be translated into data that can be understood by the control system of the injectors:

- A reference tooth (CKPS).
- A time between this tooth and the start of the pulse (Toff).
- The pulse time (Ton). (Fig. 2)

[Fig.2]



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a) Determination of the reference tooth

The injection timing advance is expressed in crankshaft degrees in relation to TDC. The advance is positive if the injection begins before TDC and is negative if it begins afterwards.

The angular position of the gap in relation to TDC is a piece of application data which depends on the orientation of the flywheel in relation to the crankshaft and on the position of the engine speed sensor on the clutch housing.

The injector opening time depends:

- On the initial characteristics of the injector (C2I).
- On the battery voltage and the resistance of the wiring loom (BRC strategy).
- On the deviation of the injector (resetting of the MDP by the accelerometer).

The opening time makes it possible to determine the angular position at which the pulse should be sent to the injector in order to ensure that the injection actually begins at the angle corresponding to the injection timing advance.

If it is known where the pulse should begin, it is possible to determine the position of the reference tooth.

b) Calculation of the Toff value

The Toff represents the time between the reference tooth and the beginning of the pulse.

The Toff value is obtained by dividing the angle between the reference tooth and the start of the pulse by the instantaneous engine speed.

c) Calculation of the Ton value

The Ton represents the pulse time. The Ton value is determined according to the flow demand and the rail pressure. The result of this calculation is then corrected by:

- The C2I, to take account of the initial characteristics of the injector.
- The BRC strategy, to take account of the variations in wiring loom resistance and battery voltage.
- The balancing strategy of the point to point flows (cylinder balancing).

Cylinder balancing strategy

a) Balancing of the point to point flows

This strategy allows the point to point flows to be balanced. The pulse of each injector is corrected according to the difference in instantaneous speed measured between two successive injections:

- The instantaneous speeds on two successive injections are first calculated.
- The difference between these two instantaneous speeds is then calculated.
- Finally, the time to be added to the main injection pulse for the different injectors is determined.
  For each injector, this time is calculated according to the initial offset of the injector and the instantaneous speed difference.

b) Detection of an injector which has stuck closed

The cylinder balancing strategy also allows the detection of an injector which has stuck closed.

The difference in instantaneous speed between two successive injections then exceeds a pre-defined threshold. In this case, a fault is signalled by the system.

Accelerometer strategy

a) Resetting the pilot injection

The accelerometer is used to reset the pilot injection flow in closed loop for each injector.

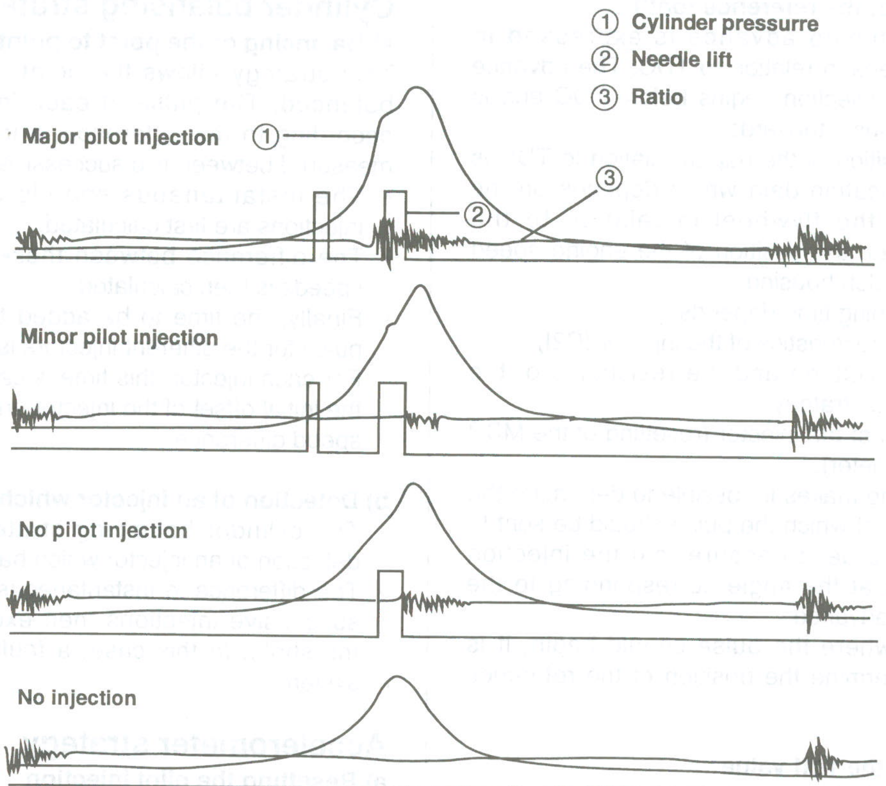
This method is self-adaptive and therefore allows the correction of any injector deviations over a period of time.

The principle of use of the accelerometer is based on the detection of the combustion noises. The sensor is positioned in such a way as to receive the maximum signal for all the cylinders.

The raw signals from the accelerometer are processed to obtain a variable which quantifies the intensity of the combustion. This variable, known as the ratio, consists of the ratio between the intensity of the background noise and the combustion noise.

- A first window is used to establish the background noise level of the accelerometer signal for each cylinder. This window must therefore be positioned at a moment when there cannot be any combustion.
- The second window is used to measure the intensity of the pilot combustion. Its position is such that only the combustion noises produced by the pilot injection are measured. It is therefore placed just before the main injection. (Fig. 3)

[Fig. 3]



The accelerometer does not allow any evaluation of the quantity injected. However, it does allow the pulse value from which the injector begins to inject to be accurately known. This pulse value is called the MDP (Minimum Drive Pulse). On the basis of this information, it is possible to efficiently correct the pilot flows because small flows are very sensitive to variations in the MDP.
The pilot injection resetting principle therefore consists of determining the MDP, in other words the pulse corresponding to the start of the increase in value of the ratio. This is done periodically under certain operating conditions.
When the resetting is finished, the new minimum pulse value replaces the value obtained during the previous resetting. The first MDP value is provided by the (C2I). Each resetting then allows the closed loop of the MDP to be updated according to the deviation of the injector.

b) Detection of leaks in the cylinders

The accelerometer is also used to detect any injector which may have stuck open. The detection principle is based on monitoring the ratio. If there is a leak in the cylinder, the accumulated fuel self-ignites as soon as the temperature and pressure conditions are favourable (high engine speed, high load and small leak). This combustion is set off at about 20 degrees before TDC, i.e. well before the combustion caused by the main injection. The ratio therefore increases considerably in the detection window.
It is this increase which allows the leaks to be detected. The threshold beyond which a fault is signalled is a percentage of the maximum possible value of the ratio. Because of the severity of the recovery process (engine shut-down), the detection must be extremely robust.
Now, an increase in the ratio can be the consequence of various causes:

- Pilot injection too strong.
- Main combustion offset in the detection window (too much advance or window offset).
- Fuel leak in the cylinder.

If the ratio becomes too high, the strategy initially restricts the pilot injection flow and retards the main injection. If the ratio remains high despite these interventions, this shows that a real leak is present, a fault is signalled and the engine is shut down.

c) Detection of an accelerometer fault

This strategy permits the detection of a fault in the sensor or in the wiring loom connecting the sensor to the DCU. It is based on detection of the combustion. When the engine is idling, the detection window is set too low for the combustion caused by the main injection. If the ratio increases, this shows that the accelerometer is working properly, but otherwise a fault is
signalled to indicate a sensor failure. The recovery modes associated with this fault consist of inhibition of the pilot injection and discharge through the injectors.

GENERAL

Specification

Input sensors	
Mass air flow sensor	HFM5 (Hot Film Sensor)
Intake air temperature sensor Resistance	Thermistor type 2.22 ~ 2.82kΩ at 20°C (68°F) 0.299 ~ 0.375kΩ at 80°C (176°F)
Engine coolant temperature sensor Resistance	Thermistor type 2.20 ~ 2.70kΩ at 20°C (68°F) 0.297 ~ 0.339kΩ at 80°C (176°F)
Vehicle speed sensor	Hall effect type
Camshaft position sensor	Hall effect type
Crankshaft position sensor	Magnetic type
Accel position sensor	Variable resistor type
Fuel pressure sensor	Piezo electricity type
Fuel temperature sensor Resistance	Thermistor type 2.27 ~ 2.73kΩ at 20°C (68°F) 0.298 ~ 0.322kΩ at 80°C (176°F)
Fuel tank capacity	75liter
Fuel filter	High pressure type
Fuel pump Driven by	Gear driven
Fuel pressure at high pressure side	1600 bar.
Injectors	Electronic type

Sealant

Engine coolant temperature sensor	LOCTITE 962T or equivalent

Service standard

Curb idle speed (rpm)	N-range	A/CON: OFF	800 ±100

Tightening torques

Item	Nm	kg•cm	lb•ft
Delivery pipe (Common Rail) installation	18.6 - 22.6	190- 230	13.7 - 16.6
Pipe from rail to Injector 1/2/3/4	35.8 - 42.7	365 - 435	26.4 - 31.5
Clamp bolt for Injector	19.6 - 21.6	200- 220	14.5 - 15.9
Retaining bolt for high pressure pump	35.8 - 42.7	365 - 435	26.4 - 31.5
High pressure pump - bolt	21.6 - 25.5	220 - 260	15.9 - 18.8
High pressure pump bracket - bolt	34.3 - 40.2	350 - 410	25.3 - 29.7
CKP - bolt	0.09 - 0.1	90 - 100	6.5 - 7.23
Knock sensor	14.7 - 24.5	150 - 250	10.8 - 18.1
Air heater terminal	3.4 - 4.9	35 - 50	2.5 - 3.6
Engine control module - nut	34.3 - 40.2	350 - 410	25.3 - 29.7
Air mass flow sensor - bolt	5.9 - 8.8	60 - 90	4.3 - 6.5

Troubleshooting

Problem	Possible cause
Engine does not start	Run out of petrol
	Starter out of order
	Pump hose supply cut
	High pressure leakage
	Fuse out of order
	The compensation of individual injector not adapted
	Drift of the water temperature sensor not detected
	Drift of the rail pressure sensor not detected
	Cam and Crank signals missing simultaneously
	Battery voltage too low
	Faulty antitheft
	EGR valve blocked open (engine doesn't start)
	IMV contaminated, stuck, jammed
	Fuel quality / presence of water
	Inversion of low pressure fuel connections
	Fuel filter not adapted
	Low pressure fuel circuit sealed
	Sealed fuel filter
	Intermittent fault connection
	Air ingress in the low pressure fuel circuit
	Back leak circuit of the pump sealed
	Air heaters out of order
	Engine compression too low
	Leakage at the injector valve
	Transfer pump out of order
	High pressure pump out of order
	Injector jammed open
	Bug soft or hardware fault not detected
Engine starts with difficulty or starts and stalls	Run out of petrol
	Back leak hose of nozzle holder cut
	High pressure leakage
	Fuse out of order
	Air filter sealed
	Alternator or voltage regulator out of order
	The compensation of individual injector not adapted
	Drift of the water temperature sensor not detected
	Drift of the rail pressure sensor not detected
	Battery voltage too low
	EGR valve blocked open (engine doesn't start)
	IMV contaminated, stuck, jammed
	Fuel quality / presence of water
	Inversion of low pressure fuel connections
	Fuel filter not adapted
	low pressure fuel circuit sealed
	Sealed fuel filter
	Oil level too high/too low
	Catalytic converter sealed or damaged
	Intermittent fault connection
	Air ingress in the low pressure fuel circuit
	Back leak circuit of the pump sealed
	Air heaters out of order
	Engine compression too low
	Back leak hose of nozzle holder sealed

Problem	Possible cause
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Petrol in fuel
	Bug soft or hardware fault not detected
Poor starting when hot	The compensation of individual injector not adapted
	Drift of the rail pressure sensor not detected
	Drift of the water temperature sensor not detected
	EGR valve blocked open (engine doesn't start)
	IMV contaminated, stuck, jammed
	Air filter sealed
	Fuel filter not adapted
	Air ingress in the low pressure fuel circuit
	Fuel quality / presence of water
	Back leak circuit of the pump sealed
	Sealed fuel filter
	Engine compression too low
	Intermittent fault connection
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Petrol in fuel
	Bug soft or hardware fault not detected
Unstable idling	Back leak hose of nozzle holder cut
	The compensation of individual injector not adapted
	Drift of the rail pressure sensor not detected
	Drift of the sensors used to evaluate the air flow not detected
	Harness resistance increased
	Fuel filter not adapted
	Air ingress in the low pressure fuel circuit
	Fuel quality / presence of water
	Sealed fuel filter
	Air filter sealed
	Back leak hose of nozzle holder sealed
	High pressure leakage
	Air heaters out of order
	Engine compression too low
	Bad flnging of the injector
	High pressure pump out of order
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Injector jammed open
Idle speed too high/too low	Drift of the water temperature sensor not detected
	Incorrect state of the electrical pack devices
	Alternator or voltage regulator out of order
	Clutch not well set
	Bug soft or hardware fault not detected
Blue, white, black smokes	The compensation of individual injector not adapted
	Drift of the sensors used to evaluate the air flow not detected
	Drift of the water temperature sensor not detected
	Drift of the rail pressure sensor not detected
	EGR valve blocked open (engine doesn't start)
	IMV contaminated, stuck, jammed
	Oil level too high/too low
	Fuel quality / presence of water
	Catalytic converter sealed or damaged
	Air filter sealed

Problem	Possible cause
	Oil suction (engine racing)
	Air heaters out of order
	Engine compression too low
	Bad flnging of the injector
	Injector washer not adapted, forgotten, doubled
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Injector jammed open
	Petrol in fuel
Engine rattling, noisy engine	The compensation of individual injector not adapted
	EGR valve blocked closed (noisy engine)
	EGR valve blocked open (engine doesn't start)
	Drift of the water temperature sensor not detected
	Drift of the sensors used to evaluate the air flow not detected
	Air heaters out of order
	Engine compression too low
	Back leak hose of nozzle holder sealed
	Drift of the rail pressure sensor not detected
	Injector washer not adapted, forgotten, doubled
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Injector jammed open
Burst noise	The compensation of individual injector not adapted
	Intermittent fault connection
	Drift of the rail pressure sensor not detected
	IMV contaminated, stuck, jammed
	Bug soft or hardware fault not detected
Untimely acceleration/deceleration and engine racing	Pedal sensor blocked (cable jammed)
	EGR valve blocked open (engine doesn't start)
	Intermittent fault connection
	Oil suction (engine racing)
	Drift of the rail pressure sensor not detected
	Bug soft or hardware fault not detected
Gap when accelerating and at re-coupling (response time)	Air inlet circuit open
	Incorrect state of the electrical pack devices
	Pedal sensor blocked (cable jammed)
	EGR valve blocked open (engine doesn't start)
	Turbo charger damaged
	Fuel filter not adapted
	Sealed fuel filter
	Engine compression too low
	High pressure leakage
	IMV contaminated, stuck, jammed
	Needle stuck (injection possible over a certain pressure)
	Bug soft or hardware fault not detected
Engine stop/ stalling	Run out of petrol
	Pump hose supply cut
	High pressure leakage
	Fuse out of order
	Fuel quality / presence of water
	low pressure fuel circuit sealed
	Sealed fuel filter
	Cam and Crank signals missing simultaneously
	EGR valve blocked open (engine doesn't start)
	IMV contaminated, stuck, jammed

Problem	Possible cause
	Alternator or voltage regulator out of order
	Intermittent fault connection
	Catalytic converter sealed or damaged
	Oil suction (engine racing)
	Transfer pump out of order
	High pressure pump out of order
	Faulty ignition key
	Petrol in fuel
	Bug soft or hardware fault not detected
Engine judder	Run out of petrol
	Back leak hose of nozzle holder cut
	Incorrect state of the electrical pack devices
	The compensation of individual injector not adapted
	Drift of the sensors used to evaluate the air flow not detected
	EGR valve blocked open (engine doesn't start)
	Fuel filter not adapted
	Air ingress in the low pressure fuel circuit
	Fuel quality / presence of water
	Sealed fuel filter
	Intermittent fault connection
	Harness resistance increased
	Air heaters out of order
	Engine compression too low
	Back leak hose of nozzle holder sealed
	Valve clearance
	Transfer pump out of order
	Injector washer not adapted, forgotten, doubled
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Injector jammed open
	Petrol in fuel
	Bug soft or hardware fault not detected
Lack of power	The compensation of individual injector not adapted
	Pedal sensor blocked (cable jammed)
	Incorrect state of the electrical pack devices
	Drift of the sensors used to evaluate the air flow not detected
	EGR valve blocked open (engine doesn't start)
	Air inlet circuit open
	Air filter sealed
	Oil level too high/too low
	Catalytic converter sealed or damaged
	Turbo charger damaged
	Fuel filter not adapted
	Sealed fuel filter
	Leakage at the injector valve
	Back leak circuit of the pump sealed
	Back leak hose of nozzle holder sealed
	Engine compression too low
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Valve clearance
Too much power	EGR valve blocked closed (noisy engine)
	The compensation of individual injector not adapted
	Oil suction (engine racing)
	Injector not adapted
	Bug soft or hardware fault not detected

Problem	Possible cause
Excessive fuel consumption	Back leak hose of nozzle holder cut
	Leakage at the IMV
	Leakage at fuel temperature sensor
	Leakage at the spacers
	High pressure leakage
	Air inlet circuit open
	Air filter sealed
	The compensation of individual injector not adapted
	EGR valve blocked open (engine doesn't start)
	Incorrect state of the electrical pack devices
	Oil level too high/too low
	Fuel quality / presence of water
	Catalytic converter sealed or damaged
	Turbo charger damaged
	Engine compression too low
	Injector not adapted
	Bug soft or hardware fault not detected
Over speed engine when changing the gear box ratio	Pedal sensor blocked (cable jammed)
	The compensation of individual injector not adapted
	Intermittent fault connection
	Clutch not well set
	Oil suction (engine racing)
	Turbo charger damaged
	Injector not adapted
	Bug soft or hardware fault not detected
Exhaust smells	EGR valve blocked open (engine doesn't start)
	Oil suction (engine racing)
	Turbo charger damaged
	Oil level too high/too low
	The compensation of individual injector not adapted
	Catalytic converter sealed or damaged
	Bad flnging of the injector
	Injector washer not adapted, forgotten, doubled
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)
	Injector jammed open
	Bug soft or hardware fault not detected
Smokes (black, white, blue) when accelerating	The compensation of individual injector not adapted
	EGR valve blocked open (engine doesn't start)
	Drift of the sensors used to evaluate the air flow not detected
	Air filter sealed
	Fuel quality / presence of water
	Oil level too high/too low
	Turbo charger damaged
	Catalytic converter sealed or damaged
	Oil suction (engine racing)
	Air heaters out of order
	Engine compression too low
	High pressure leakage
	Intermittent fault connection
	Bad flnging of the injector
	Injector washer not adapted, forgotten, doubled
	Injector not adapted
	Carbon deposit on the injector (sealed holes)
	Needle stuck (injection possible over a certain pressure)

Problem	Possible cause
	Injector jammed open
	Petrol in fuel
	Bug soft or hardware fault not detected
Fuel smells	Pump hose supply cut
	Back leak hose of nozzle holder cut
	Leakage at the IMV
	Leakage at fuel temperature sensor
	Leakage at the spacers
	High pressure leakage
The engine collapses at take off	Pedal sensor blocked (cable jammed)
	Incorrect state of the electrical pack devices
	Air filter sealed
	Inversion of low pressure fuel connections
	Fuel filter not adapted
	Fuel quality/presence of water
	Air ingress in the low pressure fuel circuit
	Sealed fuel filter
	Catalytic converter sealed or damaged
	Clutch not well set
	Intermittent fault connection
	Drift of the rail pressure sensor not detected
	IMV contaminated, stuck, jammed
	Petrol in fuel
	Bug soft or hardware fault not detected
The engine does not stop	Faulty ignition key
	Oil suction (engine racing)
	Bug soft or hardware fault not detected
Different mechanical noises	Buzzer noise (discharge by the injectors)
	Clip broken (vibrations, resonance, noises)
	Incorrect state of the electrical pack devices
	Catalytic converter sealed or damaged
	Air inlet circuit open
	Bad flnging of the injector
	Clutch not well set
	Turbo charger damaged
	Valve clearance

Check items \ Trouble symtoms	Engine will not start	Engine shut off and then restart	Engine starts only with difficult	High idle no throttle take-up	Knocking on accel. (warm-up phases)	Vibration at idle	Reduced power	Engine does not run smoothly, misfiring, knocking	Bucking
Rail Pressure Sensor			18			12	17	17	
Accel. Position Sensor				2			8		
Mechanical fault in accel.				3			9		
EGR						7	10		
HFM5 (Air Flow Meter)						9	14		
Air filter clogged			12			8	3		
Vacuum system leaking							2		
Turbocharger defective							11		
Waste-gate valve connection							12		
Fuel Temp. Sensor							16		
Checking belt tension								18	
Clutch switch									6
Brake switch									7
Vehicle speed signal									8
Checking oil level									
Radiator fan									
Radiator defective or clogged									
IG switch defective									
AC compress. SW									
AC SW									
Plug contacts			6						
Connection between turbo. and Intake manifold. Leaking			6				13		

TROUBLE-2

Troubleshooting guide chart

Check items \ Trouble symtoms	Engine will not start	Engine shut off and then restart	Engine starts only with difficult	High idle no throttle take-up	Knocking on accel. (warm-up phases)	Vibration at idle	Reduced power	Engine does not run smoothly, misfiring, knocking	Bucking
Self-diagnosis	1	1	1	1	1	1	1	1	1
Immobilizer	2								
Vehicle supply volt.	3		2					9	3
Main Relay	4	3	3					11	4
Fuse/plug wiring harness	5	2						8	2
Terminal 15	6	4	4					10	5
Crankshaft Position Sensor	7							12	
NO fuel	8								
Wrong fuel	9	5	7			2	4	3	
Lack of fuel								2	
Air in fuel system	10	6	8			3		4	
Low-pressure circuit(fuel)	11	7	13			4	5	7	
High-pressure circuit(fuel)	16	8	14			14	19	16	
Fuel filter	12		9			5	6	5	
Electric fuel pump	15		11					6	
Fuel pre-heater	13		10			6	7		
Pressure Regulator Valve	18	9	16			13		15	
Incorrect connection of injector	14		17		3	11		13	
Injector	17	10	19		4	10	18	14	
Mechanical componenet (compression, valve clearance...)	19		20				20	19	9
ECU defective	20								
TDC sensor			5						
Water Temp. Sensor			15		2		15		
Loss of coolant									
Glow-plug system			16						

TROUBLE-1

Check items \ Trouble symtoms	Engine overrun, Accel.	White/Blue smoke	Clouds of black smoke	Engine overheating	Can not shut off with IG key	Diagnosis lamp not go out or flickers	AC cannot be switched on	RAD. Fan constantly in operation
Self-diagnosis	1	1	1	1	1	1	1	1
Immobilizer								
Vehicle supply volt.								
Main Relay								
Fuse/plug wiring harness					4	2	2	4
Terminal 15					3			
Crankshaft Position Sensor								
NO fuel								
Wrong fuel				2				
Lack of fuel								
Air in fuel system		3						
Low-pressure circuit(fuel)		6						
High-pressure circuit(fuel)	7							
Fuel filter		4						
Electric fuel pump								
Fuel pre-heater		5						
Pressure Regulator Valve	6							
Incorrect connection of injector								
Injector								
Mechanical component (compression, valve clearance...)			7	7				
ECM defective					5			
TDC sensor								
Water Temp. Sensor	8	2	6	3			5	3
Loss of coolant				6				
Glow-plug system								

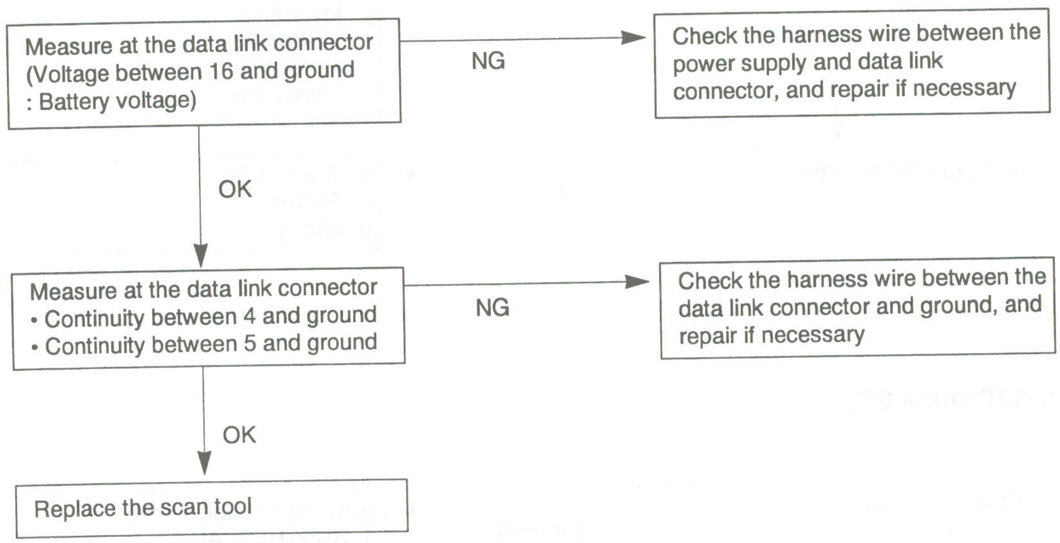
TROUBLE-3

Check items \ Trouble symtoms	Engine overrun, Accel.	White/Blue smoke	Clouds of black smoke	Engine overheating	Can not shut off with IG key	Diagnosis lamp not go out or flickers	AC cannot be switched on	RAD. Fan constantly in operation
Rail Pressure Sensor								
Accel. Position Sensor	3						6	
Mechanical fault in accel.	2							
EGR			3					
HFM5 (Air Flow Meter)			5					
Air filter clogged			2					
Vacuum system leaking			4					
Turbocharger defective	4							
Waste-gate valve connection	5							
Fuel Temp. Sensor	9							
Checking belt tension								
Clutch switch								
Brake switch								
Vehicle speed signal								
Checking oil level		7						
Radiator fan				4				
Radiator defective or clogged				5				
IG switch defective					2			
AC compress. SW							4	2
AC SW							3	
Plug contacts								
Connection between turbo. and Intake manifold. Leaking								

TROUBLESHOOTING PROCEDURES

Problem

Communication with scan tool is not possible.
(Communication with all system is not possible)



Scan tool communication with ECM is not possible

Comment	Probable cause
One of the following causes may be suspected. • No power supply to ECM • Defective ground circuit of ECM • Defective ECM • Improper communication line between ECM and scan tool	• Malfunction of ECM power supply circuit • Malfunction of the ECM • Open circuit between ECM and DLC

Engine will not start

Check electrical supply	NG	o Battery 1.Connection 2.Specific gravity, charging system 3. Drive belt 4. Voltage o Fusible link
↓ OK		
Check starting system	NG	o Starter relay o Starter o Wiring

Hard to start (Cranks OK)

Check self-diagnosis	Diagnostic trouble code	Diagnostic trouble codes o Using HI-SCAN
↓ Normal codes		
Check for vacuum leaks	Wrong	o Oil filler cap o Oil dipstic o Vacuum hose connections
↓ Ok		
Check for Injector	Wrong	o Leakage o Fuel line o Fuel filter o Fuel pump
↓ Ok		
Check injection timing	Diagnostic trouble code	Diagnostic trouble codes o Using HI-SCAN
↓ Ok		
Check fuel supply to injector o Fuel in tank o Fuel pressure	Wrong	o Oil filler cap o Oil dipstic o Vacuum hose connections
↓ Ok		
Check Engine control system	Wrong	o Wiring connections o Power to ECM 1. Fusible links 2. Fuses 3. Control relay o Engine coolant temperature sensor o Intake air temperature sensor o Injection signal circuit 1. Injector 2. ECM o Accel. position sensor o Air flow sensor

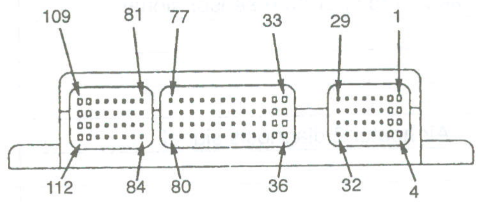
Rough idle or engine stalls

Ok ↓	Wrong →
Check self-diagnosis	Diagnostic trouble codes o Using HI-SCAN
Check for vacuum leaks	o Oil filler cap o Oil dipstic o Vacuum hose connections
Check fuel supply to injector o Fuel in tank o Fuel pressure	o Fuel line (leakage, deformation) o Fuses o Fuel pump o Fuel filter o Fuel pressure regulator
Check air cleaner filter	Filter-clean or replace
Check idle speed Standard : 800 ±100rpm	Idle speed-adjust
Check injection timing	Inspect the fuel system
Check fuel pressure	o Fuel pump o Fuel filter o Fuel pressure regulator
Check injectors	Injection condition
Check Engine control system	o Wiring connections o Power to ECM 1.Fusible links 2.Fuses 3.Control relay o Engine coolant temperature sensor o Injection signal circuit 1.Injector wiring 2.ECM

Engine hesitates or accelerates poorly

Check (Ok → next step)	Wrong
Check clutch or brakes	o Clutch-slip o Brake-drag
Check vacuum leaks in intake air line	o Oil filter cap o Oil dipstic o Hose connections
Check air cleaner filter	Clean-filter or replace
Check self-diagnosis	Diagnostic trouble codes o Using HI-SCAN
Check injection timing	Inspect the fuel system
Check fuel pressure	o Fuel pump o Fuel filter o Fuel pressure regulator
Check injectors	o Injector condition
Check the compression	o Compression check
Check Engine control system	o Wiring connections o Power to ECM 1.Fusible links 2.Fuses 3.Control relay o Engine coolant temperature sensor o Injection signal circuit 1.Injector wiring 2.ECM

ECM Terminal layout



Connector B-01

Terminal	Signal	Connected to
1	-	-
2	Acceleration position sensor 1 signal	APS
3	Acceleration position sensor 1 ground	APS
4	Power ground	Chassis ground
5	Battery voltage	Main relay
6	Acceleration position sensor 1 reference voltage	APS
7	-	-
8	Power ground	Chassis ground
9	MIL control	MIL
10	Acceleration position sensor 2 reference voltage	APS
11	Acceleration position sensor 2 signal	APS
12	Acceleration position sensor 2 ground	APS
13	-	-
14	IMMO lamp control	IMMO lamp
15	Brake switch signal 1	Brake switch
16	-	-
17	Key sensing signal	Ignition switch
18	-	-
19	-	-
20	-	-
21	-	-
22	-	-
23	-	-
24	Clutch switch signal	Clutch switch (MT)
25	-	-
26	Engine RPM	Tachometer
27	Immobilizer K-line	Immobilizer
28	Communication K-line	Data link connector
29	Glow lamp control	Glow lamp
30	P/N switch signal	Inhibitor switch (AT)
30	Ground	Chassis ground (MT)
31	-	-
32	-	-
33	Knock sensor shield ground	KS
34	-	-
35	-	-
36	Inlet metering valve control	Inlet metering valve
37	Crankshaft position sensor shield ground	CKPS
38	-	-
39	EGR solenoid valve control	EGR solenoid valve
40	-	-
41	-	-

Terminal	Signal	Connected to
42	Intake air temperature sensor signal	MAFS
43	-	-
44	-	-
45	-	-
46	Air heater 2 diagnosis signal	Air heater 2
47	-	-
48	-	-
49	-	-
50	Engine coolant temperature sensor signal	ECTS
51	Engine coolant temperature sensor ground	ECTS
52	Injector 4 low signal driver	Injector 4
53	Knock sensor signal	KS
54	Fuel temperature sensor signal	FTS
55	Fuel temperature sensor ground	FTS
56	Injector 4 high signal driver	Injector 4
57	Knock sensor ground	KS
58	Crankshaft position sensor + signal	CKPS
59	Crankshaft position sensor - signal	CKPS
60	Injector 3 low signal driver	Injector 3
61	Camshaft position sensor reference voltage	CMPS
62	Camshaft position sensor signal	CMPS
63	Camshaft position sensor ground	CMPS
64	Injector 3 high signal driver	Injector 3
65	Rail pressure sensor reference voltage	RPS
66	Rail pressure sensor signal	RPS
67	Rail pressure sensor ground	RPS
68	Injector 2 low signal driver	Injector 2
69	-	-
70	-	-
71	-	-
72	Injector 2 high signal driver	Injector 2
73	-	-
74	-	-
75	-	-
76	Injector 1 low signal driver	Injector 1
77	Mass air flow sensor reference voltage	MAFS
78	Mass air flow sensor signal	MAFS
79	Mass air flow sensor ground	MAFS
80	Injector 1 high signal driver	Injector 1
81	-	-
82	-	-
83	-	-
84	-	-
85	-	-
86	Brake switch signal 2	Brake switch
87	Cooling fan high relay control	High relay
88	Cooling fan low relay control	Low relay
89	-	-
90	Water heater diagnosis signal	Water heater 1
91	Air heater relay 1 control	Air heater relay 1
92	-	-

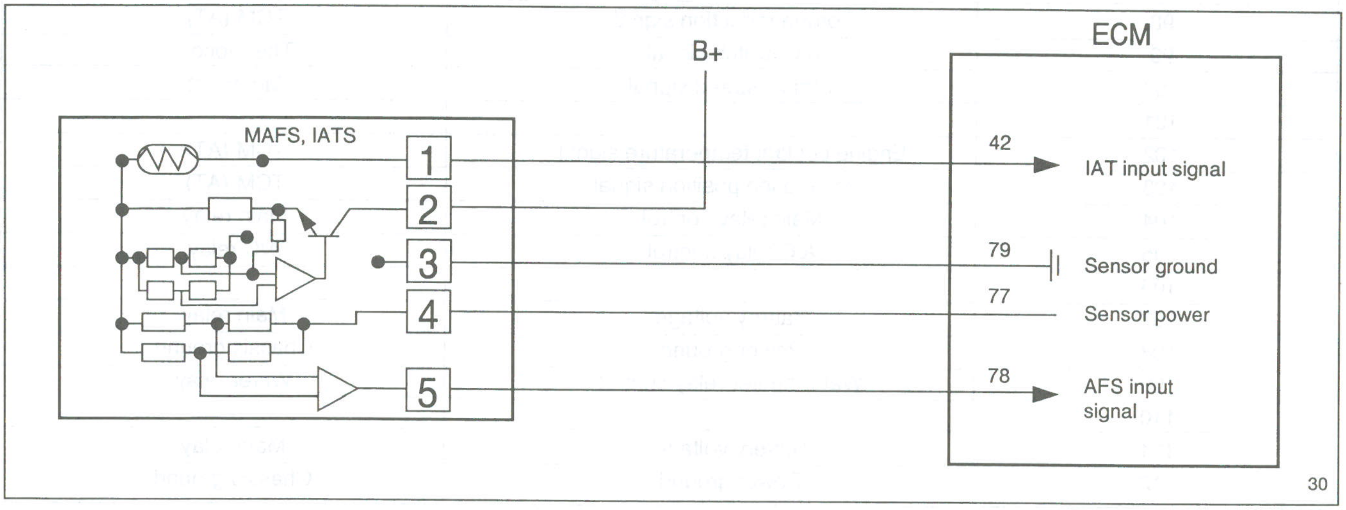
Terminal	Signal	Connected to
42	Intake air temperature sensor signal	MAFS
43	-	-
44	-	-
45	-	-
46	Air heater 2 diagnosis signal	Air heater 2
47	-	-
48	-	-
49	-	-
50	Engine coolant temperature sensor signal	ECTS
51	Engine coolant temperature sensor ground	ECTS
52	Injector 4 low signal driver	Injector 4
53	Knock sensor signal	KS
54	Fuel temperature sensor signal	FTS
55	Fuel temperature sensor ground	FTS
56	Injector 4 high signal driver	Injector 4
57	Knock sensor ground	KS
58	Crankshaft position sensor + signal	CKPS
59	Crankshaft position sensor - signal	CKPS
60	Injector 3 low signal driver	Injector 3
61	Camshaft position sensor reference voltage	CMPS
62	Camshaft position sensor signal	CMPS
63	Camshaft position sensor ground	CMPS
64	Injector 3 high signal driver	Injector 3
65	Rail pressure sensor reference voltage	RPS
66	Rail pressure sensor signal	RPS
67	Rail pressure sensor ground	RPS
68	Injector 2 low signal driver	Injector 2
69	-	-
70	-	-
71	-	-
72	Injector 2 high signal driver	Injector 2
73	-	-
74	-	-
75	-	-
76	Injector 1 low signal driver	Injector 1
77	Mass air flow sensor reference voltage	MAFS
78	Mass air flow sensor signal	MAFS
79	Mass air flow sensor ground	MAFS
80	Injector 1 high signal driver	Injector 1
81	-	-
82	-	-
83	-	-
84	-	-
85	-	-
86	Brake switch signal 2	Brake switch
87	Cooling fan high relay control	High relay
88	Cooling fan low relay control	Low relay
89	-	-
90	Water heater diagnosis signal	Water heater 1
91	Air heater relay 1 control	Air heater relay 1
92	-	-

Terminal	Signal	Connected to
93	Blower switch signal	Blower switch
94	Air heater 1 diagnosis signal	Air heater 1
95	-	-
96	Air heater relay 2 control	Air heater relay 2
97	MT/AT detection signal	Chassis ground (AT)
97	MT/AT detection signal	Not connected (MT)
98	Torque reduction signal	TCM (AT)
99	A/C switch signal	Thermocon
100	Vehicle speed signal	Meter set
101	-	-
102	Engine coolant temperature signal	TCM (AT)
103	Acceleration position signal	TCM (AT)
104	Main relay control	Main relay
105	A/C relay control	A/C relay
106	-	-
107	Battery voltage	Main relay
108	Power ground	Chassis ground
109	Water heater relay control	Water relay
110	-	-
111	Battery voltage	Main relay
112	Power ground	Chassis ground

COMPONENT INSPECTION

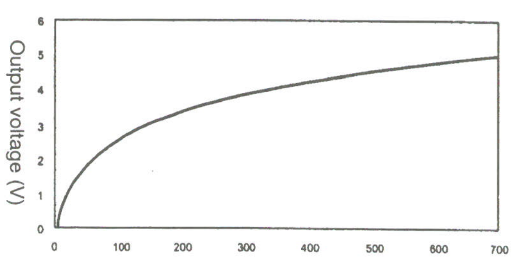
MAFS, IATS

The air flow sensor adopts the feature of maintaining a certain temperature of the heater for sensor to make the hot film element detect the air flow and send related signal to the ECM.
The ECM then determines the fuel amount and ignition timing and check the information to apply the fuel and A/C load correction.
The IAT is used to detect the temperature of intake air to support the correction of fuel flow and ignition timing, and the compensation of air temperature for idle control.



[Major features of HOT FILM AFS]

Item	Features	Remarks
Power supply	7.5 ~ 16 v	
Temperature regulating range	-40°C ~ 125°C	
Flow detecting range	7 ~ 640kg/h	
Output voltage	0 ~ 5V	
Connector	PIN1: Intake air temperature sensor output	
	PIN2: Battery power	
	PIN3: Sensor ground	
	PIN4: Sensor power (5V)	
	PIN5: Air flow sensor output	



KFW5239A

Troubleshooting hints

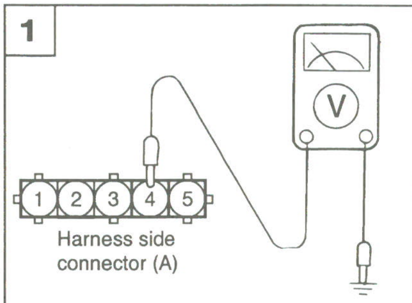
1. If the engine stalls occasionally, start the engine and shake the MAFS harness. If the engine stalls, check for poor contact at the MAFS connector.
2. If the MAFS sensor output voltage is other than 0 when the ignition switch is turned ON(do not start the engine), check for faulty MAFS and ECM.
3. If the engine can idle even if the MAFS output voltage is out of specification, check the conditions as below:
   - Air flow distributed from MAFS, disconnected air duct and clogged air cleaner filter.
   - Poor combustion in the cylinder, faulty spark plug, ignition coil, injector and incorrect comparison.
4. Though no MAFS malfunction occurs, check the mounting direction of the MAFS.

✱ *Notice*

1. *The air quantity of mass air flow sensor will be about 10% higher in case of new vehicle (within initial running of about 500km (300 miles)).*
2. *Use an accurate digital voltmeter.*
3. *Before checking, warm up the engine until the engine coolant temperature reaches 80~90°C (175~198°F)*

Harness inspection (MAFS)

1



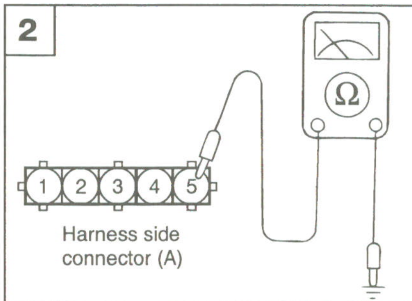
Measure the power supply voltage for the MAFS sensor.
- o Connector: Disconnected.
- o Ignition switch : ON.
- o Voltage (V) : 4.8-5.2 V.

OK ⇒ **2**

NG ⇒ Repair the harness.

EFJB705B

2



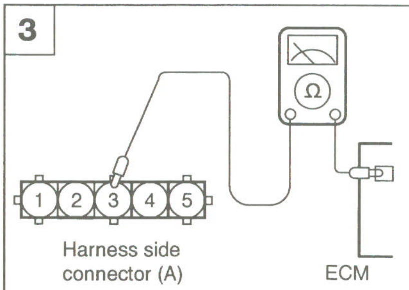
Check for an open circuit, or a short circuit to ground between the powertrain control module and the MAFS sensor.
- o Connector : Disconnected
- o PCM connector : Disconnected

OK ⇒ **3**

NG ⇒ Repair the harness.

EFJB705C

3



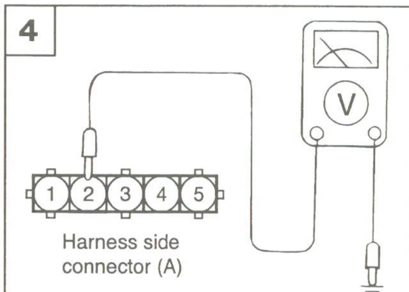
Check for continuity of the sensor ground circuit.
- o Connector : Disconnected.

OK ⇒ **4**

NG ⇒ Repair the harness.

EFJB705D

4



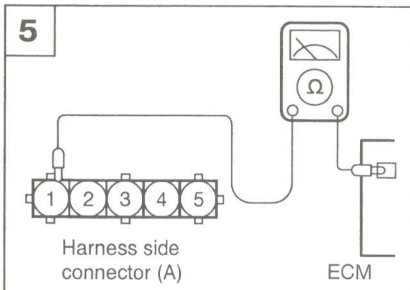
Check the power supply(Bat) voltage for MAF sensor.
- o Connector : Disconnected
- o PCM connector : Connected
- o Voltage : Battery voltage

OK ⇒ **5**

NG ⇒ Repair the harness.

EFJB705E

5



Check for an open-circuit, or a short-circuit to ground between the PCM and MAF sensor.
- o Connector : Disconnected
- o PCM connector : Disconnected

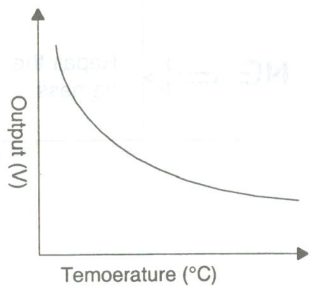
OK ⇒ **END !**

NG ⇒ Repair the harness.

EFJB705F

Features of IAT output

For the measure feature of the IAT at malfunction, if the coolant temperature is normal, the intake air substitution value is 0°C when the coolant temperature is below 69.75°C while the value is 60°C when the coolant temperature is over 69.75°C. The substitution value should be 60°C when the engine coolant temperature sensor is failed simultaneously.



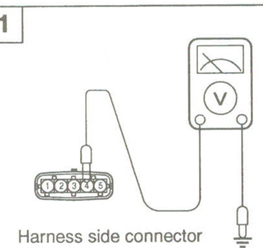
P-38

Using voltmeter

Item to check	Data output	Condition to check	Intake air temp.	Resistance
Intake air temp. sensor	Intake air temp.	Ignition switch: ON or starting	-40°C	33.85~61.20 kΩ
			20°C	2.22~2.82 kΩ
			80°C	0.299~0.375 kΩ

Harness inspection (MAFS)

1



Meaure the reference power supply voltage.

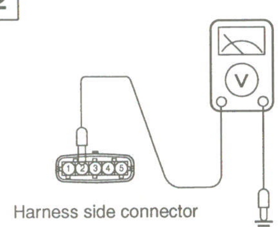
- Connector : Disonnected
- Ignition switch : ON
- Power(V) : 4.8~5.2

OK ⇨ 2

NG ⇨ Repair the harness

KFW5240A

2



Measure the voltage of power supply for sensor.

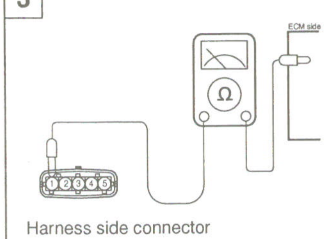
- Connector : Disonnected
- Ignition switch : ON
- Voltage (V) : B+

OK ⇨ 3

NG ⇨ Repair the harness

KFW5241A

3



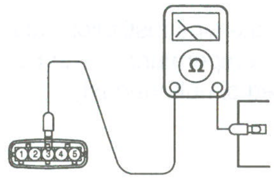
Check for an open or short circuit between ECM and IAT signal circuit.

- ECM connector : Disconnected.
- IAT sensor connector : Disconnected

OK ⇨ 4

NG ⇨ Repair the harness

KFW5244A

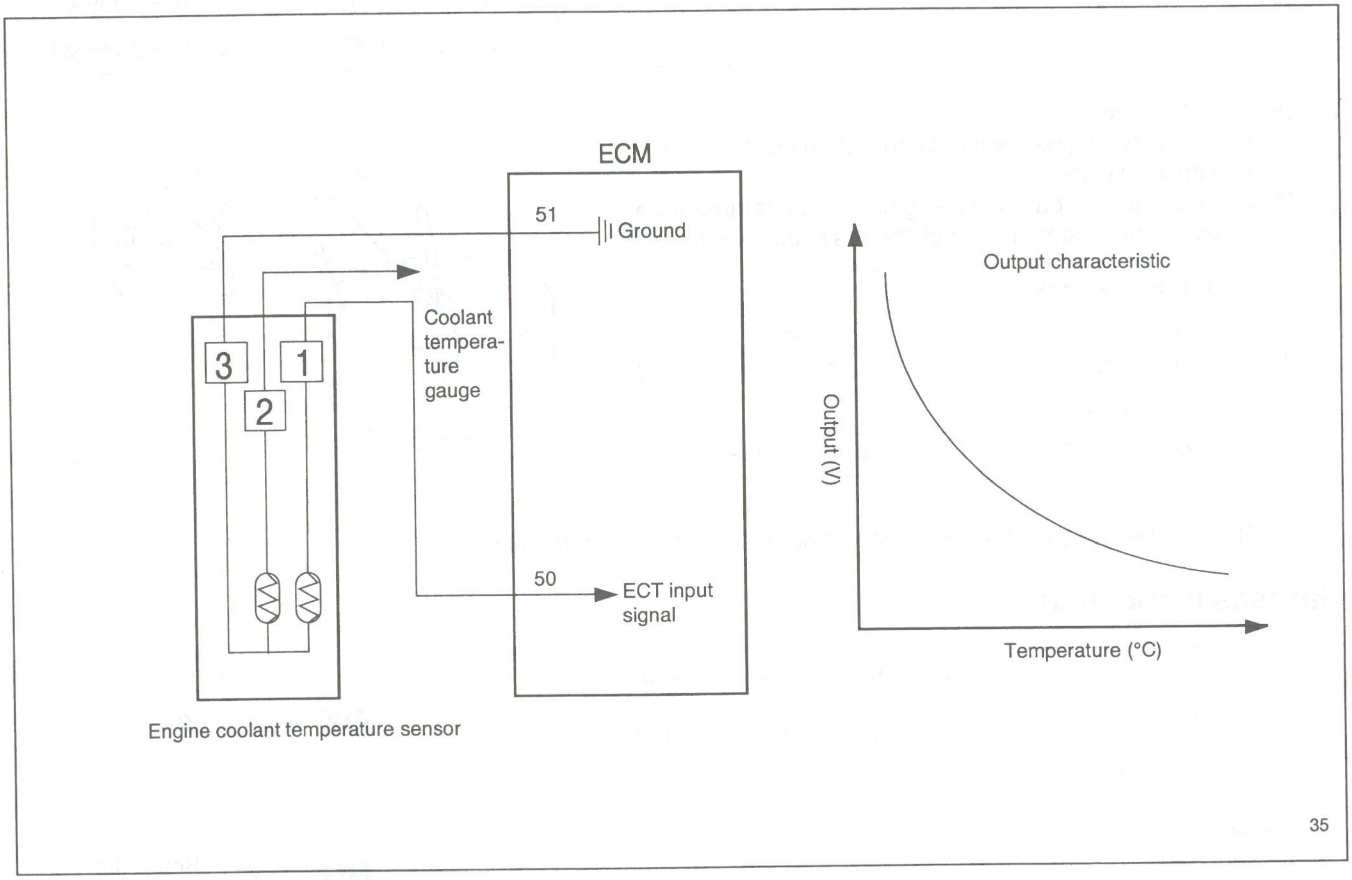
4			
 Harness side connector	Check for continuity of the sensor ground circuit. • Connector : Disconnected	OK ⇨ NG ⇨	END Repair the harness

KFW5243A

ECTS

Measure engine coolant temperature using NTC (Negative temperature coefficient) element. The thermistor resistance of NTC element decrease in response to rise of temperature.
It's used in determination of basic fuel quantity and ignition timing at starting, determination of basic idle control duty at starting, fuel and cooling fan control, and emission gas temperature modeling necessary for controlling emissions.

[ECTS circuit and output features]



The measure at sensor malfunction is to take the initial intake air temperature as basic substitution value of coolant temperature and increase it up to max. 110°C in the interval of 0.5 sec in response to the quantity of air.
In case of the intake air temperature sensor malfunction, first take the substitution value of coolant temperature at 20°C and increase it up to 110°C in the interval of 0.5 second by the air quantity.
In case of intake air temperature sensor malfunction during engine running, first determine a proper temperature before first finding the trouble cause, and then increase it up to 110°C in the interval of 0.5 second by the air quantity.

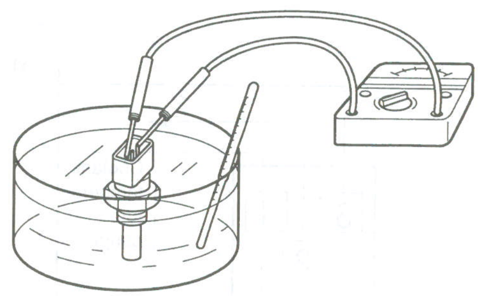
Checking the sensor

1. Using Hi-scan

item	display	conditions	temp. sensor	
Coolant temperature sensor	Coolant temperature sensor	Ignition switch: ON or starting condition	-40 °C (-4 °F)	43.51 ~ 53.26 kΩ
			20 °C (68 °F)	2.20 ~ 2.70 kΩ
			80 °C (176 °F)	0.297 ~ 0.339 kΩ
			110 °C (230 °F)	0.145 ~ 0.149 kΩ

2. Using multi-tester
   1) Remove the engine coolant temperature sensor from air intake manifold.
   2) Soak the sensor part of the engine coolant temperature sensor to hot water and check the resistance value.

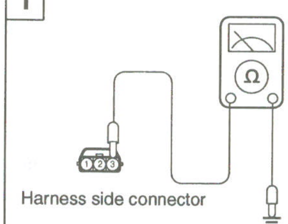
(°C)Resistance (kΩ)	
0 °C (32 °F)	5.9
20 °C (68 °F)	2.20 ~ 2.70
40 °C (104 °F)	1.1
80 °C (176 °F)	0.297 ~ 0.339



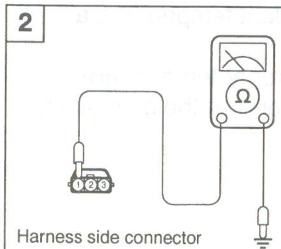
KFW5223A

   3) Replace the sensor if the resistance deviates from the standard value.

Harness inspection

1 	Check for continuity of the ground circuit. • Connector: Disconnected.	OK ⇒ NG ⇒	2 Repair the harness

KFW5245A

2 	Check for an open or short circuit between ECM and coolant temperature sensor.	OK ⇒ NG ⇒	END Repair the harness

KFW5246A

Troubleshooting hints

If the fast idle speed is not enough or the engine gives off dark smoke during the engine warm-up operation, the engine coolant temperature sensor might be faulty.

Installation

1. Apply sealant LOCTITE 962T or equivalent to the threaded portion.
2. Install the engine coolant temperature sensor and tighten it to specified torque.

   Tightening torque
   Engine coolant temperature sensor : 14.5~28.9 lb•ft (200~400 kg•cm)

3. Securely connect the harness connector.

Knock sensor

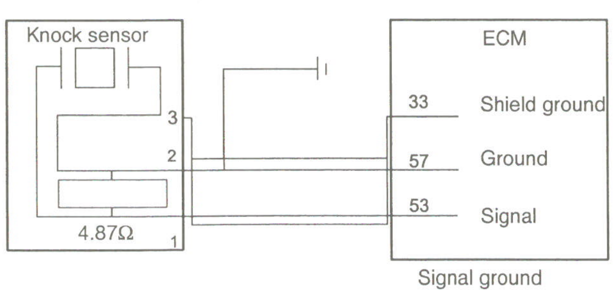
A knock sensor with piezoelectric element (ceramic) is attached to the center of cylinder block of each bank #1/#2 to sense the engine knocking condition (Check for knocking for each cylinder).
The piezoelectric device output (V) = Q/C =2dF/C (d= piezoelectric integer, C = Electrostatic capacity).
The ignition timing for MBT, Minimum spark advance for best torque, is located at the positions front and rear to the knocking limit and the ECM performs the control to make the engine to operate in optimum condition before the knocking limit.

(Knock sensor circuit diagram)

When the knock sensor malfunctions, the ignition timing is corrected by the MAP values such as engine rate, air flow and engine coolant temperature, etc.

Trobleshooting hints

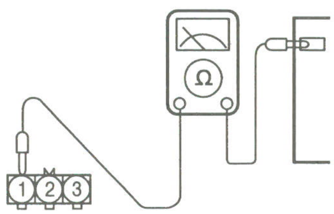
1. The MIL is ON or the DTC is displayed on the HI-SCAN under following condition.
   - The knock sensor signal is not detected when the engine is in overload condition.
2. The knock sensor signal is abnormally low.



P-47

Harness inspection procedures

1



Check for an open or short circuit between ECM and knock sensor.

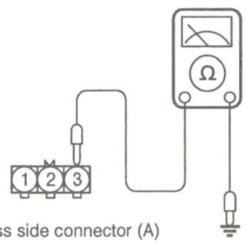
- ECM connector: Disconnected.
- Knock sensor connector: Disconnected.

OK ⇒ **2**

NG ⇒ Repair the harness

KFW5262A

2



Check for continuity of the ground circuit.

- Connector: Disconnected.

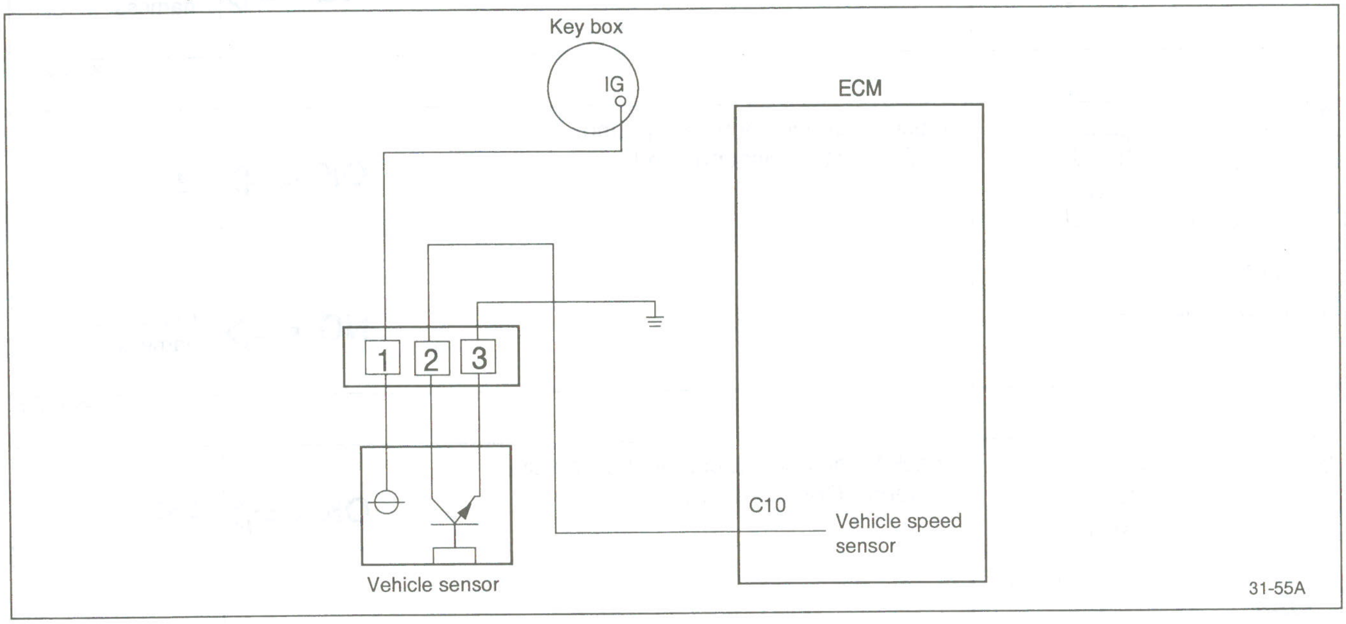
OK ⇒ **END**

NG ⇒ Repair the harness

KFW5263A

Vehicle speed sensor

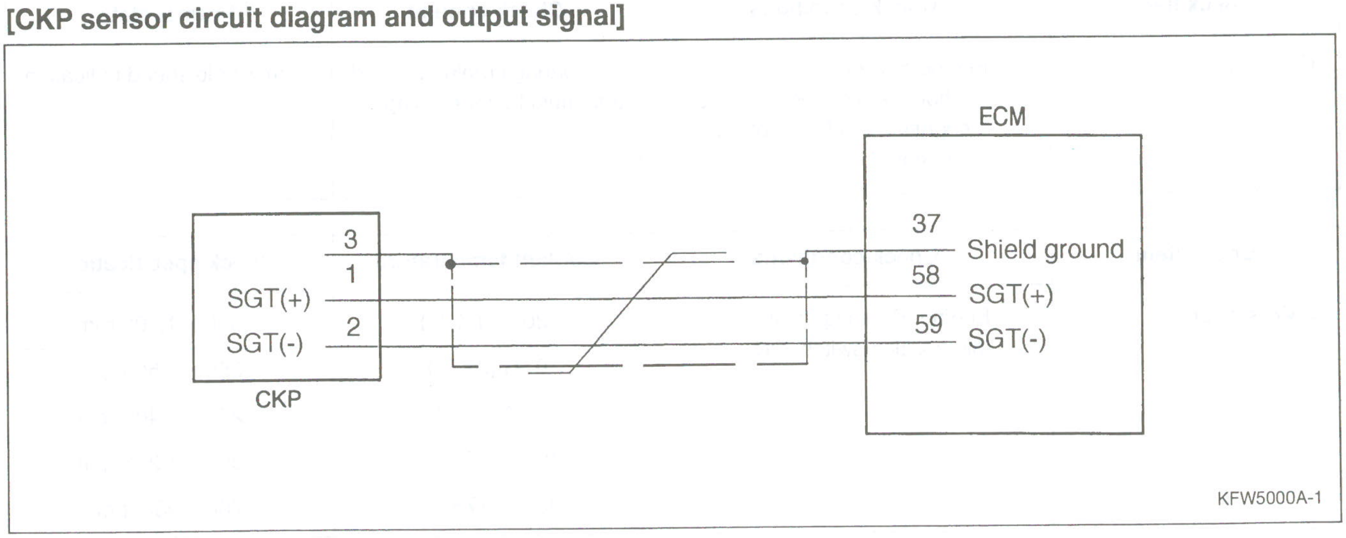
The function of vehicle speed sensor is to sense the TOOTH signal in T/M housing (4 pulses are output per 1 turn) and send relevant signal to ECM. The signal is used for computing the vehicle speed and the speed display on the tachometer as well.
The information is used for idle control correction duty range (the range of correction is limited with the vehicle speed and A/C load), cooling fan control, fuel injection prohibition at over vehicle speed, vehicle jerk control and traction control (At the torque being reduced with the exhaust gas modeling).
The action against malfunctions of the sensor is to fix the speed at 0 KPH. (The highest engine revolution should be limited to 2500 rpm)



CKPS

The CKP sensor compares the signal from the crank position sensor with that from TDC sensor to measure the upper dead point of each cylinder piston. The position of CAM is detected immediately at the same time when the ignition key is turned ON.
It outputs digital signal by two hall devices.

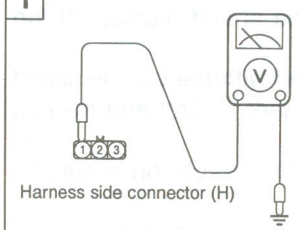
[CKP sensor circuit diagram and output signal]



In case of faulty TDC sensor, the CKP signal can be used to compute the TDC (The probability of cylinder #1 TDC is 50%) and engine rate to control the fuel quantity and ignition timing and provide availability of driving the engine.

Harness inspection

1



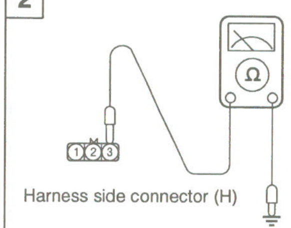
Measure the voltage.
- Connector: Disconnected.
- Ignition switch: ON
- Voltage (V) : 4.8~5.2V

OK ⇨ 2

NG ⇨ Repair the harness

KFW5272A

2



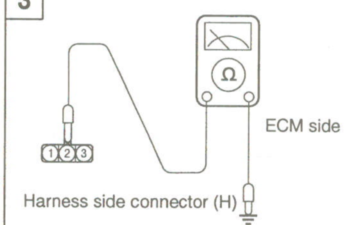
Check for continuity of the ground.
- Connector: Disconnected.

OK ⇨ 3

NG ⇨ Repair the harness

KFW5273A

3



Check for an open circuit or short circuit between ECM and CMPS.

OK ⇨ END

NG ⇨ Repair the harness

KFW5274A

Using HI-SCAN

Check item	Check conditions	Check content	Normal state
CMP sensor	• Engine cranking • Tachometer connection (Check the ignition coil for on/off by tachometer)	Comparing cranking speed and multi-tester reading.	Permissible speed indication

Check item	Check conditions	Coolant temperature	Check specification
CMP sensor	• Engine: Running at idle • Idle position switch: ON	-20 °C (-4 °F)	1,500 ~ 1,700 rpm
		0 °C (32 °F)	1,350 ~ 1,550 rpm
		20 °C (68 °F)	1,200 ~ 1,400 rpm
		40 °C (104 °F)	1,000 ~ 1,200 rpm
		80 °C (176 °F)	700 ~ 900 rpm

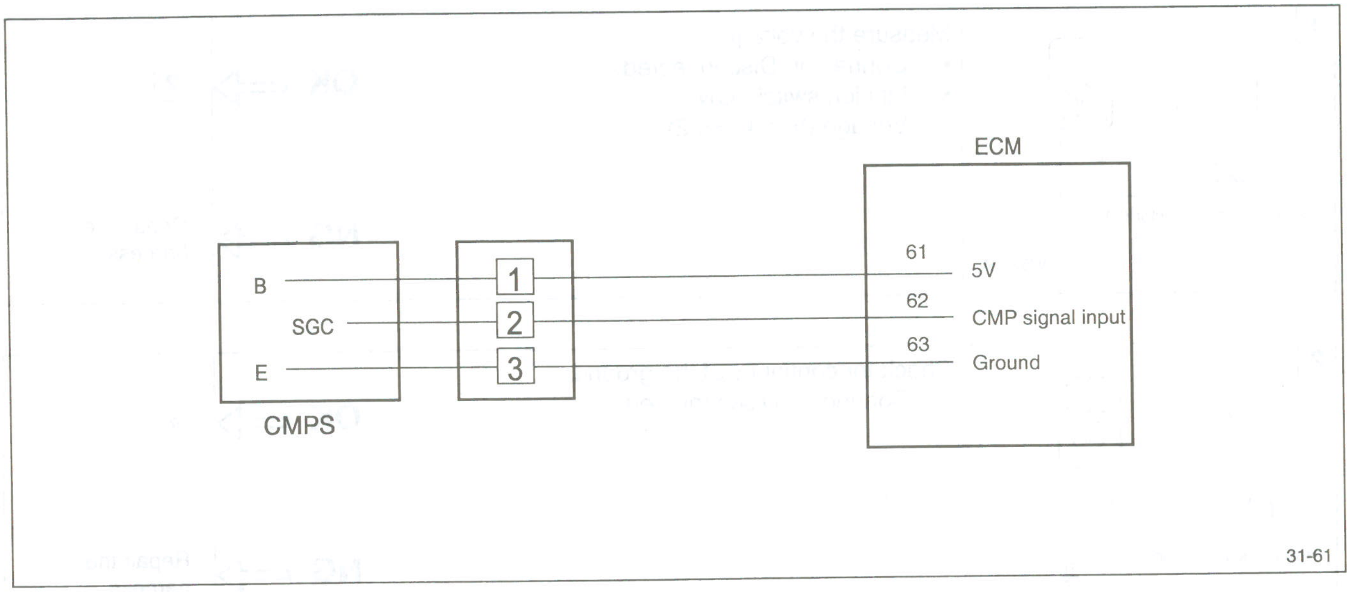
Troubleshooting hints

An abnormal operation of camshaft position sensor may cause engine stall, engine hesitation in idling or acceleration unavailability due to abnormal injection.

CMPS

The camshaft position sensor senses the position of crankshaft (piston) in reference to the upper dead point of compression of each cylinder and send the signal, based on which the ECM computes the engine speed and controls the fuel injection timing and ignition timing. Engine running condition (idle, partial load and full load) is determined in this process. It outputs digital signal by two hall devices.

[Circuit diagram and CMP signal features]



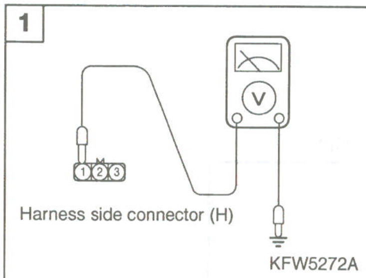
In case of faulty CMP, the TDC signal is analyzed to computing the crank position and engine rpm to further control the fuel quantity and ignition timing. Engine running is available at the same time. There is no engine stall at faulty CMP like existing system. (When the CMP is failed during engine running, the engine stalls, but restart of engine is available by the procedures of operation as IG KEY OFF → ON.)

Troubleshooting hints

1. If an unexpected shock or engine stall occurs in running, try to shake the harness of crankshaft position sensor. Check the sensor connector(s) for defective contacts if engine stalls in the case.
2. If 0 rpm is indicated on tachometer with the engine in idling, check for faulty crankshaft angle sensor, damaged timing belt or faulty ignition system.
3. Check for the points as below if the crankshaft angle sensor indicates a value out of the specification though the engine is available of starting in idle.
   - Faulty engine coolant temperature sensor.
   - Faulty idle speed control motor.
   - Failed standard idle speed control.

Harness inspection procedures

1

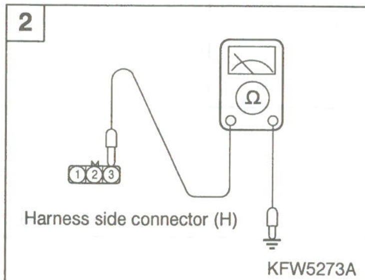


Measure the voltage.
- Connector: Disconnected.
- Ignition switch: ON
- Voltage (V) : 4.8~5.2V

OK ⇨ 2

NG ⇨ Repair the harness

2

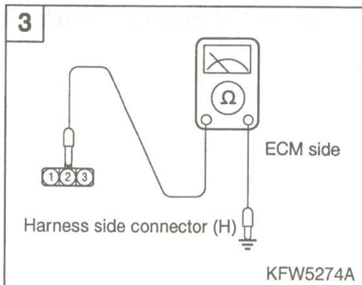


Check for continuity of the ground.
- Connector: Disconnected.

OK ⇨ 3

NG ⇨ Repair the harness

3



Check for an open circuit or short circuit between ECM and CMPS.

OK ⇨ END

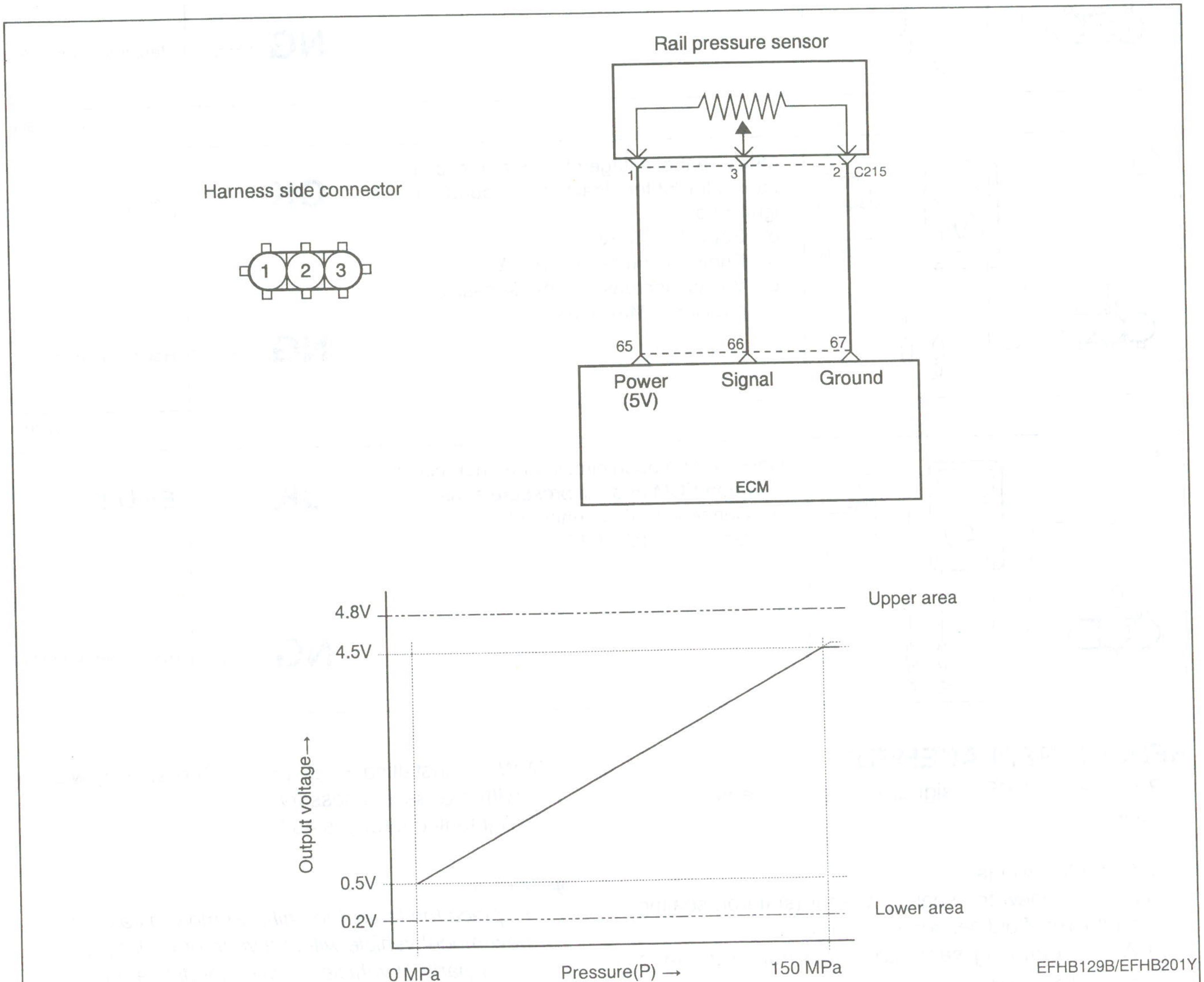
NG ⇨ Repair the harness

RAIL PRESSURE SENSOR (RPS)

In order to output a voltage signal to the ECM which corresponds to the applied pressure, the rail-pressure sensor must measure the instantaneous pressure in the rail.

The fuel flows to the rail-pressure sensor through an opening in the rail, the end of which is sealed off by the sensor diaphragm. Pressurized fuel reaches the sensor's diaphragm through a blind hole. The sensor element (semiconductor device) for converting the pressure to an electric signal is mounted on this diaphragm. The signal generated by the sensor is inputted to an evaluation circuit which amplifies the measuring signal and sends it to the ECM.

[CIRCUIT DIAGRAM]



EFHB129B/EFHB201Y

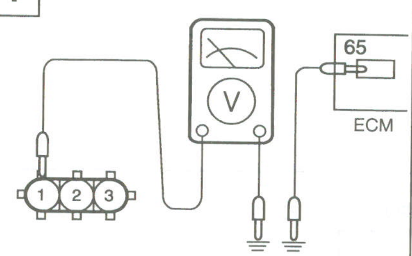
SENSOR INSPECTION

USING HI-SCAN

Check item	Data display	Check conditions	Set value	Standard value
Rail pressure sensor	Rail pressure value	Engine at idle	-220 - 300bar	260bar

HARNESS INSPECTION PROCEDURES

1



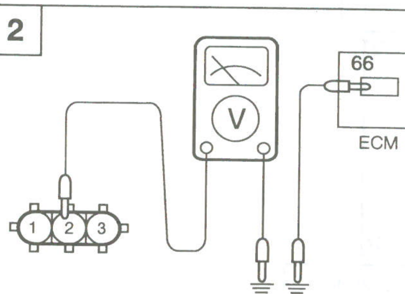
Measure the power supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.5 - 5.5V

OK ⇨ 2

NG ⇨ Repair the harness

EFHB130B

2



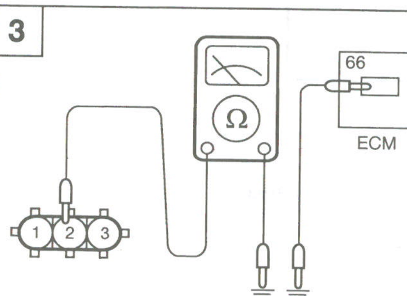
Measure the voltage of RPS harness side connector #2 terminal to the ground with ignition on.
- o Set value : 0.5V
- o Engine idling set value : 1V
- o Voltage increases with inereasing pressure : Max. 4.5V

OK ⇨ 3

NG ⇨ Repair the harness

EFHB131B

3



Check for an open circuit, or a short circuit between ECM and rail pressure sensor.
- o Connector : Disconnected
- o Ignition switch : OFF

OK ⇨ END !

NG ⇨ Repair the harness

EFHB131C

SENSOR REPLACEMENT

1. Replace the RPS if signal voltage exceeds the set value.

2. Note the followings.
   1) Always renew the sealing washer (soft iron sealing ring) even if old sensor is re-used.
   2) When removing seal, take care not to damage sealing surface.
   3) When installing RPS, provide the sealing washer with grease if necessary.
   4) Tightening torque is 40 Nm.

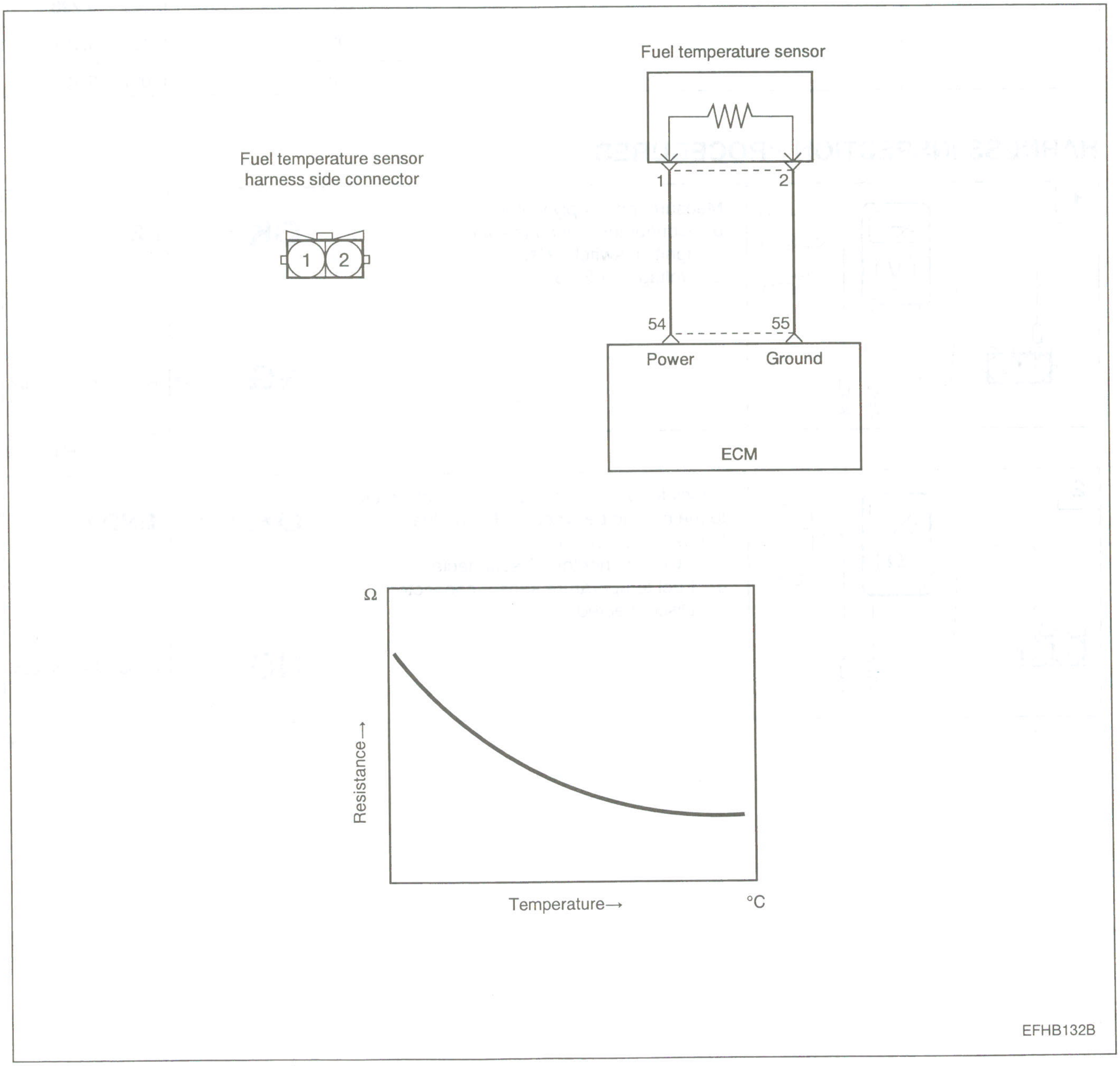
✱ *Notice*

Replace the faulty fuel rail assembly in case of new model vehicle within a year, or replace the faulty parts of vehicle of which model year is more than a year.

FUEL TEMPERATURE SENSOR (FTS)

The fuel temperature sensor is equipped with a temperature-dependent resistor with a negative temperature coefficient (NTC) which is part of a voltage-divider circuit across which 5V are applied.
The voltage drop across the resistor is inputted into the ECM through an analog-to-digital converter (ADC) and is a measure for the temperature. A characteristic curve is stored in the ECM microcomputer which defines the temperature as a function of the given voltage value.

[CIRCUIT DIAGRAM]



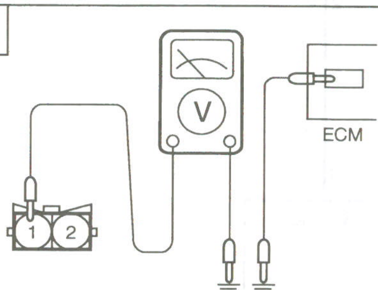
SENSOR INSPECTION

USING VOLTMETER

Check item	Output data	Check condition	Fuel temperature (°C)	Resistance (KΩ)
Fuel temperature sensor	Fuel temperature	Ignition switch : ON or START	-30	22.22 ~ 31.78
			-20	13.24 ~ 18.10
			0	5.18 ~ 6.60
			20	2.27 ~ 2.73
			40	1.059 ~ 1.281
			60	0.538 ~ 0.650
			80	0.322 ~ 0.298
			100	0.185 ~ 0.167
			120	0.097 ~ 0.127

HARNESS INSPECTION PROCEDURES

1



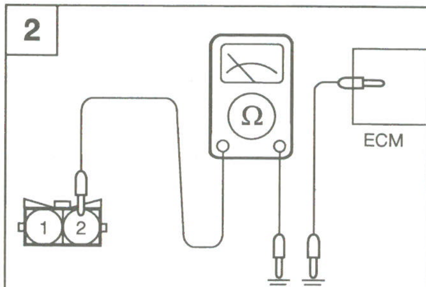
Measure the supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage : 4.8 - 5.2V

OK ⇨ **2**

NG ⇨ Repair the harness

EFHB133B

2



Check for an open circuit, or a short circuit to the ground between ECM and fuel temperature sensor.
- o ECM Connector : Disconnected
- o Fuel temperature sensor connector : Disconnected

OK ⇨ **END !**

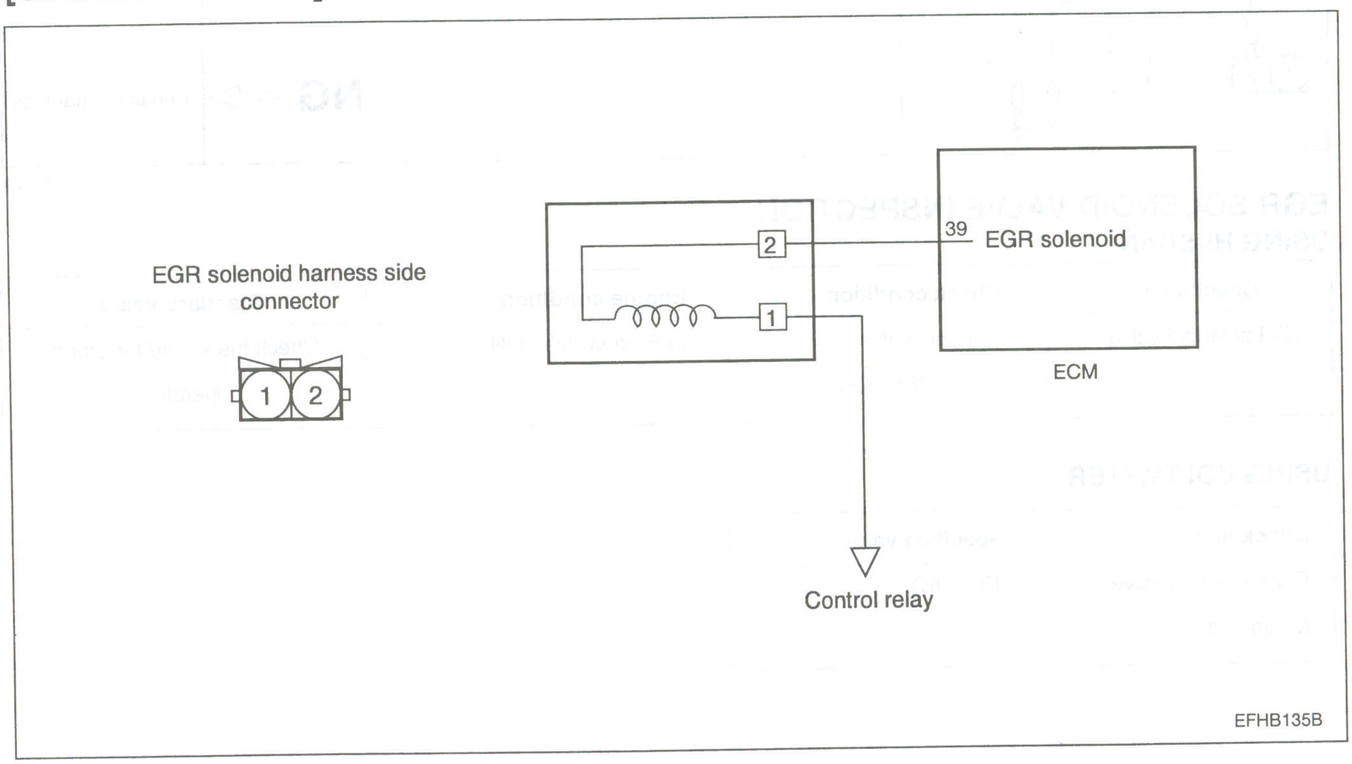
NG ⇨ Repair the harness

EFHB134B

EGR SOLENOID VALVE

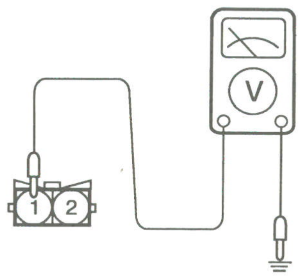
With exhaust-gas recirculation (EGR) a portion of the exhaust gas is led into the engine's intake tract. Up to a certain degree, an increasing portion of the residual exhaust gas content has a positive effect upon energy conversion and therefore upon the exhaust-gas emissions. Depending upon the engine's operating point, the air/gas mass drawn into the cylinders can be composed of up to 40% exhaust gas.
For ECM control, the actual drawn-in fresh-air mass is measured and compared at each operating point with the air-mass setpoint value. Using the signal generated by the control circuit, the EGR valve opens so that exhaust gas can flow into the intake tract.

[CIRCUIT DIAGRAM]



HARNESS INSPECTION PROCEDURES

1



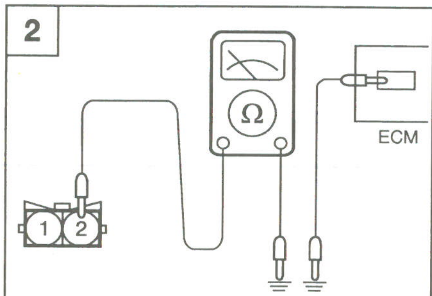
Measure the supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : Battery voltage

OK ⇒ 2

NG ⇒ Repair the harness

EFHB136B

2



Check for an open circuit, or a short circuit to the ground between ECM and EGR solenoid valve.
- o Connector : Disconnected

OK ⇒ END !

NG ⇒ Repair the harness

EFHB137B

EGR SOLENOID VALVE INSPECTION

USING HI-SCAN

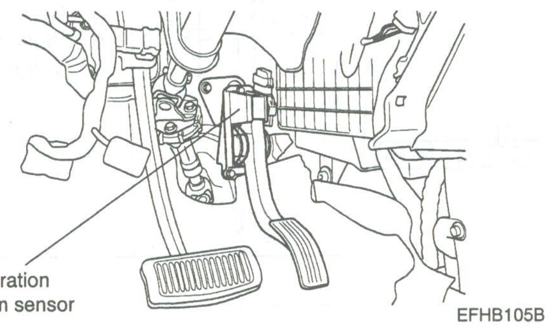
Check item	Check condition	Engine condition	Standard value
EGR solenoid valve	solenoid valve OFF / ON	Ignition switch : ON	Check the sound for proper operation

USING VOLTMETER

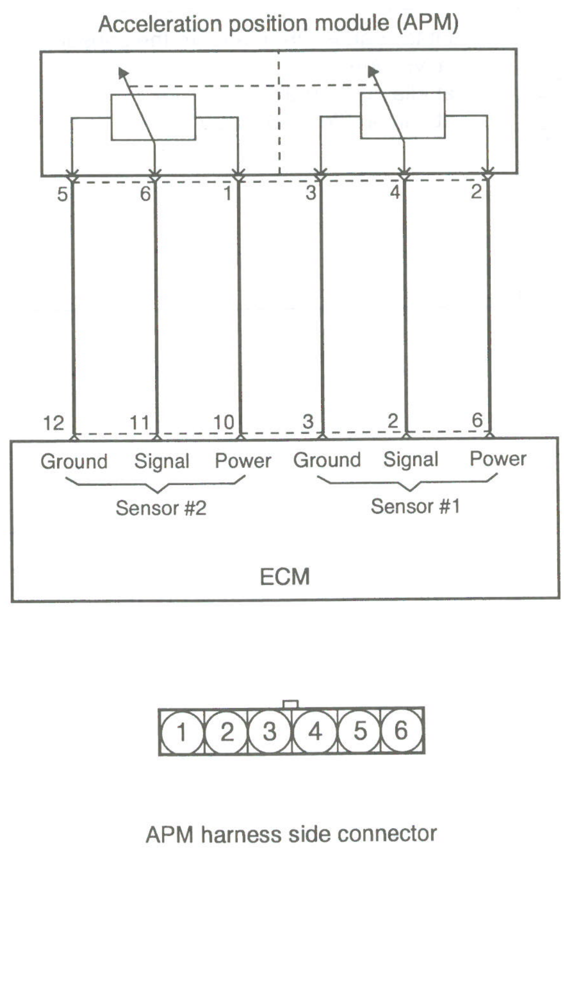
Check item	Specified value
EGR solenoid valve resistance	15 ~ 16Ω

ACCELERATION POSITION SENSOR (APS)

In contrast to conventional distributor and in-line injection pumps, with EDC the driver's acceleration input is no longer transmitted to the injection pump by Bowden cable or mechanical linkage, but is registered by an acceleration position sensor and transmitted to the ECM (this is also known as drive-by-wire).
A voltage is generated across the potentiometer in the acceleration position sensor as a function of the accelerator-pedal setting. Using a programmed characteristic curve, the pedal's position is then calculated from this voltage.

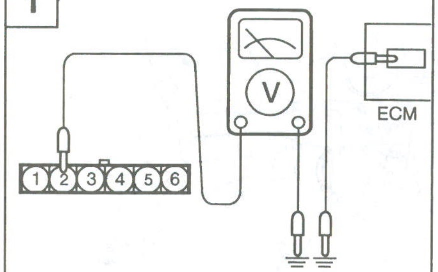


[CIRCUIT DIAGRAM]



APPLYING ACCELERATION POSITION MODULE (APM)

1



Measure the sensor supply voltage

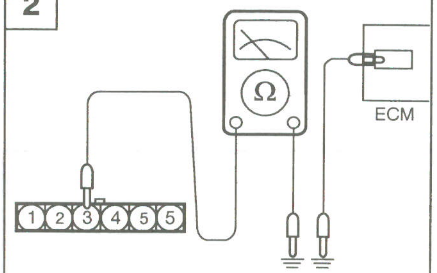
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.5 - 5.5V

OK ⇒ 2

NG ⇒ Repair the harness

EFHB145B

2



Check for an open circuit, or a short circuit between ECM and acceleration position sensor

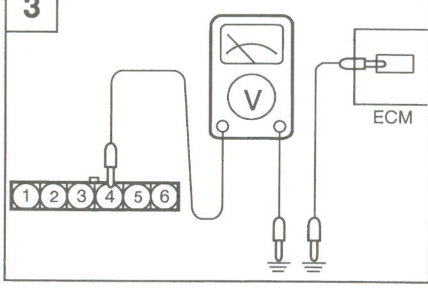
- o Connector : Disconnected
- o Ignition switch : OFF

OK ⇒ 3

NG ⇒ Repair the harness

EFHB146B

3



If contact lead is OK, measure the sensor signal voltage

- o at idle : 0.6 - 0.9V
- o at full throttle : 3.6 - 4.6V

OK ⇒ **END !**

NG ⇒ Repair the harness

EFHB147B

REMOVAL AND REASSEMBLY

Special features of the common rail system

Principle of operation

The common rail injection system permits individual control of the timing advance and of the flow, allowing perfect control of combustion on a cylinder-by-cylinder basis. Furthermore, the injection pressure can be adjusted over a wide range of values according to the engine's operating conditions:

- When idling and on low load, the low injection pressures (of roughly 200 bars)mark it possible to obtain low injection rates and very accurate adjustment of the amount of fuel injected.
- On full load, the high injection pressures (of roughly 1400 bars) ensure very fine atomization of the fuel.

In the common rail system, the fuel is pumped at high pressure (up to 1400 bars) into a reservoir known as the rail. This pressure is electronically controlled according to the engine's operating conditions. The opening and closing of the injectors is electronically controlled by electromagnets fitted to each injector holder.

Risk of engine damage

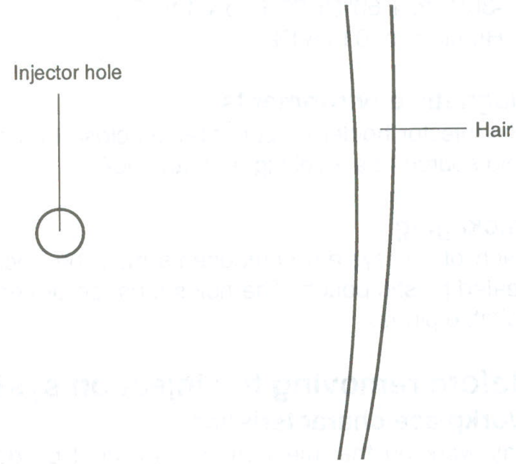
In a conventional injection system, if an injector needle seizes in the open position it is impossible to achieve injection pressure, thereby disrupting fuel supply to the combustion chamber. As atomization is no longer assured, combustion becomes unreliable. This results in serious contamination of the cylinder, considerable oil dilution, smoky exhaust emissions and loss of performance. The injection flow and timing are not however changed, since it is the pump which is responsible for distributing the correct amount of diesel fuel to each injector at the right moment.

In a common rail injection system, if an injector needle seizes in the open position, all or part of the fuel held in the rail is injected into the cylinder. The volume of diesel fuel thus accumulated in the cylinder will auto-ignite as soon as the temperature and pressure conditions allow (high engine speed, high load and low leakage). This combustion occurs at about 20 degrees before TDC, i.e. well before the main injection. In this case, the combustion pressure can reach very high values (>250 bars) which th eengine will obviously be unable to withstand for very long.

Furthermore, the high pressure required by the common rail injection system makes it necessary to have much smaller holes and much tighter adjustments than those found in conventional injection systems.

It is therefore absolutely essential to ensure impeccable cleanliness whenever work is being done on a common rail type injection system.

[Fig. 1]



General cleanliness instructions

Storage of parts

Environmental conditions

- -30°C to + 60°C(-22°F to + 140°F).
- Humidity of 0 to 80%.

Magnetic environments

The injector holder must not be left close to a magnetic field source at a level higher than 400A/m.

Packaging

Each of the system components must be packed in a sealed plastic pouch. The holes must be protected with suitable plugs.

Before removing the injection system

Workplace characteristics

Any work on the injection system must be done in a clean area. The dedicated area:

- Must be cleaned periodically to prevent the accumulation of dust;
- Must not be co-located with any machine-tools or welding equipment liable to produce swarf of metal particles;
- Must be separated from areas where the ordinary mechanical operations are carried out, in opder to prevent any risk of contamination of the injection system by brake pad dust for example.

Preparation of repair area and tooling

The work station and the tools must be cleaned with a brush and a solvent. Blow the cleaned parts with compressed air.

The work station must be fabricated from materials offering no risk of detachment of particles of fibers liable to contaminate the injdection system (wood should be avoided). DELPHI DIESEL SYSTEMS recommend covering the work surface with a stainless steel or aluminium plate.

General remarks

The garments worn by the operator must be clean.

The operator must wash his hands before and during the work if necessary.

For obvious reasons of safety and cleanliness, it is strictly forbidden to smoke while working on the injection system.

Cleaning the engine and the injection system

Before starting cleaning, protect the electrical components from any liquid damage (starter motor, alternator).

It is essential to clean the repair area before opening up the fuel circuit and removing any part of the injection system.

Cleaning of the repair area and the injection system must be done with a new brush and an effective solvent. The solvent must be dispensed from a clean container. Never reuse contaminated solvent.

Carefully clean each connection to be undone, sealing surfaces and all external surfaces of the injection system. Wherever possible, use a suction device to collect impurities. The use of a high pressure cleaner and a blower is prohibited because of the risk of impurities getting into inaccessible areas.

During the removal of the injection system

When the injection system has been opened, it is strictly prohibited to use a blower, a brush or a tubebrush, since these tools might cause impurities to get into the system.
As soon as an orifice has been opened, it is essential to block it using the appropriate plug.

⚠ WARNING
THE PLUGS MUST BE DISCARDED AFTER USE.

After operning up and blocking the holes, each component of the injection system must be stored in a new sealed pouch.

Cleaning of the injector is strictly forbidden, even with an ultrasonic cleaner. Moreover, the separation of the injector from the injector holder is prohibited.

During reassembly of the injection system

The packaging of the spare parts should be opened just before they are used. Moreover, the sealing plugs must not be removed until the final connection is made. The plugs and the sealed pouches must be discarded after use.

Any part which has been dropped must be returned to DELPHI DIESEL SYSTEMS for assessment.
Before fitting the injector, is it essential to ensure that its socket is clean.

Safety instructions

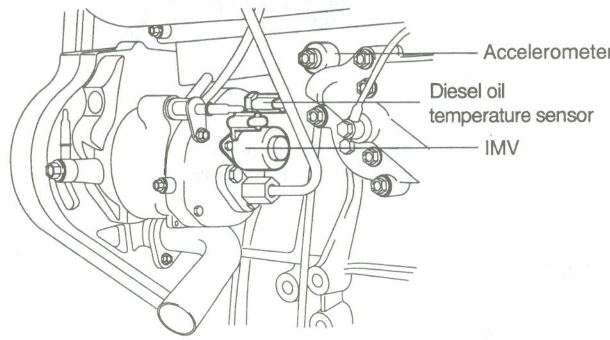
- It is strictly prohibited to smoke or to eat while working on the Common Rail injection system.
- It is essential to disconnect the battery before any work is done on the Common Rail injection system.
- It is strictly forbidden to work on the Common Rail injection system with the engine running.
- It is necessary to read the value of the rail pressure and of the diesel oil temperature with the aid of the diagnostic tool before any work is done on the fuel circuit. The opening of the circuit can only begin if the diesel oil temperature is less than 50°C(122°F) and the rail pressure is close to 0 bar. If it is not possible to communicate with the computer, wait for 5 minutes after the engine has stopped before starting any work on the fuel circuit.
- It is strictly prohibited to supply an actuator directly off an external power supply.
- The injector must not be dismantled.
- The HP sensor must not be removed from the rail. If the HP sensor fails, it is essential to replace the complete rail.
- The IMV, the diesel temperature sensor and the venturi must not be removed from the pump. If one of these components is faulty, the whole pump must be replaced.
- The HP pipes are not reusable: a removed pipe must be replaced.
- Decarbonizing the injector in an ultrasonic bath is strictly prohibited.
- The computer's metal casing must never be used as an earth!
- During welding jobs (bodywork repairs), the ECU must be carried out by qualified staff who have received training at the DELPHI DIESEL SYSTEMS training center.

Presentation of the injection system

Sensors and actuators

Diesel oil temperature sensor, IMV and accelerometer

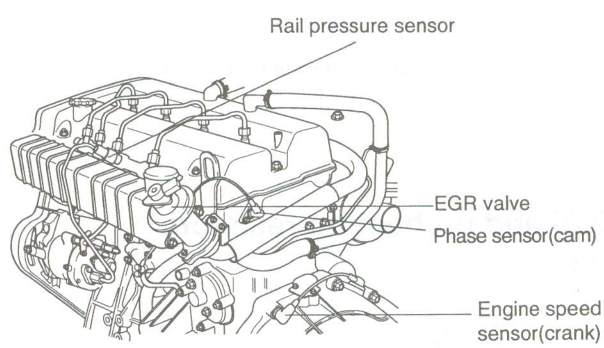
[Fig.1]



CFL0FL010

Rail pressure, engine speed, phase sensors and EGR valve

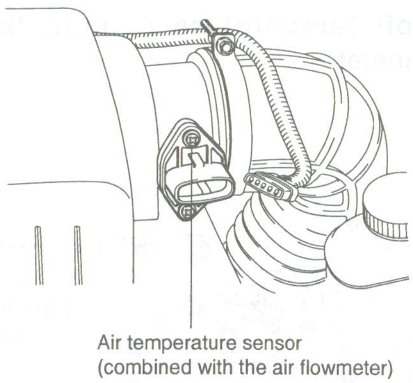
[Fig.2]



CFL0FL011

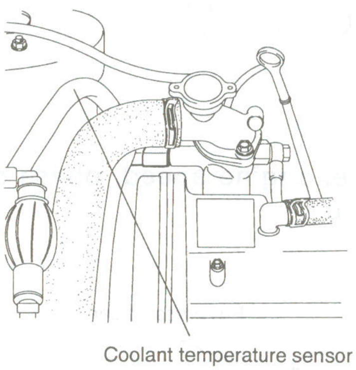
Air temperature and coolant temperature sensor

[Fig.3]



CFL0FL012

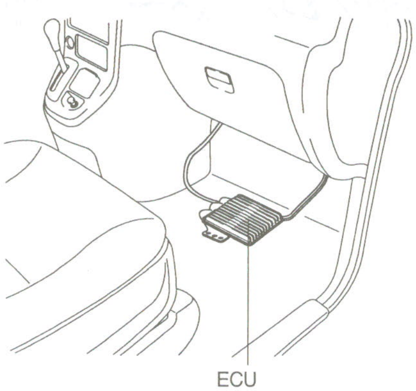
[Fig.4]



CFL0FL013

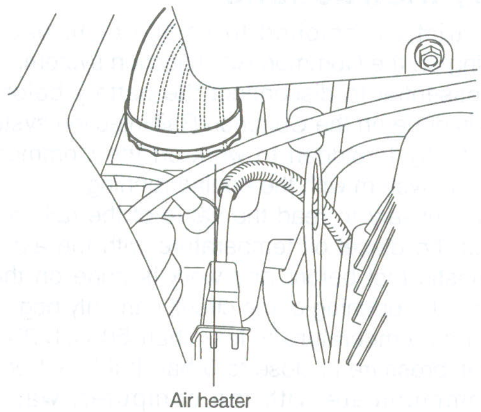
ECU and preheating resistors

[Fig.5]



CFL0FL014

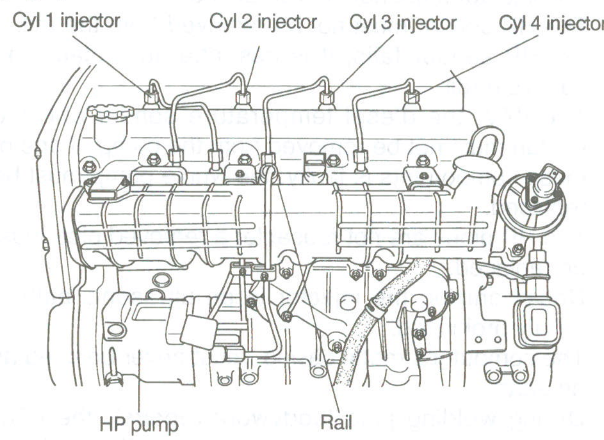
[Fig.6]



CFL0FL015

Rail, Pump and injectors

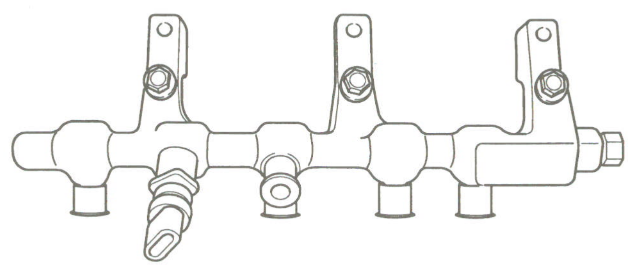
[Fig.7]



CFL0FL016

Rail

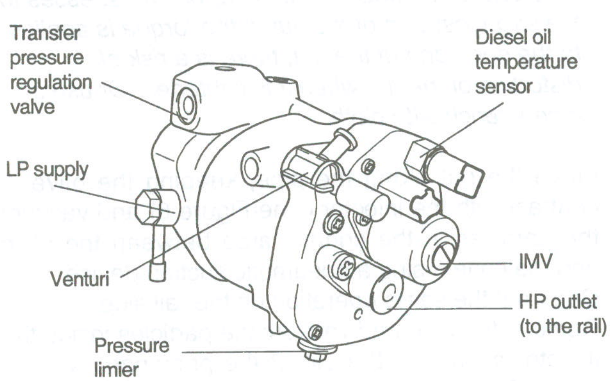
[Fig.8]



CFL0FL017

Pump

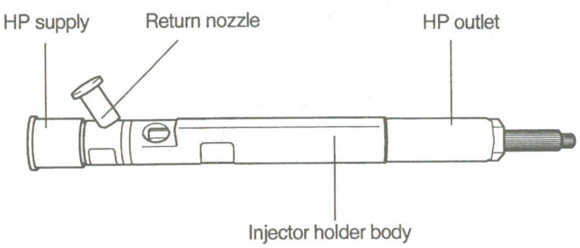
[Fig.9]



CFLOFL018

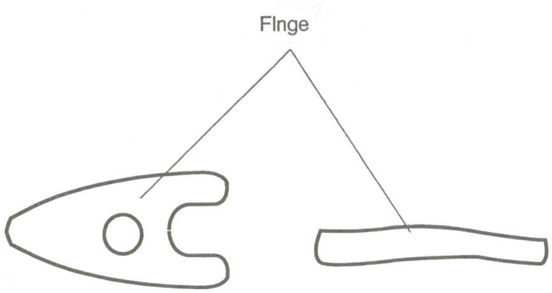
Injector

[Fig.10]



CFLOFL019

[Fig.11] [Fig.12]

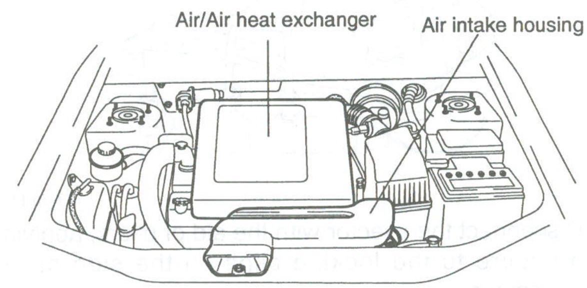


High pressure pipes

Removal a rail / injector pipe

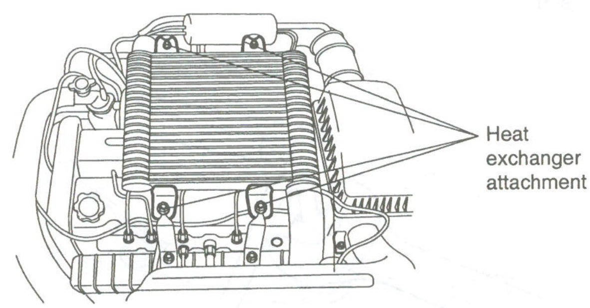
- Remove all the items liable to restrict access:
- Remove the intake housing
- Remove the air / air heat exchanger.

[Fig.1]



CFLOFL020

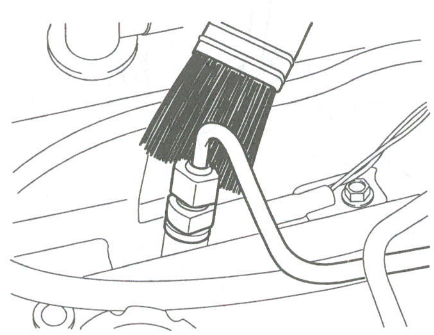
[Fig.2]



CFLOFL021

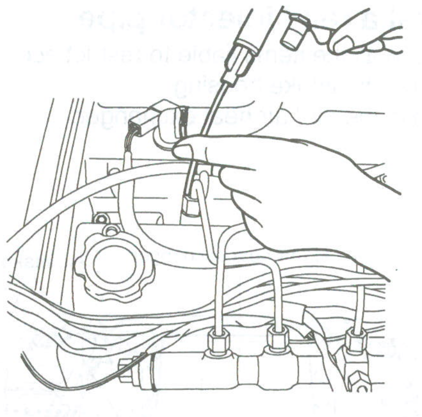
- Clean the nuts of the HP unions with a solvent (CARCLEAN type) applied with a clean brush (Figure 3).
- Vacuum the particles with the aid of a 'BLOVAC BV11' type suction device (Figure 4).

[Fig.3]



CFLOFL022

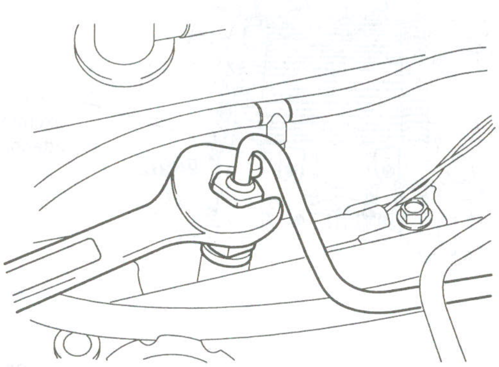
[Fig.4]



CFLOFL023

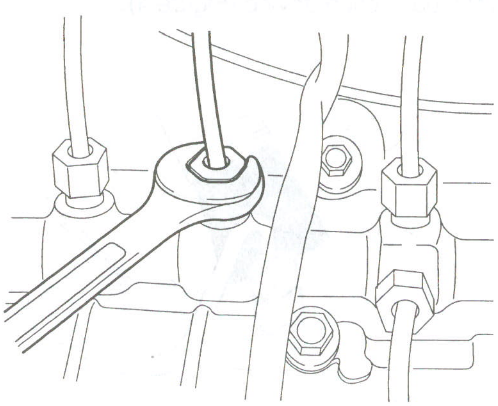
- Disconnect the injector with the aid of pliers, applying pressure to the locking clips on the side of the connector.
- Slacken the nut screwed onto the injector using a 17 mm (0.67 in) open wrench (Figure 4).
- Slacken the nut screwed onto the rail using a 17 mm (0.67 in) open wrench (Figure 5).

[Fig.4]



CFLOFL024

[Fig.5]



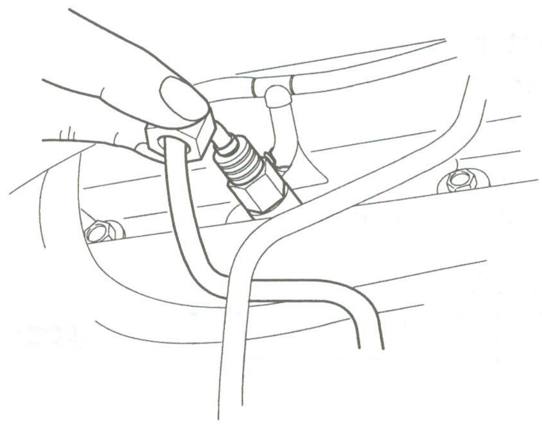
CFLOFL025

✱ *Notice*

It is improtant to position the wrench level with the solid end of the nut, in order to apply the stresses to the strongest part of the nut. If the torque is applied to the open end of the nut, there is a risk of distortion of the nut when it is tightened. Or use a pipe-wrench with cloth.

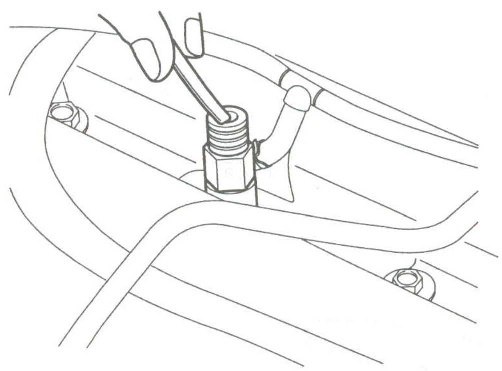
- Move the nut along the pipe, keeping the olive in contract with the injector cone(Figure 6) and vacuum the particles in the contact area between the olive and the cone, using a pneumatic suction device.
- Carry out the same operation on the rail side.
- Remove the pipe and vacuum the particles inside the injector cone with the aid of the pneumatic suction device(Figure 7).
- Carry out the same operation on the rail side.

[Fig.6]



CFLOFL026

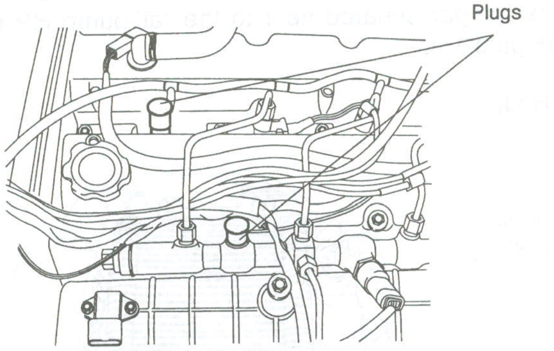
[Fig.7]



CFLOFL027

- Immediately seal the HP outlets with the aid of the recommended plugs(Figure 8).

[Fig.8]



CFL0FL028

Reassembly a rail/injector pipe

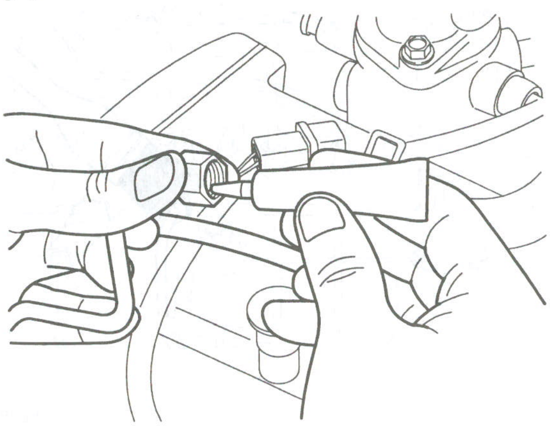
- Reconnect the injector.
- Take the new pipe out of its packing just before fitting it.

⚠ WARNING
IT IS FORBIDDEN TO RE-USE AN OLD PIPE.

- Remove the plugs inserted at each end of the pipe.
- Lubricate the threads of the nuts with the lubricant supplied in the kit before fitting the pipe (Figure 9).

- Remove the protective plugs from the HP outlets of the rail and the injector.

[Fig.9]

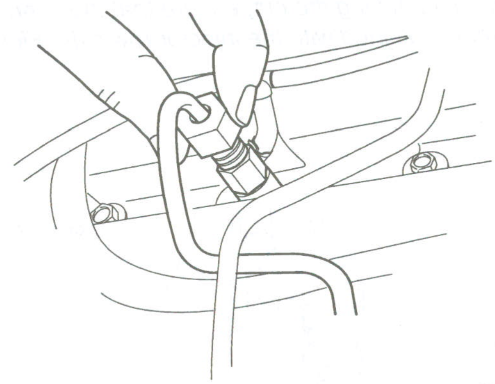


CFL0FL029

⚠ WARNING
THE PLUGS MUST BE DISCARDED AFTER USE.

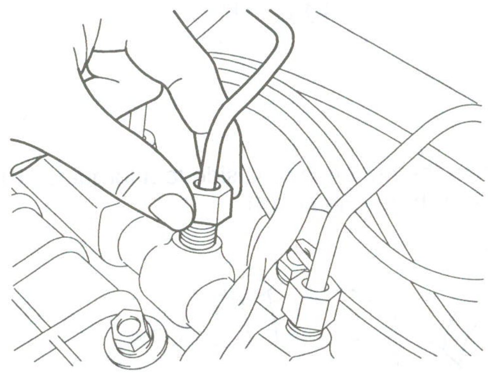
- Fit the pipe olive into the injector cone and tighten the nut by hand (Figure 10).
- Fit the pipe olive into the rail cone and tighten the nut by hand (Figure 11).

[Fig.10]



CFL0FL030

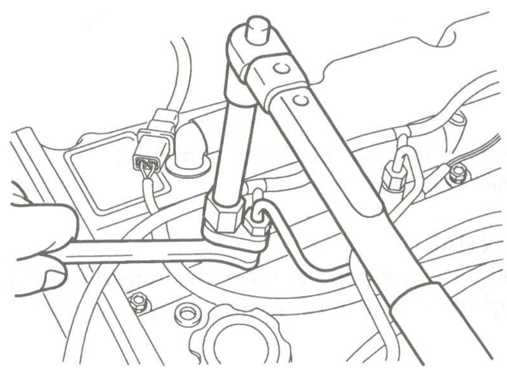
[Fig.11]



CFL0FL031

- Tighten the nut on the injector side to 40 Nm(29.5 lb-ft), applying reverse torque with the support tool for the injector holder (Figure 12).

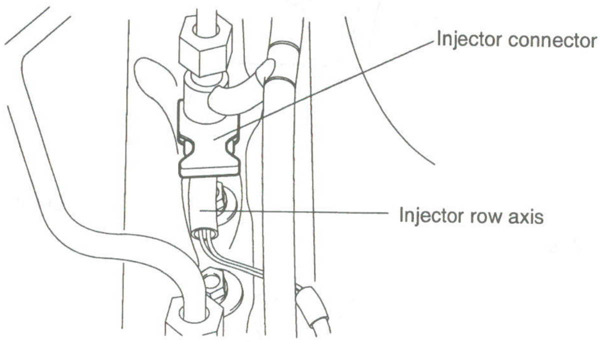
[Fig.12]



CFL0FL032

✱ *Notice*
When tightening the nut, ensure that the connector remains aligned with the injector row axis (Figure 13).

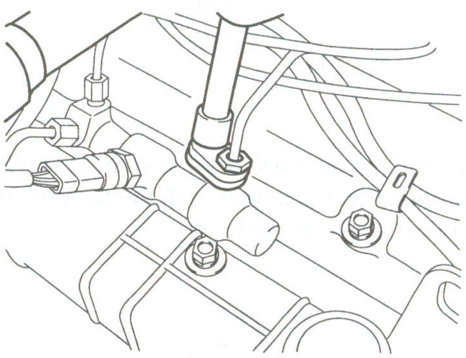
[Fig.13]



CFL0FL033

- Tighten the nut on the rail side to a torque of 40 Nm(29.5 lb-ft) (Figure 14).

[Fig.14]



CFL0FL034

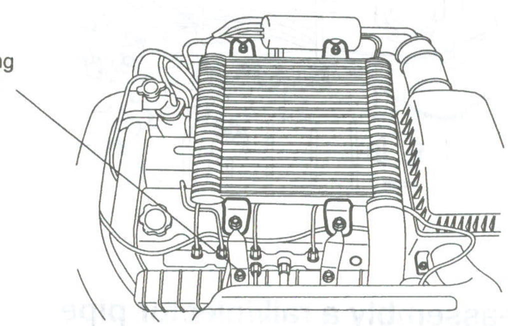
- Reassembly all the items removed to assist access.

ESSENTIAL
To validate the repair, start the engine and check the tightness of the HP connection.

Removal of rail/pump pipe

- Remove all the items liable to restrict access:
- Remove the air intake housing
- Remove the mounting bracket of the air/air heat exchanger situated next to the rail/pump HP pipe (Figure 15).

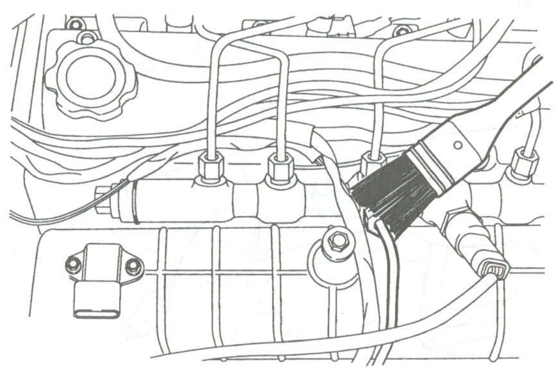
[Fig.15]



CFL0FL021

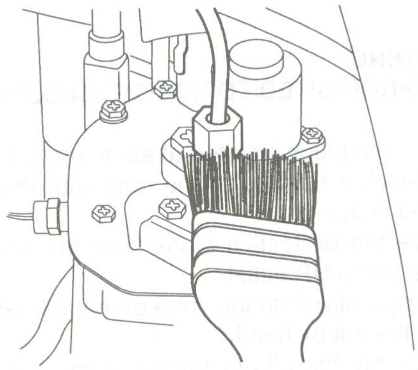
- Clean the HP connections with a solvent (CARCLEAN type) applied with a clean brush (Figures 16 and 17).
- Vacuum the particles with a 'BLOVAC BV11' type pneumatic suction device (Figures 18 and 19).

[Fig.16]



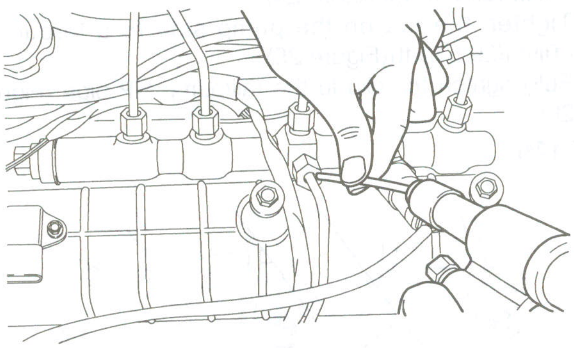
CFL0FL035

[Fig.17]



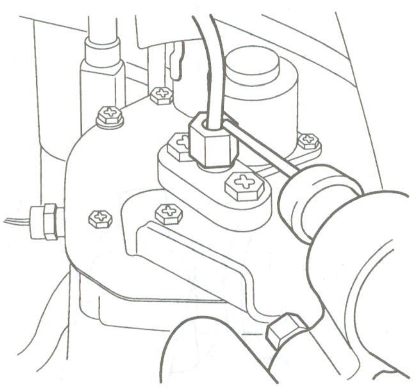
CFL0FL036

[Fig.18]



CFL0FL037

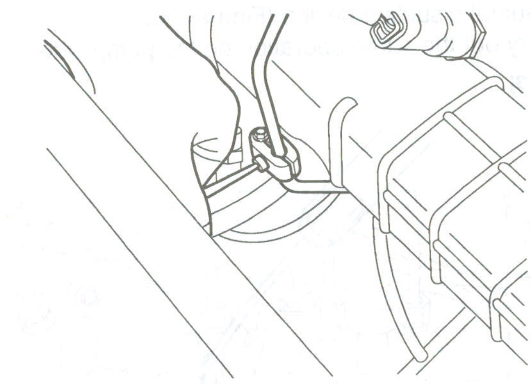
[Fig.19]



CFL0FL038

- Partially release the clip of the rail/pump HP pipe (Figure 20).

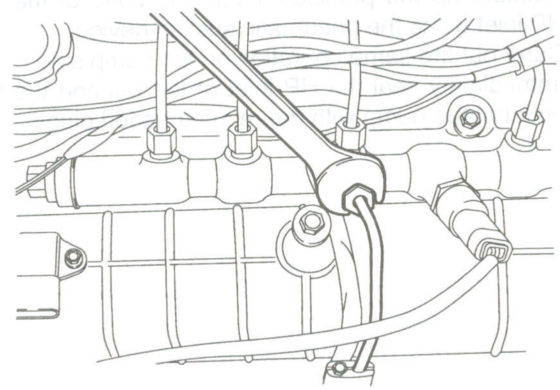
[Fig.20]



CFL0FL039

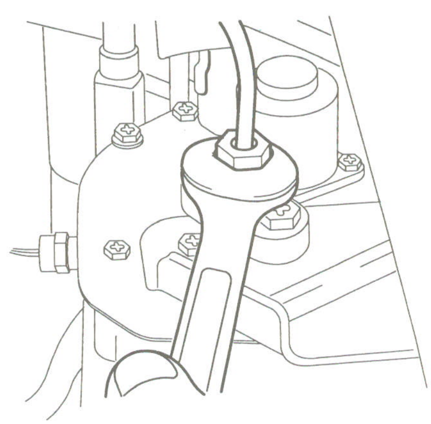
- Slacken the nut screwed onto the rail using a 19 mm(0.748 in) open wrench (Figure 21).
- Slacken the nut screwed onto the pump using a 19 mm (0.748 in) open wrench (Figure 22).

[Fig.21]



CFL0FL040

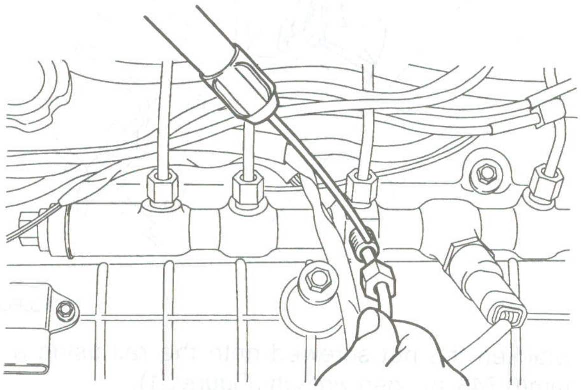
[Fig.22]



CFL0FL041

- Move th nut along the pipe, keeping the olive in contact with the cone of the HP inlet of the rail and vacuum up the particles in the area of contact between the olive and the cone with the aid of the pneumatic suction device (Figure 23).
- Carry out the same operation on the pump side.

[Fig.23]



CFL0FL042

- Remove the clip of the rail/pump HP pipe.
- Remove the rail/pump HP pipe.
- Vacuum up the particles inside the cone of the rail HP inlet using the pneumatic suction device.
- Carry out the same operation on the pump side.
- Immediately seal the HP inlet of the rail and the HP outlet of the pump with the recommended plugs.

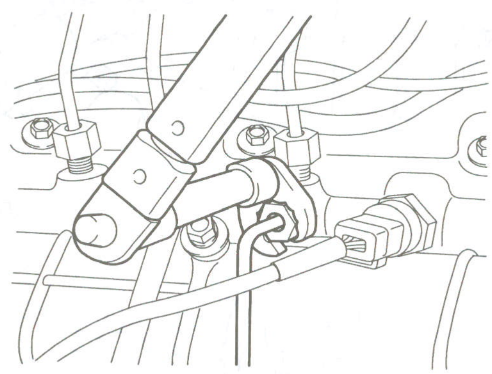
Reassembly fo rail/pump pipe

- Take the new pipe out of its packing just before fitting it.

⚠ WARNING
IT IS PROHIBITED TO RE-USE AN OLD PIPE.

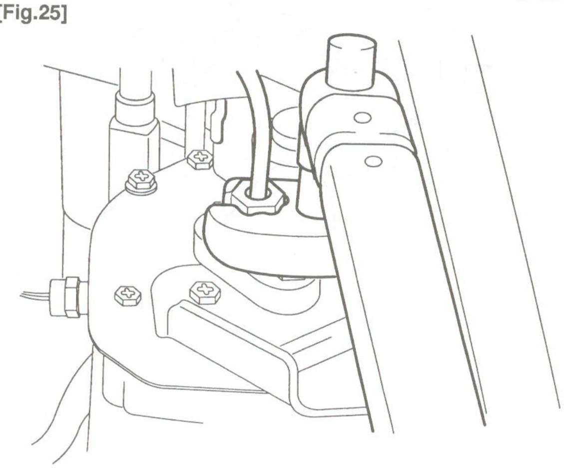
- Remove the plugs inserted at each end of the pipe.
- Lubricate the threads of the nuts with the lubricant supplied in the kit.
- Remove the protective plugs from the rail HP inlet and the pump HP outlet.
- Fit the pipe olive into the cone of the rail HP inlet and tighten the nut by hand.
- Reassembly the clip of the rail/pump HP pipe and partially tighten it.
- Fit the pipe olive into the cone of the pump HP outlet and tighten the nut by hand.
- Tighten the nut on the rail side to a torque of 40Nm(29.5 lb-ft)(Figure 24).
- Tighten the nut on the pump side to a torque of 40Nm(29.5 lb-ft)(Figure 25).
- Fully tighten the clip fo the rail/pump HP pipe (Figure 26).

[Fig.24]



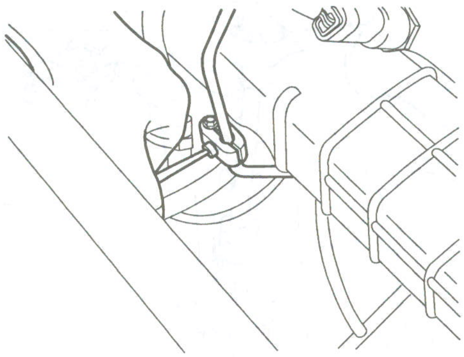
CFL0FL043

[Fig.25]



CFL0FL044

[Fig.26]



CFL0FL039

- Reassembly all the items removed to assist access.

ESSEMTIAL
To validate the rapair, start the engine and check the tightness of the HP connections.

Replacement of a full set of pipes

The HP pump and the injectors are considered to be in place.
The HP pipes are considered to have been removed according to the recommended method.
The HP inlets/outlets are assumed to be sealed.

- Fit the pump/rail HP pipe:
  - Remove the plugs inserted at each end of the pipe.
  - Lubricate the threads of the nuts with the lubricant suplied in the kit.
  - Remove the protective plugs from the pump HP outlet and the rail HP inlet.

WARNING
THE PLUGS MUST BE DISCARDED AFTER USE.

- Insert the rail side olive into the cone of the rail HP inlet.
- Reassembly the pump/rail HP pipe clip and partially tighten it.
- Insert the pump side olive into the cone of the pump HP outlet
- Tighten the HP nuts of the pump/rail pipe by hand.
- Fit the rail/injector HP pipes. For each pipe:
- Remove the plugs inserted at each end of the pipe.
- Lubricate the threads of the nuts with the lubricant supplied in the kit.

WARNING
THE PLUGS MUST BE DISCARDED AFTER USE.

- Remove the protective plugs from the rail HP outlet and the injector HP inlet.
- Insert the injector side olive into the cone of the injector HP inlet.
- Insert the rail side olive into the cone of the rail HP outlet.
- Tighten the nuts of the rail/injector HP pipe by hand.

✱ *Notice*
The order in which the pipes are fitted is of no importance.

- Tighten the HP connections of the pump/rail pipe
  - Tighten the rail side HP connection to a torque of 40Nm(29.5 lb-ft).
  - Tighten the pump side HP connection to a torque of 40Nm(29.5 lb-ft).
- Tighten the HP connections of the rail/injector pipes. For each pipe:
  - Tighten the injector side HP connection to a torque fo 40Nm(29.5 lb-ft).
  - Tighten the rail side HP connection to a torque of 40Nm(29.5 lb-ft).

- Reassembly all the items removed to assist access.

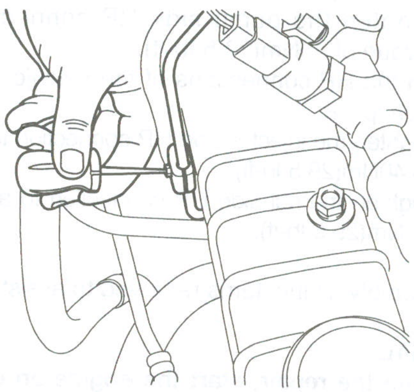
ESSENTIAL
To validate the repair, start the engine an check the tightness of the HP connections.

Injector holder-removal and reassembly

Removal of injector holder

- Remove the HP pipe of the injector being removed (following the method indicated in refer to page).
- Disconnect the injector, respecting the following procedure:
  - Apply pressure to the locking clips with a set of pliers (Figure 1).
  - Pull the connector in the direction of the arrow (Figure 1).
  - Check that the connector gasket has not remained stuck to the injector.

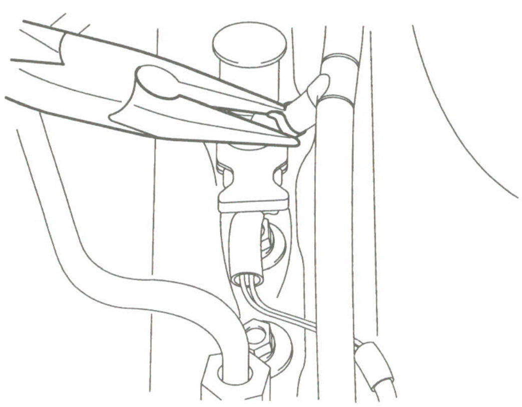
[Fig.1]



CFL0FL045

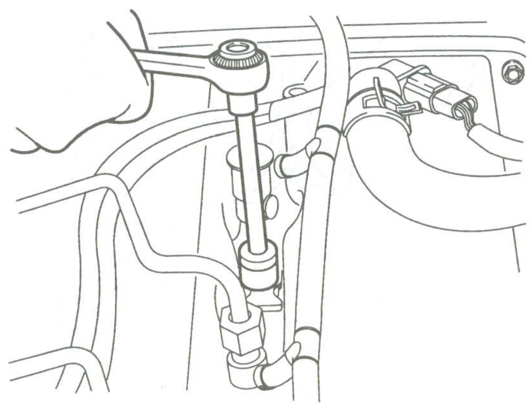
- Disconnect the injector leakage return hose (Figure 2).
- Slacken off the flnge of the injector holder (Figure 3).

[Fig.2]



CFL0FL046

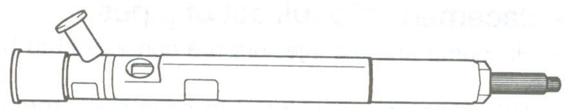
[Fig.3]



CFL0FL047

- Remove the injector with the flnge and its bolts.

[Fig.4]

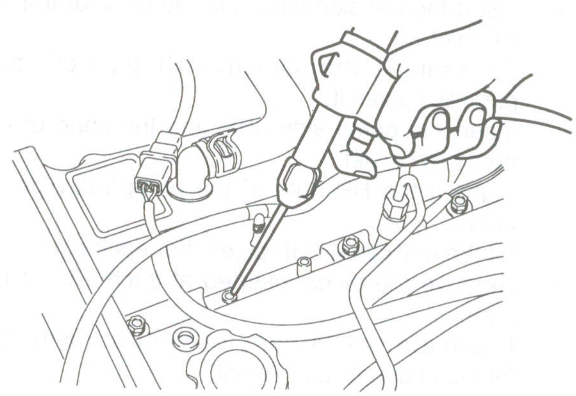


CFL0FL019

Reassembly of injector holder

- Clean the socket of the injector holder and vacuum the particles using the pneumatic suction device (Figure 5).
- Clean the flnge of the injector holder with solvent (CARCLEAN type) using a clean brush.
- Place a new geat protection washer on the seat of the injector holder.

[Fig.5]

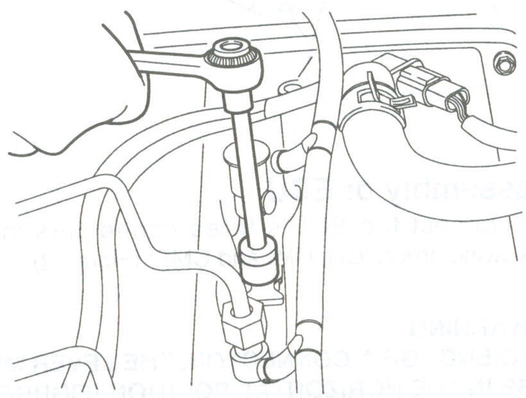


CFL0FL051

⚠ WARNING
IT IS PROHIBITED TO RE-USE AN OLD HEAT PROTECTION WASHER!

- Fit the injector holder with its flnge.
- Tighten the injector holder flnge bolt to a torque of 19 Nm(14.01 lb-ft) (Figure 6).
- Reconnect the return hose of the injector holder.
- Reconnect the injector.
- Reassembly the HP pipe, referring to the method described in page.

[Fig.6]



CFL0FL047

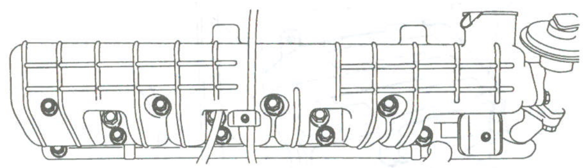
⚠ WARNING
THE NEW INJECTOR POSSESSES DIFFERENT CHARACTERISTICS FROM THE ONE WHICH WAS ORIGINALLY FITTED TO THE ENGINE. THESE CHARACTERISTICS ARE SUMMARIZED IN THE 16-CHARACTER CODE SHOWN ON THE LABEL STUCK TO THE TOP OF THE INJECTOR HOLDER (C2I). THIS CODE MUST BE ENTERED INTO THE COMPUTER MEMORY WITH THE AID OF A SERVICE AVAILABLE ON THE DIAGNOSTIC TOOL (WRITING A NEW C2I). REFER TO THE DIAGNOSTIC MANUAL.

Rail-Removal and reassembly

Removal of rail

- Remove the five HP pipes (following the method indicated in refer to page.
- Disconnect the HP sensor.
- Unscrew the EGR valve.
- Remove the inlet mainfold (Figure 1).

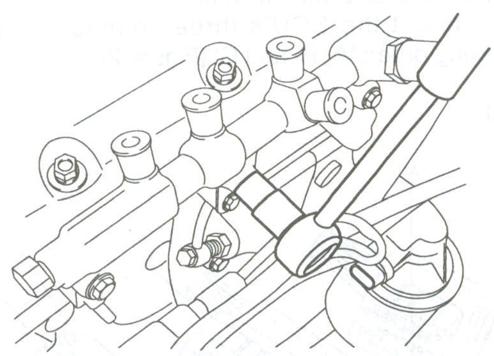
[Fig.1]



CFL0FL052

- Remove the rail from its supports (Figure 2).

[Fig.2]



CFL0FL053

Reassembly of rail

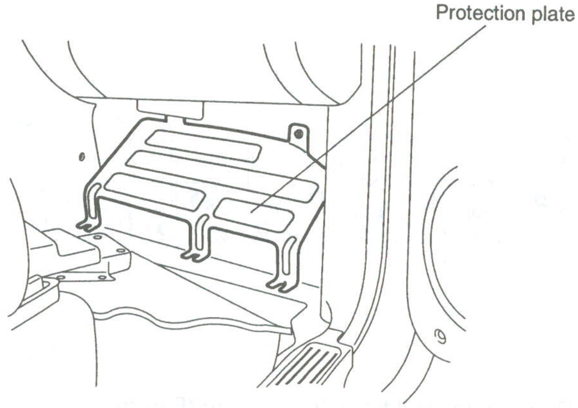
- Tighten the three rail mounting bolts to a torque of 19Nm(14.01 lb-ft).
- Replace the inlet manifold and the EGR valve.
- Reconnect the HP sensor.
- Replace the HP pipes by new parts (following the procedure described in refer to page).

ECU Raemoval and reassembly

Removal of ECU

- Switch off the ignition and wait for 30 seconds.(End of the Power Latch phase).
- Disconnect the battery earth terminal connector.
- Lift the passenger side carpet, then remove the protection plate (Figure 1).

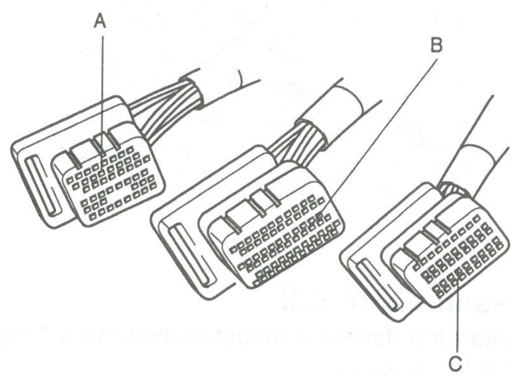
[Fig.1]



CFL0FL054

- Remove the ECU mounting nuts.
- Disconnect the ECU's three connectors in the following order: 'A, BI and C' (Figure 2).

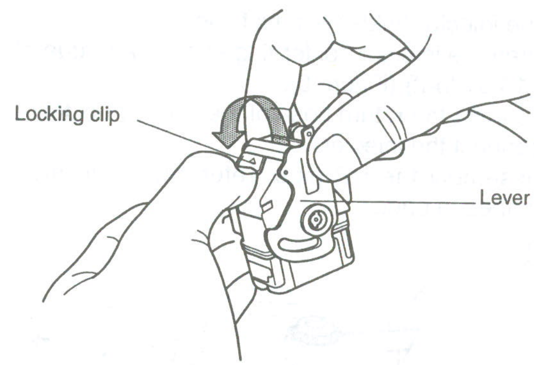
[Fig.2]



CFL0FL055

To release a connector, press on the locking clip then turn the lever in the direction of the arrow (Figure 3).

[Fig.3]



CFL0FL056

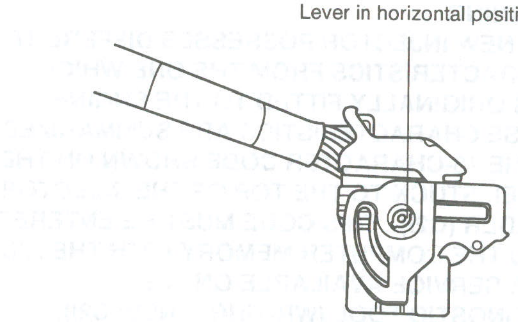
Reassembly of ECU

- Reconnect the ECU's three connectors in the following order: 'CH, CMI and CME' (Figure 2).

⚠ **WARNING**

TO ENGAGE A CONNECTOR, THE LEVER MUST BE IN THE HORIZONTAL POSITION (FIGURE 4).

[Fig.4]

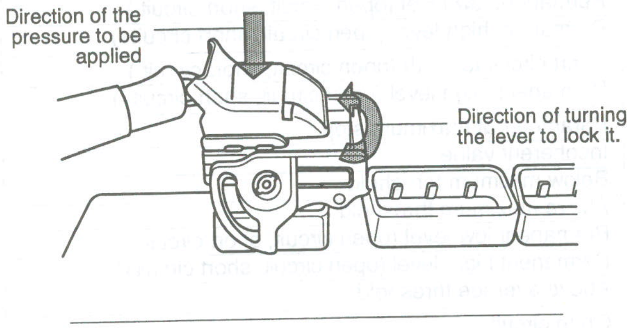


CFL0FL057

To lock the connector, apply a light pressure to it then the lever in the direction of the arrow to bring it to the vertical position (Figure 5).

- Tighten the three ECU mounting nuts.
- Reassembly the protection plate then put back the carpet.
- Reconnect the battery earth terminal connector.

[Fig.5]



CFL0FL058

✱ *Notice*

- *It is essential to set the C2 of all the injectors before starting the vehicle. Unless this has been done, a recovery strategy fixes the engine speed at 1300 rpm, without pedal control.*
- *It is also necessary to re-copy the programmed values to the memory of the new DCU and to programme coded keys in order to re-initialize the engine immobiliser.*
- *For these operations, refer to the instructions given in the diagnostic manual.*

Tightening torques

Component being tightened	Torque
HP pipes	40 ¡ 10N•m(29.5 ¡ 7.38 lb-ft)
Rail mounting bolt	19N•m(14.01 lb-ft)
Pump mounting bolt	19N•m(14.01 lb-ft)
Injector holder flnge bolt	19N•m(14.01 lb-ft)
Pump pulley nut	65N•m(47.94 lb-ft)
Low pressure actuator mounting bolt (IMV)	5.5 ¡ 0.6Nm(4.1 ¡ 0.44lb-ft)
Venturi mounting bolt	5.5 ¡ 0.6Nm(4.1 ¡ 0.44lb-ft)
Diesel oil temperature sensor	15 ¡ 1.5Nm(11.1 ¡ 1.1lb-ft)

DIAGNOSTIC TROUBLE CODES TABLE

Number	Title	Status
0100	Air flow test	Parameter at minimum stop
		Parameter at maximum stop
0101	Air flowmeter sensor circuit	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
0115	Coolant temperature sensor circuit	Short circuit to earth (short circuit-)
		Permanent high level (open circuit, short circuit+)
0120	Pedal sensor track 1 circuit	Incoherent value
		Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
0180	Fuel temperature sensor circuit	Short circuit to earth (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
0190	Rail pressure sensor circuit	Parameter at maximum stop
		Incoherent value
		Below minimum threshold
		Above maximum threshold
		Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
		Above average threshold
0201	Cylinder 1 control circuit	Open circuit
		Parameter at minimum stop
		Line in short circuit (short circuit)
		Combustion too low
		Combustion too hight
0202	Cylinder 3 control circuit	Open circuit
		Parameter at minimum stop
		Line in short circuit (short circuit)
		Combustion too low
		Combustion too high
0203	Cylinder 4 control circuit	Open circuit
		Parameter at minimum stop
		Line in short circuit (short circuit)
		Combustion too low
		Combustion too high
0204	Cylinder 2 control circuit	Open circuit
		Parameter at minimum stop
		Line in short circuit (short circuit)
		Combustion too low
		Combustion too high
0220	Padal sensor track 2 circuit	Short circuit to earth (short circuit-)
		Short circuit to +V_B (short circuit+)
		Permanent low level (open circuit, short circuit-)
		Permanent high leve (open circuit, short circuit+)
0226	Pedal fault	Incoherent value
		Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
0325	Accelerometer circuit	No signal
		Above maximum threshold
0335	Engine speed sensor circuit	Incoherent value
		No signal
		Too many additional teeth
		Teeth missing
		Additional teeth
		Too many teeth missing
0340	Cylinder reference sensor circuit	Incoherent value
		No signal

Number	Title	Status
0380	Preheating command 1	Short circuit to $+V_B$ (short circuit+)
		Permanent low level (open circuit, short circuit-)
0381	Preheating warning light circuit	Short circuit to $+V_B$ (short circuit+)
		Permanent low level (open circuit, short circuit-)
0382	Preheating command 2	Short circuit to $+V_B$ (short circuit+)
		Permanent low level (open circuit, short circuit-)
0400	EGR control circuit	Short circuit to $+V_B$ (short circuit+)
		Permanent low level (open circuit, short circuit-)
0560	Battery voltage	Below minimum threshold
		Above maximum threshold
0650	Fault warning light circuit	Short circuit to $+V_B$ (short circuit+)
		Permanent low level (open circuit, short circuit-)
1119	Rail pressure test fault	Trim<min high flow
		Trim>max high flow
		Trim<min low flow
		Trim>max low flow
1120	Low pressure actuator circuit	Short circuit to $+V_B$ (short circuit+)
		Parameter at minimum stop
		Parameter at maximum stop
		Below minimum threshold
		Permanent low level (open circuit, short circuit-)
1140	Air temperature sensor circuit	Short circuit to earth (short circuit-)
		Permanent high level (open circuit, short circuit+)
1150	Atmospheric pressure sensor circuit	Short circuit to $+V_B$ (Short circuit)
		Permanent low level (open circui,t short circuit-)
1300	C2I data fault	Incorrect injector parameters
1310	Injector control	Short circuit to earth (Short circuit-)
		Short circuit to $+V_B$ (Short circuit+)
1458	Air conditioning input signal	Incoherent value
1500	Vehicle speed circuit	Incoherent value
		No signal
1540	Clutch switch circuit	
1543	Brake switch circuit	Short circuit to earth (Short circuit-)
		Short circuit to $+V_B$ (Short circuit+)
		Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
		Line in short circuit (Short circuit)
1608	Sequencer fault	Overload
		Analogue/digital converter fault
1610	Sensor feed voltage	Below minimum threshold
		Above maximum threshold
1611	Coded immobiliser fault	Transponder data corrupt
		Transponder error
		Transponder programming error
1612	Coded immobiliser fault	Transponder antenna fault
		ECU-SMARTRA communication fault
		No response from SMARTRA
		SMARTRA-ECU communication fault
1613	Coded immobiliser fault	SMARTRA fault
		Communication fault

Number	Title	Status
1614	Computer fault	EEPROM write fault
		EEPROM read fault
		RAM integrity fault
		Software fault
		Watchdog fault
		Injector control line noise
		Watchdog fault
1620	Air conditioning relay command	Short circuit to +V_B (short circuit+)
		Permanent low level (open circuit, short circuit-)
1626	Immobiliser warning light circuit	Short circuit to + V_B (short circuit+)
		Permanent low level (open circuit, short circuit-)
1640	Feed relay	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1672	Control GMV 1	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1673	Control GMV 2	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1674	Air conditioning fan control	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1690	Water heater control	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1780	Torque reduction request	Incoherent value
		Above maximum threshold
		Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)
1786	Engine speed information output	Permanent low level (open circuit, short circuit-)
		Permanent high level (open circuit, short circuit+)