FUEL SYSTEM

COMMON RAIL ACCUMULATOR FUEL-INJECTION SYSTEM

SYSTEM OVERVIEW

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. 1350 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 Bosch "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.

FUNCTIONS

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-speed sensor,
- Camshaft-speed sensor,
- Accelerator-pedal sensor,
- Boost-pressure sensor,
- Rail-pressure sensor,
- Coolant sensor and
- Air-mass meter.

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-speed sensor, and the camshaft-speed 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 air-mass 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. Insofar as the engine is equipped with an exhaust-gas turbocharger and boost-pressure control, the boost-pressure sensor also measures boost-pressure. At low outside temperatures and with the engine cold, the ECU applies the data from the coolant-temperature and air-temperature sensors to adapt the setpoint values for start of injection, post injection, and further parameters to the particular operating conditions. Depending upon the vehicle in question, in order to comply with the increasing demands for safety and comfort, further sensors and data lines provide inputs to the ECU.
Fig. 1 shows an example of a 4-cylinder diesel engine fitted with a fuel-injection installation using the "Common Rail" accumulator injection system. Various components are shown.

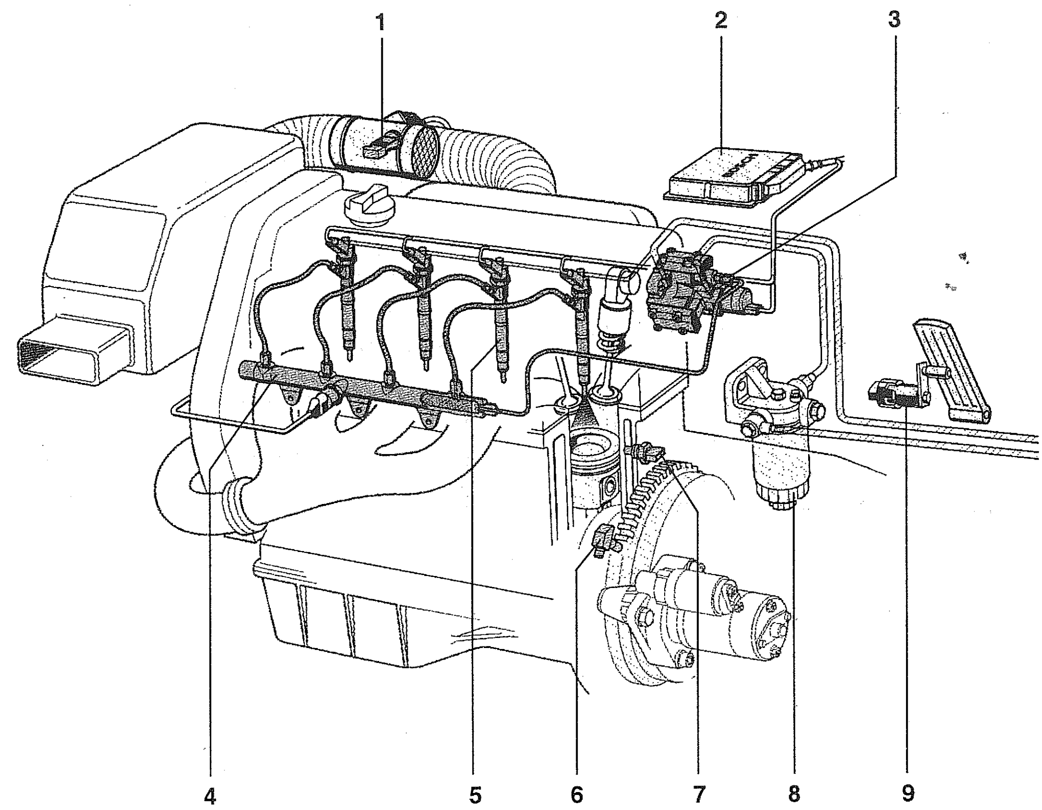
Basic functions

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), boost-pressure control, 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

1. Air-mass meter
2. ECU
3. High-pressure pump
4. High-pressure accumulator (rail)
5. Injectors
6. Crankshaft-speed sensor
7. Coolant-temperature sensor
8. Fuel filter
9. Accelerator-pedal sensor

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

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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. 1). 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:

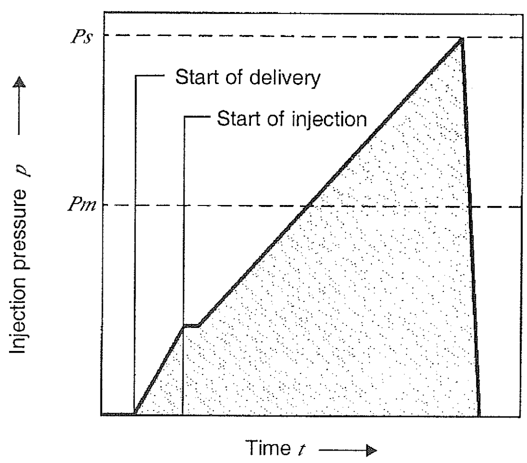
- Smaller injected fuel quantities are injected with lower pressures than larger injected fuel quantities (refer to Fig. 1)
- The peak pressure is more than double that of the mean injection pressure, and
- In line with the requirements for efficient combustion, the rate-of discharge curve is practically 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. 1]

Rate-of-discharge curve for conventional fuel injection

P_m Mean injection pressure, P_S Peak pressure.



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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).

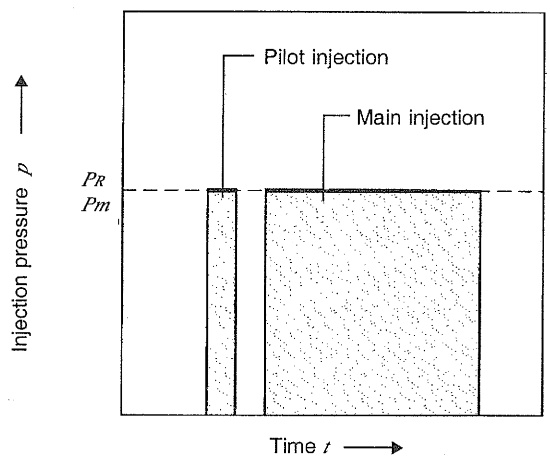
These requirements are complied with in the Common rail accumulator injection system with its pilot and main-injection features (Figs. 2 and 4).
The Common Rail system is a modular system, and essentially the following components are responsible for the injection characteristic:

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

[Fig. 2]

Rate-of-discharge curve for Common Rail fuel injection

P_m Mean injection pressure, P_R Rail pressure.



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

- Electronic control unit (ECU),
- Crankshaft-speed sensor, and
- Camshaft-speed sensor (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).

Pilot injection

Pilot injection can be advanced by up to 90° crankshaft (90°cks) referred to TDC. If the start of injection occurs less than 40°cks BTDC, fuel can be deposited on the surface of the piston and the cylinder walls, and can lead to unwanted dilution of the lube-oil. With pilot injection, a small amount of diesel fuel (1...4 mm^3) is injected into the cylinder to "precondition" the combustion chamber. Combustion efficiency can be improved as a result, and the following effects are achieved:

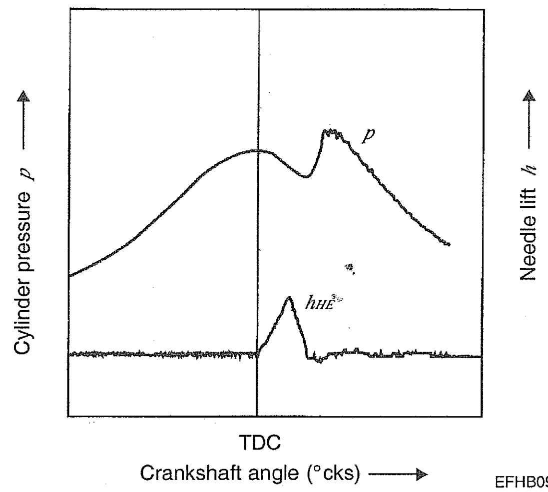
- The compression pressure is increased slightly due to pilot reaction and partial combustion, this in turn leads to
- The main-injection ignition delay being reduced, and
- A reduction of combustion-pressure rise and of the combustion-pressure peaks (softer combustion).

These effects reduce the combustion noise, the fuel consumption, and in many cases the exhaust-gas emissions as well. In the case of a rate-of-discharge curve without pilot injection (Fig. 3), in line with the compression only a slight, flat pressure rise is evident just before TDC, after which it peaks relatively sharply at the point of maximum pressure. The steep pressure increase together with the sharp peak contribute considerably to the diesel engine's combustion noise. As shown by the rate-of-discharge curve with pilot injection, (Fig. 4), pressure in the vicinity of TDC reaches a somewhat higher value, and the combustion-pressure increase is less rapid.
Since it reduces the ignition delay, pilot injection makes an indirect contribution to the generation of engine torque. The specific fuel consumption can increase or decrease as a function of the start of main injection and the time between the pilot and main injection sequences.

[Fig. 3]

Needle lift in the injector nozzle, and rate-of-discharge curve without pilot injection

h_{HE} Needle lift for main injection.



Main injection

The energy for the engine's output work comes from the main injection sequence. This means that essentially the main injection is responsible for the development of the engine's torque. With the Common Rail accumulator fuel-injection system, the injection pressure remains practically constant throughout the whole of the injection process.

Secondary injection

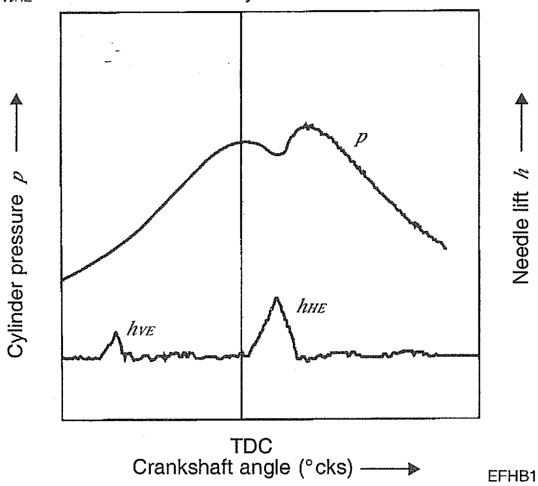
With certain versions of NOx catalytic converter, secondary injection can be applied for NOx combustion (reduction). It follows the main injection process and is timed to take place during the expansion or exhaust cycle up to 200°cks after TDC. Secondary injection introduces a precisely metered quantity of fuel to the exhaust gas.

In contrast to the pilot and main injection processes, the injected fuel does not combust but instead vaporises due to the residual heat in the exhaust gas. During the exhaust cycle, the resulting mixture of exhaust gas and fuel is forced out through the exhaust valves and into the exhaust-gas system. Part of the fuel though is returned for combustion via the EGR system and has the same effects as very advanced pilot injection. Provided suitable NOx catalytic converters are fitted, these utilise the fuel in the exhaust gas as a reduction agent to lower the NOx content in the exhaust gas.

[Fig. 4]

Needle lift in the injector nozzle, and rate-of-discharge curve with pilot injection

h_{VE} Needle lift for pilot injection.
h_{HE} Needle lift for main injection.



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Since very late secondary injection leads to dilution of the engine lube oil, it must be approved by the engine manufacture.

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 ($\lambda > 1$). 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.

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 CR 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 flame 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 (11).

LOW-PRESSURE DELIVERY

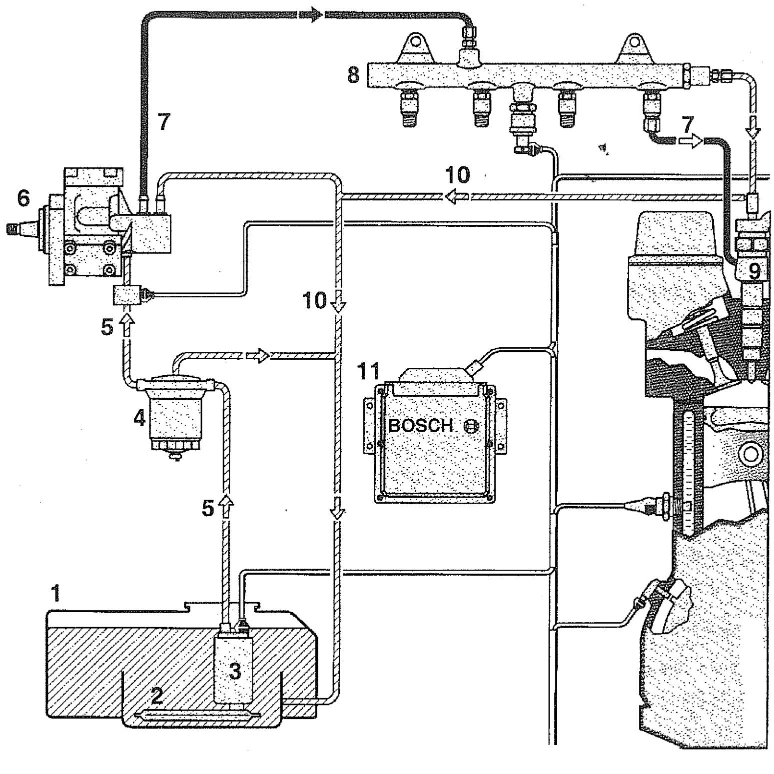
The low-pressure stage of the Common Rail fuel system incorporates:

- Fuel tank with pre-filter,
- Presupply pump,
- Fuel filter, and
- Low-pressure fuel lines.

Fuel lines for the low-pressure stage

As an alternative to steel pipes, flame-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

1. Fuel tank
2. Pre-filter
3. Presupply pump
4. Fuel filter
5. Low-pressure fuel lines
6. High-pressure pump
7. High-pressure fuel lines
8. Rail
9. Injector
10. Fuel-return line
11. ECU

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Low-pressure system components

Presupply pump

The presupply pump is either an electric fuel pump with pre-filter, or a gear-type fuel 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 high-pressure 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 1,350bar. 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 1,500bar. 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.

DESIGN AND FUNCTION OF THE COMPONENTS

LOW-PRESSURE STAGE

The low-pressure stage (Fig. 1) provides enough fuel for the high-pressure section. The most important components are:
- Fuel tank,
- Pre-supply pump with prefilter,
- Low-pressure fuel lines for supply and return,
- Fuel filter and
- Low-pressure area of the high-pressure pump.

Pre-supply pump

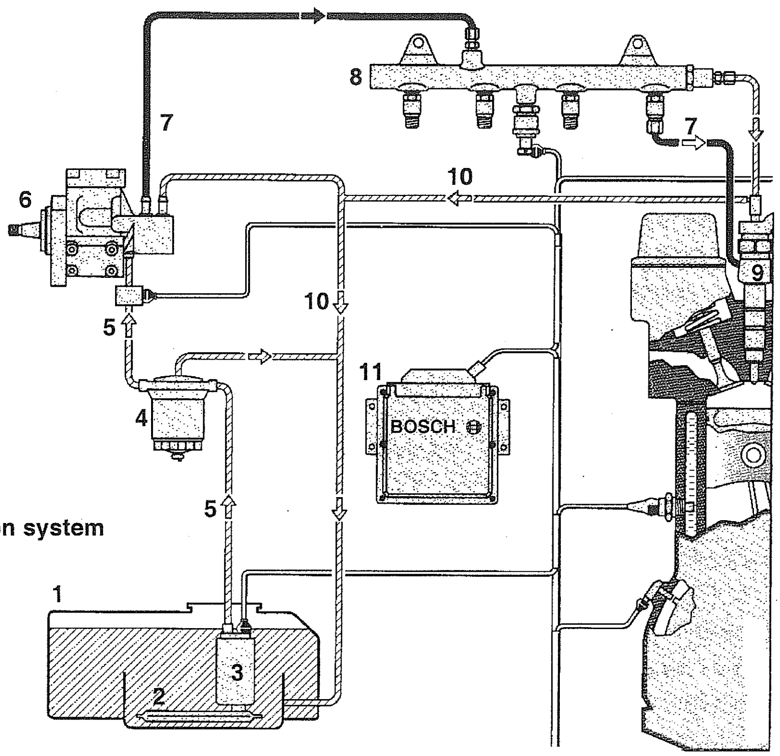
It is the pre-supply pump's job to maintain an adequate supply of fuel to the high-pressure pump. This applies
- In every operating state,
- At the necessary pressure, and
- Throughout the complete service life.

At present, there are two possible versions. An electric roller-cell fuel pump is the standard solution. An alternative is the mechanically driven gear-type fuel pump.

Electric fuel pump

The electric fuel pump is only used in passenger cars and light commercial vehicles. It is not only responsible for delivering the fuel to the high-pressure pump, but within the framework of system monitoring it must also interrupt the flow of fuel in case of an emergency.
Beginning with the engine cranking process, the electric fuel pump runs continuously independent of engine speed. This means that the pump permanently delivers fuel from the fuel tank, and through the filter to the high-pressure pump. Excess fuel can flow back to the tank through an overflow valve.
A safety circuit is provided to prevent the delivery of fuel should the ignition be on with the engine stopped.
Electric fuel pumps are available as in-line or in-tank versions. In-line fuel pumps are installed outside the tank in the fuel line between the tank and the fuel filter. They are attached to the vehicle's floor assembly. In-tank fuel-pump versions on the other hand are installed in the fuel tank itself using a special mounting. Apart from the electrical and hydraulic connections to the outside, this mounting usually incorporates a fuel strainer, a fuel-level indicator, and a swirl pot which acts as a fuel reservoir.

[Fig. 1]



Fuel system for a Common Rail fuel-injection system

1. Fuel tank
2. Pre-filter
3. Presupply pump
4. Fuel filter
5. Low-pressure fuel lines
6. High-pressure pump
7. High-pressure fuel lines
8. Rail
9. Injector
10. Fuel-return line
11. ECU

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An electric fuel pump comprises the three function elements:
- Pumping element,
- Electric motor, and
- End cover.

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).

HIGH-PRESSURE STAGE

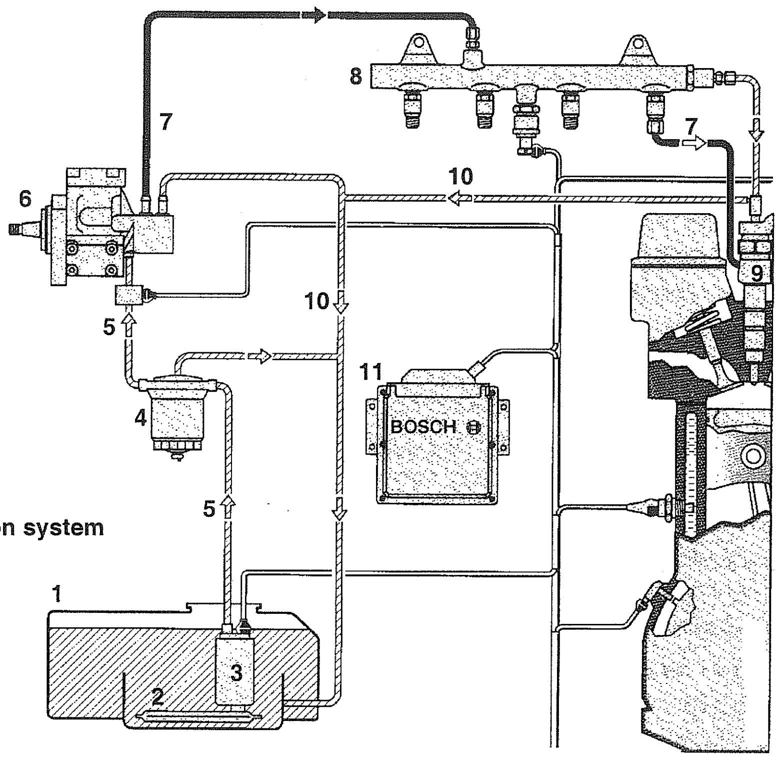
In addition to high-pressure generation, fuel distribution and fuel-metering also take place in the high-pressure stage (Fig. 1). The most important components are:
- High-pressure pump with element shutoff valve and pressure-control valve,
- High-pressure accumulator,
- Rail-pressure sensor,
- Pressure-limiter valve,
- Flow limiter and
- Injectors.

High-pressure pump

Assignments

The high-pressure pump (Figs. 7 and 8) is the interface between the low-pressure and the high-pressure stages. Under all operating conditions, it is responsible for providing adequate high-pressure fuel throughout the

[Fig. 1]



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11. ECU

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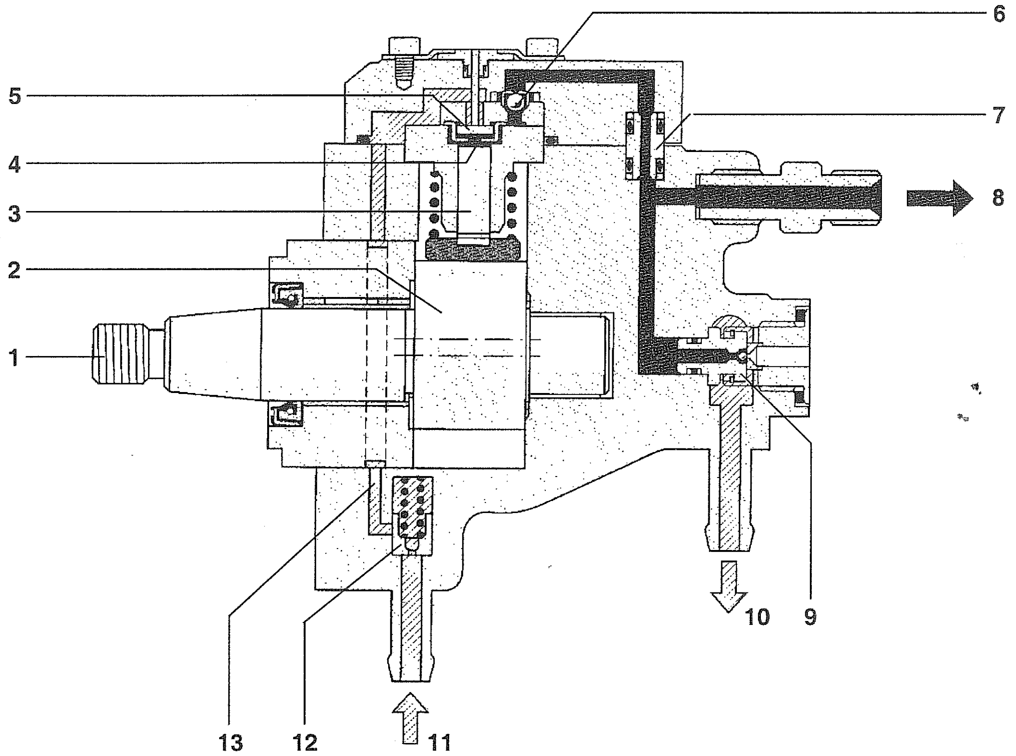
vehicle's complete service life. This also includes the provision of extra fuel as needed for rapid starting and for rapid build-up of pressure in the rail.

The high-pressure pump continually generates the system pressure as needed in the high-pressure accumulator (rail). This means therefore, that in contrast to conventional systems, the fuel does not have to be specially compressed for each individual injection process.

[Fig. 7]



High-pressure pump (schematic, longitudinal section)

1. Driveshaft
2. Eccentric cam
3. Pumping element with pump plunger
4. Pumping-element chamber
5. Suction valve
6. Outlet valve
7. Seal
8. High-pressure connection to the rail
9. Ball valve
10. Fuel return
11. Fuel inlet from the presupply pump
12. Safety valve with throttle bore
13. Low-pressure passage to the pumping element

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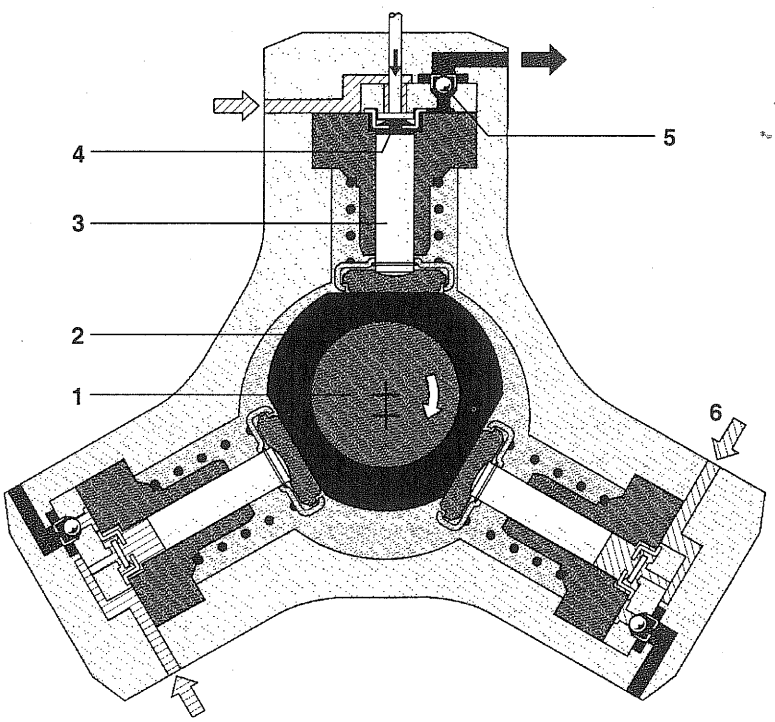
Design and construction

The high-pressure pump is installed preferably at the same point on the diesel engine as a conventional distributor pump. It is driven by the engine (at half engine speed, but max. 3000 min^{-1}) through a coupling, gear-wheel, chain, or toothed belt, and lubricated by the diesel fuel which it pumps.
Depending on available space, a pressure-control valve is installed directly on the high-pressure pump or remote from it. Inside the high-pressure pump, the fuel is compressed with three radially arranged pump pistons which are at an angle of 120° to each other. Since three delivery stokes take place for every revolution, only low peak drive torques are generated so that the stress on the pump drive remains uniform. With 16Nm, the torque is only about 1/9 of that required to drive a comparable distributor pump. This means that Common Rail places less loading on the pump drive than is the case with conventional injection system. The power required to drive the pump climbs in proportion to the pressure set in the rail and to the pump's speed (delivery quantity). For a 2-liter engine turning at rated speed, and with a set pressure of 1,350 bar in the rail, the high-pressure pump requires 3.8kW presuming a mechanical efficiency of approx. 90%. The higher power demand (higher than theoretically necessary) results from the leak-fuel and control quantities at the injector, and from the fuel return through the pressure-control valve.

[Fig. 8]



High-pressure pump (schematic, cross-section)

1. Driveshaft
2. Eccentric cam
3. Pumping element with pump piston
4. Inlet valve
5. Outlet valve
6. Inlet

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Method of operation

Via a filter with water separator, the presupply pump pumps fuel from the tank to the high-pressure pump through the fuel inlet (Fig. 7) and the safety valve. It forces the fuel through the safety valve's throttle bore and into the high-pressure pump's lubrication and cooling circuit. The driveshaft with its eccentric cams moves the three pump plungers up and down in accordance with the shape of the cam.
As soon as the delivery pressure exceeds the safety valve's opening pressure (0.5 ... 1.5bar), the pre-supply pump can force fuel through the high-pressure pump's inlet valve into the pumping-element chamber whose pump piston is moving downwards (suction stroke). The inlet valve closes when the pump piston passes through BDC and, since it is impossible for the fuel in the pumping-element chamber to escape, it can now be compressed beyond the delivery pressure. The increasing pressure opens the outlet valve as soon as the rail pressure is reached, and the compressed fuel enters the high-pressure circuit.
The pump piston continues to deliver fuel until it reaches TDC (delivery stroke), after which the pressure collapses so that the outlet valve closes. The fuel remaining in the pumping-element chamber relaxes and the pump piston moves downwards again.
As soon as the pressure in the pumping-element chamber drops below the presupply-pump pressure, the inlet valve opens and the pumping process starts again.

Fuel-delivery rate

Since the high-pressure pump is designed for large delivery quantities, excess high-pressure fuel is delivered during idle and part-load operation. This excess fuel is returned to the tank via the pressure-control valve. The compressed fuel relaxes in the tank, and the energy is lost which was used for compressing the fuel in the first place. In addition to the unnecessary heating up of the fuel, overall efficiency is also reduced.
To a certain extent, this loss of efficiency can be compensated for by switching off one of the pumping elements.

Element switch-off:

When one of the pumping elements (Fig. 7) is switched off, this leads to a reduction of the amount of fuel which is pumped into the rail. Switch-off involves the suction valve (Fig. 7) remaining open permanently. When the solenoid valve of the pumping-element switchoff is triggered, a pin attached to its armature continually holds the inlet valve open. The result is that the fuel drawn into this pumping element cannot be compressed during the delivery stroke. No pressure is generated in the element chamber since the fuel flows back into the low-pressure passage again. With one of its pumping elements switched off when less power is needed, the high-pressure pump no longer delivers the fuel continuously but rather with brief interruptions in delivery.

Transmission ratio:

The high-pressure pump's delivery rate is proportional to its rotational speed. And this, in turn, is a function of the engine speed. During the injection-system application-engineering work on the engine, the transmission ratio is defined so that on the one hand the amount of excess fuel is not too high, and on the other, the fuel requirements can still be satisfied during WOT operation. Referred to the crankshaft, transmission ratios of 1:2 and 2:3 are possible.

High-pressure accumulator (rail)

Assignments

The high-pressure accumulator (the Rail in Fig. 10) 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.

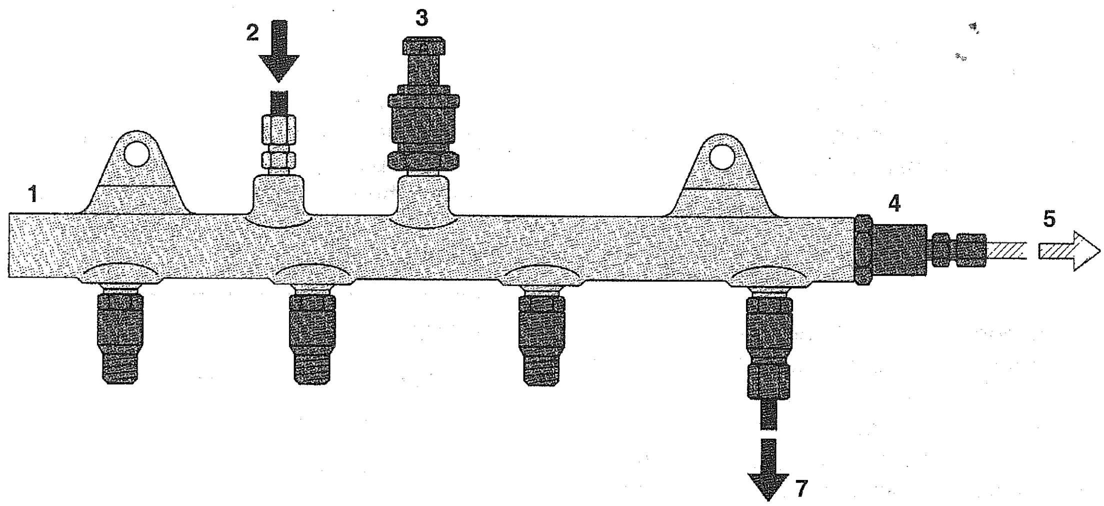
Design and construction

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. 10]



High-pressure accumulator (rail)

1. Rail
2. Inlet from the high-pressure pump
3. Rail-pressure sensor
4. Return from the rail to the fuel tank
5. Line to the injector

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Rail-pressure sensor

Assignment

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

- With adequate accuracy, and
- As quickly as possible

Design and construction

The rail-pressure sensor (Fig. 12) comprises the following components:

- An integrated sensor element welded to the pressure fitting,
- A printed-circuit board (pcb) with electrical evaluation circuit, and
- A sensor housing with electrical plug-in connection.

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 ECU.

Function

The rail-pressure sensor (Fig. 12) operates as follows: When the diaphragm's shape changes, the electrical resistance of the layers attached to the diaphragm also change. The change in shape (approx. 1 mm at 1500bar) which results from the buildup of system pressure, changes the electrical resistance and causes a voltage change across the 5V resistance bridge.

This voltage change is in the range 0 ... 70mV (depending upon the applied pressure) and is amplified by the evaluation circuit to 0.5 ... 4.5V.
The precise measurement of rail pressure is imperative for correct system functioning. This is one of the reasons for the very tight tolerances which apply to the rail-pressure sensor during pressure measurement. In the main operating range, the measuring accuracy is approx. ± 2% of full-scale reading. If the rail-pressure sensor should fail, the pressure-control valve is triggered "blind" using an emergency (limp-home) function and fixed values.

Pressure limiter valve

Assignment

The pressure limiter valve has the same job as an overpressure valve. In case of excessive pressure, the pressure limiter valve limits the rail pressure by opening an escape passage. The pressure limiter permits a short-time maximum rail pressure of 1500 bar.

Design and construction

The pressure-limiter valve is a mechanical device comprising the following components:

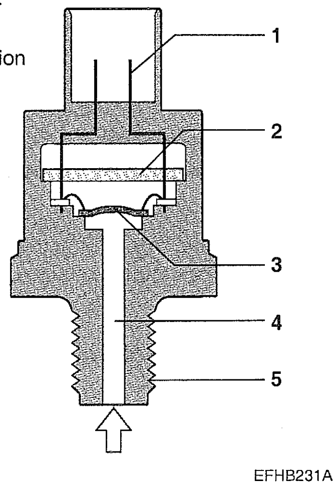
- Housing with external thread for screwing to the rail,
- A connection to the fuel-tank return line,
- A movable plunger, and
- A spring.

At the connection end to the rail, the housing is provided with a passage which is closed by the cone-shaped end of the plunger coming up against the sealing seat inside the housing. At normal operating pressures (up to 1350bar), a spring forces the plunger against the seat and the rail remains closed. As soon as the maximum system pressure is exceeded, the plunger is forced up by the rail pressure against the force of the spring. The fuel under high pressure can now escape, whereby it flows through passages into the plunger's interior from where it is led through a collector line back to the fuel tank. When the valve opens. fuel leaves the rail so that the rail pressure drops.

[Fig. 12]

Rail-pressure sensor (schematic)

1. Electric connections
2. Evaluation circuit
3. Diaphragm with sensor element
4. High-pressure connection
5. Mounting thread



Injector's

Assignment

The start of injection and the injected fuel quantity are adjusted by electrically triggered injectors. These injectors supersede the nozzle-and-holder assembly (nozzle and nozzle-holder).
Similar to the already existing nozzle-holder assemblies in direct-injection (DI) diesel engines, clamps are preferably used for installing the injectors in the cylinder head. This means that the Common Rail injectors can be installed in already existing DI diesel engines without major modifications to the cylinder head.

Design and construction

The injector (Fig. 16) can be sub-divided into a number of function blocks:
- The hole-type nozzle,
- The hydraulic servo-system, and
- The solenoid valve.

Referring to Fig. 16, fuel is fed from the high-pressure connection, to the nozzle through the passage, and to the control chamber through the feed orifice. The control chamber is connected to the fuel return via a bleed orifice which is opened by the solenoid valve.
With the bleed orifice closed, the hydraulic force applied to the valve control plunger exceeds that at the nozzle-needle pressure shoulder. As a result, the needle is forced into its seat and seals off the high-pressure passage from the combustion chamber.
When the injector's solenoid valve is triggered, the bleed orifice is opened. This leads to a drop in control-chamber pressure and, as a result, the hydraulic pressure on the plunger also drops. As soon as the hydraulic force drops below the force on the nozzle-needle pressure shoulder, the nozzle needle opens and fuel is injected through the spray holes into the combustion chamber. This indirect control of the nozzle needle using a hydraulic force-amplification system is applied because the forces which are necessary for opening the needle very quickly cannot be directly generated by the solenoid valve. The so-called control quantity needed for opening the nozzle needle is in addition to the fuel quantity which is actually injected, and it is led back to the fuel-return line via the control chamber's orifices.
In addition to the control quantity, fuel is also lost at the nozzle-needle and valve-plunger guides. These control and leak-off fuel quantities are returned to the fuel tank via the fuel return and the collector line to which overflow valve, high-pressure pump, and pressure-control valve and also connected.

Method of operation

The injector's operation can be subdivided into four operating states with the engine running and the high-pressure pump generating pressure:
- Injector closed (with high pressure applied),
- Injector opens (start of injection),
- Injector opened fully, and
- Injector closes (end of injection).

These operating states result from the distribution of the forces applied to the injector's components. With the engine at standstill and no pressure in the rail, the nozzle spring closes the injector.

Injector closed (at-rest status):

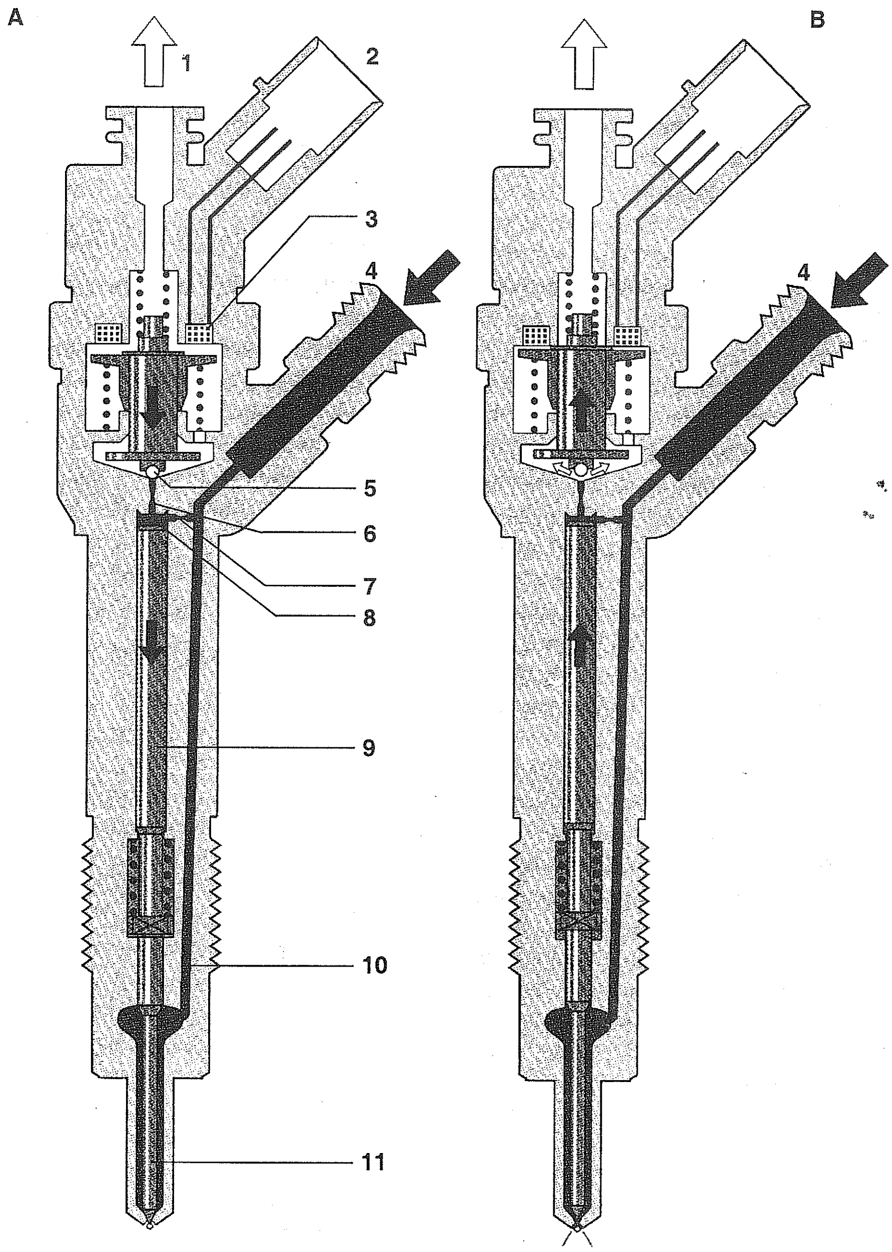
In the at-rest state, the solenoid valve is not energized and is therefore closed (Fig. 16a).
With the bleed orifice closed, the valve spring forces the armature's ball onto the bleed-orifice seat. The rail's high pressure builds up in the valve control chamber, and the same pressure is also present in the nozzle's chamber volume. The rail pressure applied at the control plunger's end face, together with the force of the nozzle spring, maintain the nozzle in the closed position against the opening forces applied to its pressure stage.

Injector opens (start of injection):

The injector is in its at-rest position. The solenoid valve is energized with the pickup current which serves to ensure that it opens quickly (Fig. 16b). The force exerted by the triggered solenoid now exceeds that of the valve spring and the armature opens the bleed orifice. Almost immediately, the high-level pick-up current is reduced to the lower holding current required for the electromagnet. This is possible due to the magnetic circuit's air gap now being smaller. When the bleed orifice opens, fuel can flow from the valve-control chamber into the cavity situated above it, and from there via the fuel return to the fuel tank, The bleed orifice prevents complete pressure balance, and the pressure in the valve control chamber sinks as a result. This leads to the pressure in the valve-control chamber being lower than that in the nozzle's chamber volume which is still at the same pressure level as the rail. The reduced pressure in the valve-control chamber causes a reduction in the force exerted on the control plunger, the nozzle needle opens as a result, and injection starts.

The nozzle needle's opening speed is determined by the difference in the flow rate through the bleed and feed orifices. The control plunger reaches its upper stop where it remains supported by a cushion of fuel which is generated by the flow of fuel between the bleed and feed orifices. The injector nozzle has now opened fully, and fuel is injected into the combustion chamber at a pressure almost equal to that in the fuel rail. Force distribution in the injector is similar to that during the opening phases.

[Fig. 16]



Injector (schematic)

A. Injector closed (at-rest status)
B. Injector opened (injection)
1. Fuel return
2. Electrical connection
3. Triggering element (solenoid valve)
4. Fuel inlet (high pressure) from the rail
5. Valve ball
6. Bleed orifice
7. Feed orifice
8. Valve control chamber
9. Valve control plunger
10. Feed passage to the nozzle
11. Nozzle needle

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Injector closes (end of injection):

As soon as the solenoid valve is no longer triggered, the valve spring forces the armature downwards and the ball closes the bleed orifice. The armature is a 2-piece design. Here, although the armature plate is guided by a driver shoulder in its downward movement, it can "overspring" with the return spring so that it exerts no downwards-acting forces on the armature and the ball. The closing of the bleed orifice leads to pressure buildup in the control chamber via the input from the feed orifice. This pressure is the same as that in the rail and exerts an increased force on the control plunger through its end face. This force, together with that of the spring, now exceeds the force exerted by the chamber volume and the nozzle needle closes.

The nozzle needle's closing speed is determined by the flow through the feed orifice. Injection ceases as soon as the nozzle needle comes up against its bottom stop again.

SYSTEM CONTROL USING EDC

SYSTEM BLOCKS

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

1. Sensors 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 electrical 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.

SENSORS (FIG. 12)

Crankshaft-speed sensor

The piston position in the combustion chamber is decisive in defining the start of injection. All the engine' s pistons are connected to the crankshaft by connecting rods (conrods). A sensor on the crankshaft can therefore provide information on the position of all the pistons. The rotational speed defines the number of crankshaft rotations per minute.
This important input variable is calculated in the ECU using the signal from the inductive crankshaft-speed sensor.

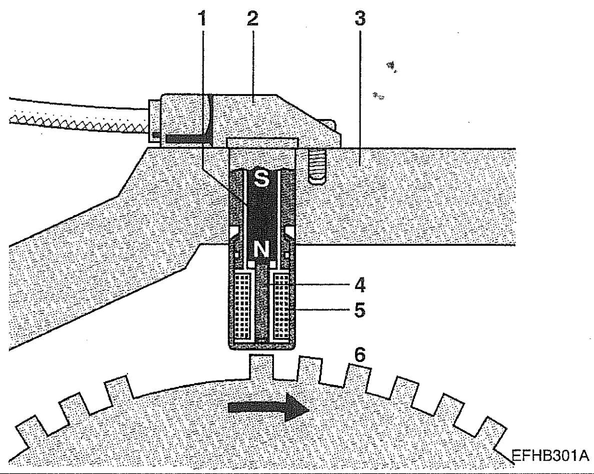
Signal generation

A 60-tooth ferromagnetic trigger wheel is attached to the crankshaft. On the actually used trigger wheel 2 teeth are missing. The large gap is allocated to a defined crankshaft position for cylinder 1.
The crankshaft-speed sensor registers the trigger wheel' s tooth sequence. It comprises a permanent magnet and a soft-iron core with a copper winding (Fig. 1). The magnetic flux in the sensor changes as the teeth and gaps pass by, and a sinusoidal AC voltage is generated the amplitude of which increases sharply in response to higher engine (crankshaft) speeds. Adequate amplitude is already available from speeds as low as 50 min^{-1}.

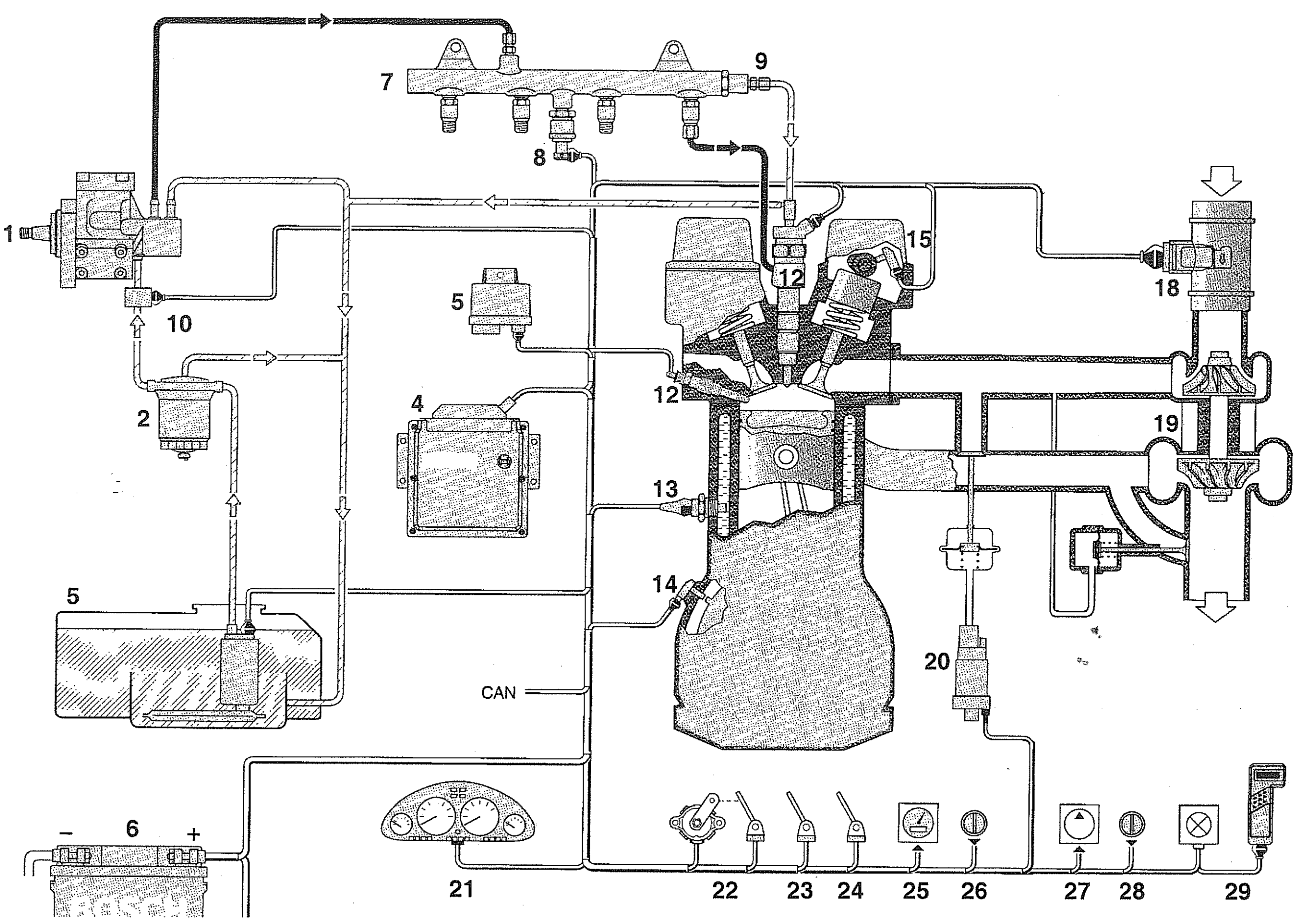
[Fig. 1]

Crankshaft-speed sensor

1. Permanent magnet
2. Housing
3. Engine crankcase
4. Shoft-iron core
5. Winding
6. Trigger wheel



[Fig. 12]



System overview of a Common Rail injection system and a variety of system components

1. High-pressure pump
2. Fuel filter
3. Fuel tank with preliminary filter and presupply pump
4. ECU
5. Glow control unit
6. Battery
7. High-pressure accumulator (rail)
8. Rail-pressure sensor
9. Pressure limiter valve
10. Fuel-temperature sensor
11. Injector
12. Sheathed-element glow plug
13. Coolant-temperature sensor
14. Crankshaft sensor
15. Camshaft sensor
16. Intake-air temperature sensor
17. Boost-pressure sensor (BPS)
18. Air-mass meter
19. Turbocharger
20. EGR positioner
21. Instrument panel with display for fuel consumption, engine speed etc.
22. Accelerator-pedal sensor
23. Brake contacts
24. Clutch switch
25. Road-speed sensor
26. Operator unit for vehicle-speed controller
27. Air-conditioner compressor
28. Air-conditioner operator unit
29. Diagnosis display with connection for diagnostic unit

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Camshaft-speed sensor

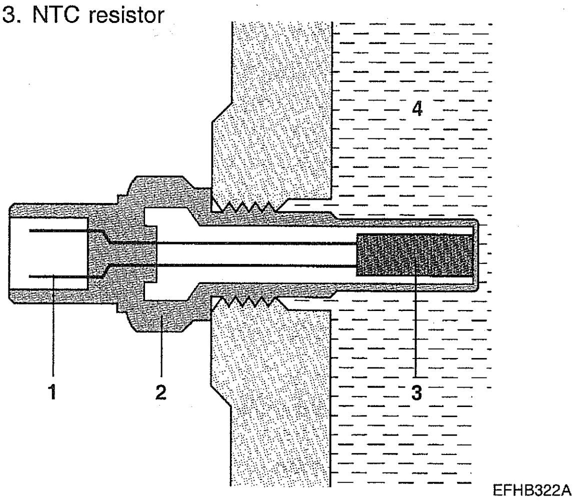
The camshaft controls the engine' s intake and exhaust valves. It turns at half the speed of the crankshaft. When a piston travels in the directions of TDC, the camshaft position determines whether it is in the compression phase with subsequent ignition, or in the exhaust phase. The information cannot be generated from the crankshaft position during the starting phase. During normal engine operation on the other hand, the information generated by the crankshaft sensor suffices to define the engine status. In other words, this means that if the camshaft sensor should fail while the vehicle is being driven, the ECU still receives information on the engine status from the crankshaft sensor.

The camshaft sensor utilises the Hall effect when establishing the camshaft position. A tooth of ferromagnetic material is attached to the camshaft and rotates with it. When this tooth passes the semiconductor wafers of the camshaft sensor, its magnetic field diverts the electrons in the semiconductor wafers at right angles to the direction of the current flowing through the wafers. This results in a brief voltage signal (Hall voltage) which informs the ECU that cylinder 1 has just entered the compression phase.

[Fig. 3]

Coolant-temperature sensor (schematic)

1. Electrical connections
2. Housing
3. NTC resistor



Temperature sensors

Temperature sensors are installed at a number of different points:

- In the coolant circuit, to establish engine temperature by way of the coolant temperature (Fig. 3),
- In the intake manifold to measure the temperature of the intake air,
- In the engine lube oil to measure the oil temperature (optional), and
- In the fuel-return line to measure the fuel temperature (optional).

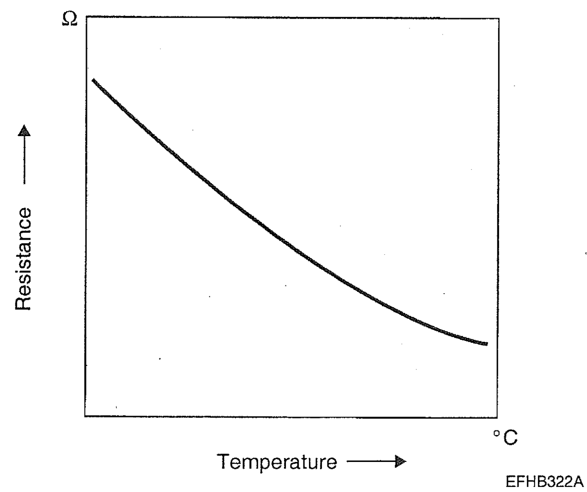
The sensors are equipped with a temperature-dependent resistor with a negative temperature coefficient (NTC) which is part of a voltage-divider circuit across which 5V are applied.
The voltage drop across the resistor is inputted into the ECU through an analog-to-digital converter (ADC) and is a measure for the temperature. A characteristic curve is stored in the ECU microcomputer which defines the temperature as a function of the given voltage value (Fig. 4).

Hot-film air-mass meter

Particularly during dynamic operation, precise compliance with the correct A/F ratio is imperative in order to comply with the exhaust-gas limits as stipulated by law. This necessitates the use of sensors which precisely register the air-mass flow actually being drawn in by the engine at a particular moment. This load sensor' s measuring accuracy must be completely independent of pulsation, reverse flow, EGR, variable camshaft control, and changes in the intake-air temperature.

[Fig. 4]

Characteristic curve of a temperature sensor (NTC)

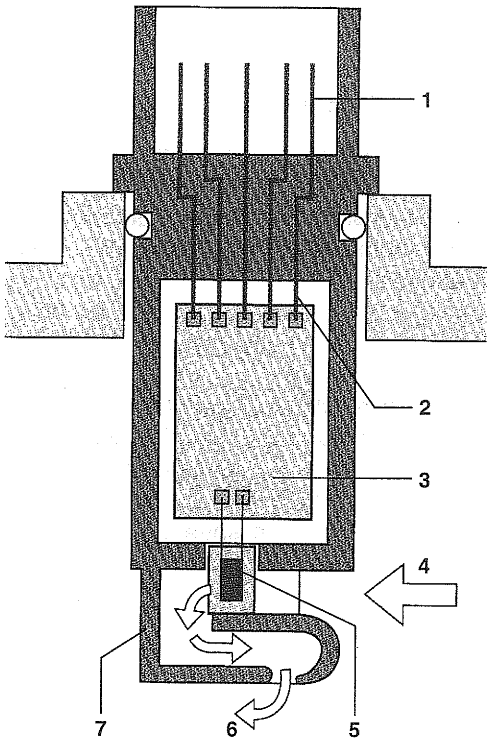


A hot-film air-mass meter was selected as being most suitable for complying with the above stipulations. The hot-film principle is based on the transfer of heat from a heated sensor element to the air-mass flow (Fig. 5). A micromechanical measuring system is utilised which permits registration of the air-mass flow and detection of flow direction. Reverse flows are also detected in case of strongly pulsating air flow.
The micromechanical sensor element is located in the plug-in sensor' s flow passage (Fig. 5,). The plug-in sensor can be installed in the air filter or in a measuring tube in the engine' s air intake duct.

[Fig. 5]

Hot-film air-mass meter (schematic)

1. Electrical connections
2. Internal connections
3. Evaluation electronics (hybrid circuit)
4. Air inlet
5. Sensor element
6. Air outlet
7. Housing



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There are a variety of different-sized measuring tubes available, depending upon the maximum air throughput reqauired by the engine. The signal voltage curve, as a function of the air mass flow, is divided into signal ranges for forward flow and reverse flow. In order to increase measuring accuracy, the measuring signal is referred to a reference voltage outputted by the engine management. The characteristic curve has been designed so that during diagnosis in the workshop and open circuit conductor, for instance, can be detected with the help of the engine management.
A temperature sensor can be incorporated for measuring the intake-air temperature.

Accelerator-pedal sensor

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 accelerator-pedal sensor and transmitted to the ECU (this is also known as drive-by wire).
A voltage is generated across the potentiometer in the accelerator-pedal sensor as a function of the accelerator-pedal setting. Using a programmed characteristic curve, the pedal' s position is then calculated from this voltage.

Boost-pressure sensor

The boost-pressure sensor (BPS) is pneumatically connected to the intake manifold and measures the intake manifold' s absolute pressure between 0.5 and 3 bar. The sensor is sub-divided into a pressure cell with two sensor elements, and a chamber for the evaluation circuit. The sensor elements and the evaluation circuit are mounted on a common ceramic substrate.
Each sensor element comprises a bell-shaped thick-film diaphragm, containing a reference volume with defined internal pressure. The diaphragm is displaced to a greater or lesser degree as a function of charge pressure.

Piezoresistive resistors are located on the diaphragm's surface whose resistance changes when mechanical stress is applied. These resistors are connected as a bridge so that when the diaphragm moves this causes a change in the bridge balance. This means that the bridge voltage is a measure for the boost pressure.
The evaluation circuit is responsible for amplifying the bridge voltage, compensating for temperature influences, and for linerization of the pressure characteristic. The evaluation circuit's output signal is inputted to the ECU where, with the help of a programmed characteristic curve, it is used for calculating the boost pressure.

ECU

Assignment and method of operation

The ECU evaluates the signals it receives from the external sensors and limits them to the permissible voltage level.
From this input data, and from stored characteristic maps, the ECU microprocessors calculate the injection times and the instants of injections, and convert these times to signal characteristics which are adapted to the movements of the engine pistons and crankshaft. The specified accuracy and the engine's high dynamic response demands high levels of computing power.
The output signals from the ECU microprocessors are used to trigger driver stages which provide adequate power for switching the actuators rail-pressuresure control and element switch-off. In addition, actuators for engine function are triggered (e.g. EGR actuator, boost-pressure actuator, and the relay for the electric fuel pump), as well as those for further auxiliary functions such as blower relay, auxilary-heater relays, glow relay, air-conditioner). The driver stages are proof against short-circuit and destruction due to brief electrical overloading. Errors of this type, and open-circuit or unplugged lines, are reported to the microprocessor. Diagnosis functions in the injector driver stages detect faulty signal characteristics, and in addition a number of the output signals are transferred via interfaces for use in other systems in the vehicle. And within the framework of a special safety concept, the ECU monitors the complete fuel-injection system.
Injector triggering places particularly heavy demands on the driver stages. In the injector, the current from the driver stage generates a magnetic force in the triggering element which is applied to the injector's high-pressure system. In order to ensure very tight tolerances, and high reproducibility of the injected fuel quantity, this coil must be triggered with steep current flanks. This necessitates high voltages being made available in the ECU.
A current control circuit divides the energisation time (injection time) into a pickup-current phase and a hold phase. It must operate so accurately that the injector guarantees reproducible injection under all operating conditions. In addition, it must reduce the power loss in the ECU and the injectors.

Operating conditions

High demands are made upon the ECU regarding
- The surrounding (ambient) temperatures (in normal cases from -40 ... +85° C),
- The resistance to fuels and lubricants etc.,
- The resistance to humidity, and
- Mechanical loading.

Very high demands are also made upon electromagnetic compatibility (EMC) and upon the radiation of HF interference signals.

Design and construction

The ECU has a metal housing. The sensors, the actuators, and power supply are connected to the ECU through a multi-pole plug-in connector.
The power components which directly trigger the actuators are integrated in the ECU in such a manner that they can efficiently dissipate their heat to the ECU housing. Both sealed and non-sealed versions of the ECU are available.

Operating-state control

In order that the engine operates with optimum combustion in every operating state, the ECU in each case calculates the appropriate injected fuel quantity. In the process, a number of parameters must be taken into account (Fig. 6).

Start quantity

For starting, the injected fuel quantity is calculated as a function of temperature and cranking speed. The start quantity is injected from the moment the starting switch is turned to “Start" (Fig. 6, Pos. A) until the engine has reached a given minimum speed. The driver has no influence upon the start quantity.

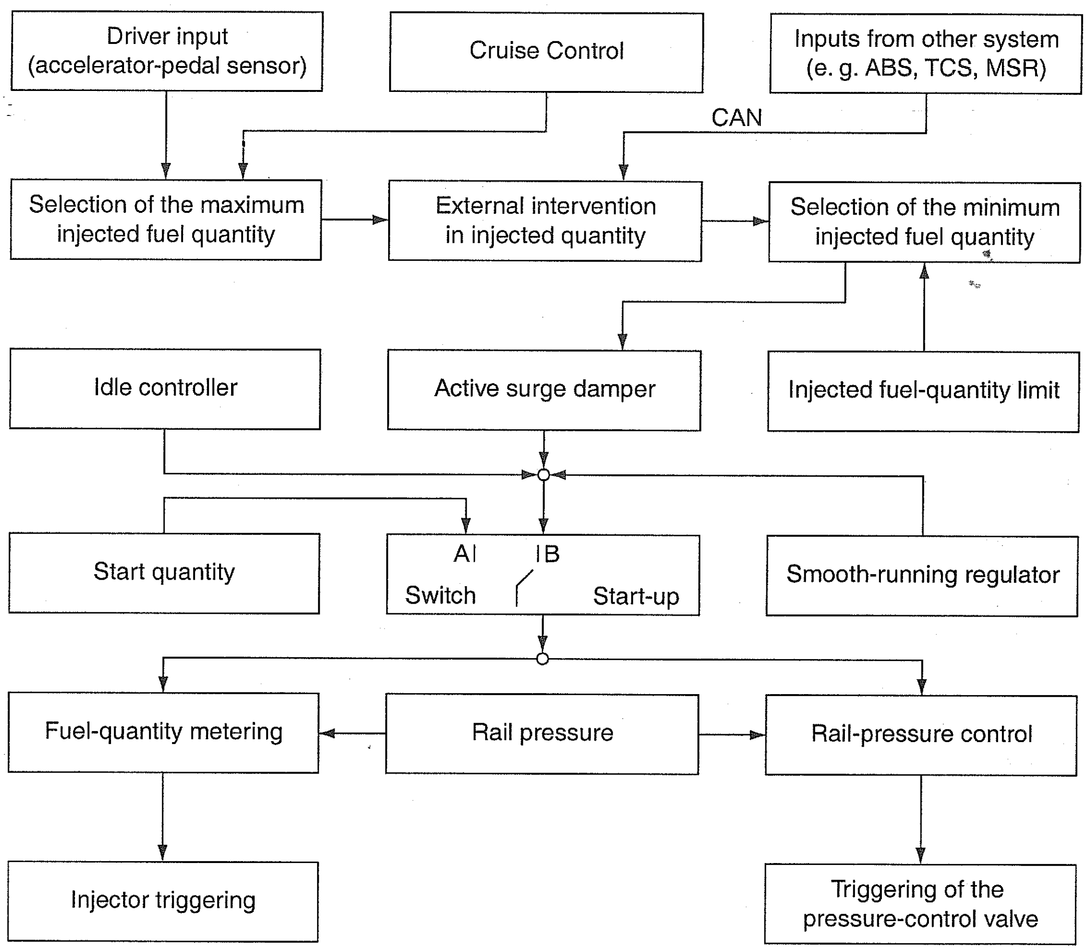
Drive mode

When the vehicle is being driven normally (Fig. 6, stating switch in Pos. B), the injected fuel quantity is calculated from the accelerator-pedal setting (accelerator-pedal sensor) and the engine speed. Calculation utilises the driving map so that the driver input and the engine O.P power are optimally matches to each other.

[Fig. 6]

Calculation in the ECU of the injected fuel quantity

Starting-switch position A : Start
Starting-switch position B : Drive mode



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Idle-speed control

At idle, fuel consumption depends for the most part on engine efficiency and idle speed. Since a considerable portion of a vehicle's fuel consumption in dense traffic conditions is attributable to this operating state, it is obvious that idle speed must be kept to a minimum. The idle speed though, must be set so that no matter what the operating conditions, it does not drop so far under load that the engine runs roughly or even stops. This applies for instance when the vehicle electrical system is loaded, when the air-conditioner is switched on, when a gear is engaged on an automatic transmission, or when the power steering is in operation. In order to regulate to the desired idle speed, the idle controller varies the injected fuel quantity until the actual engine speed equals the desired idle speed. Here, the desired idle speed and the control characteristic are influenced by the selected gear and by the engine temperature (coolant-temperature sensor). In addition to the external load moments must also be taken into account and compensated for by the idle-speed control. These change minimally but steadily throughout the vehicle's service life, as well as being highly dependent upon temperature.

Smooth-running control

Due to mechanical tolerance and ageing, there are differences in the torques generated by the engine's individual cylinders. This leads to rough or irregular running, particularly at idle. The smooth-running (cylinder-balancing) control measures the engine-speed changes every time a cylinder has "fired" and compares them with each other. The injected fuel quantity of reach cylinder is then adjusted in accordance with the measured differences in engine speed between the individual cylinders, so that each cylinder makes the same contribution to the torque generated by the engine. The smooth-running control is only operative in the lower engine-speed range.

Vehicle-speed controller

The vehicle-speed controller (Cruise Control) comes into operation when the vehicle is to be driven at a constant speed. It controls the vehicle speed to that inputted by the driver at the operator unit in the instrument panel.
The injected fuel quantity is increased or reduced until the actual speed equals the set speed. While the Cruise Control is in operation, the control process is interrupted if the driver depresses the clutch, or applies the brakes. If the accelerator pedal is pressed, the vehicle can be accelerated beyond the speed which has been set with the Cruise Control.

As soon as the accelerator pedal is released, the Cruise Control regulates the speed back down again to the previous set speed. Similarly, if the Cruise Control has been switched off, the driver only needs to press the reactivate key in order to again select the last speed which had been set.

Controlling the injected fuel quantity limit

There are a number of reasons why the fuel quantity desired by driver (or the maximum physically possible quantity) must not be injected.
These include:
- Excessive pollutant emissions,
- Excessive soot emissions,
- Mechanical overloading due to excessive torque or engine speed, or
- Thermal overload as a result of excessive coolant, lube-oil, or turbocharger temperature.

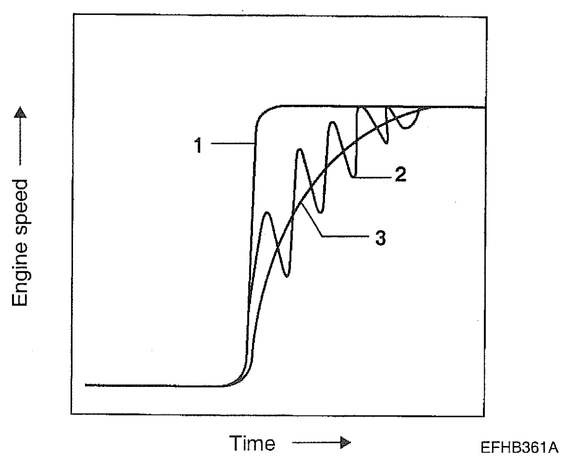
The limit for the injected fuel quantity is formed from a number of input variables, for instance intake air mass, engine speed, and coolant temperature.

Active surge-damping control

When the accelerator pedal is abruptly depressed or released, this causes the injected fuel quantity to change rapidly with the result that there is also a rapid change in the torque developed by the engine. These abrupt load changes lead to the resilient engine mountings and the drivertrain generating bucking oscillations which result in fluctuations of engine speed (Fig. 7).

[Fig. 7]

Active surge damper
1. Sudden accelerator-pedal movement (driver input)
2. Engine-speed curve without active surge-damping control
3. With active surge-damping control



The active surge-damper reduces these periodic speed fluctuations by varying the injected fuel quantity at the same frequency as the periodic speed fluctuations:
Less fuel is injected when the speed increases, and more when it decreases.
This effectively damps the surge movements.

Engine switch off

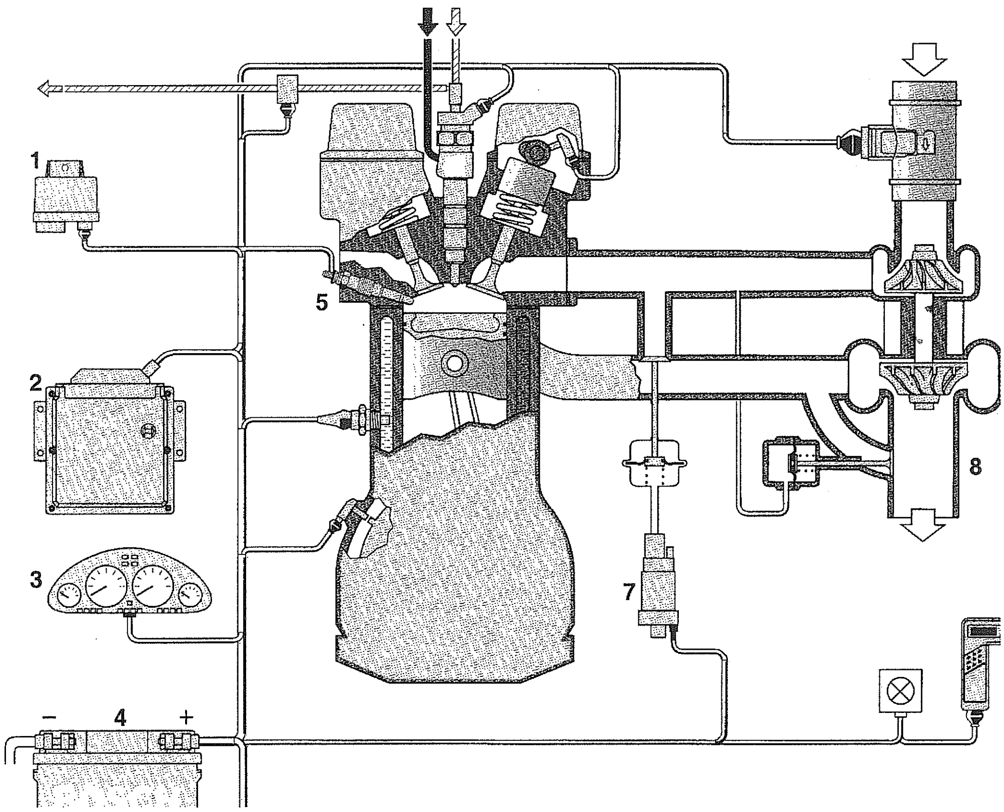
The diesel engine operates according to the "auto-ignition" principle. This means that it can only be switched off by interupting its supply of fuel.
In the case of the "Electronic Diesel Control (EDC)", the engine is switched off by ECU stipulating "injected fuel quantity zero". The system also features a number of additional (redundant) switch-off paths.

ACTUATORS (FIG.8)

Injector

Special injectors with hydraulic servo system and electrical triggering element (solenoid valve) are used with the Common Rail system in order to achieve efficient start of injection and precise injected fuel quantity. At the start of injection, a high pickup current is applied to the injector so that the solenoid valve opens quickly. As soon as the nozzle needle has travelled its complete stroke, and the nozzle has opened completely, the energizing current is reduced to a lower holding value. The injected fuel quantity is now defined by the injector opening time and the rail pressure. Injection is terminated when the solenoid valve is no longer triggered and closes as a result

[Fig. 8]



High-pressure pump (schematic, longitudinal section)

1. Glow control unit
2. ECU
3. Instrument panel with displays for fuel consumption, engine speed etc.
4. Battery
5. Glow plug
6. Injector
7. EGR positioner
8. Charge-pressure actuator
9. Vacuum pump
10. Turbocharger

EFHB371A

Pressure -control valve

The ECU uses the pressure-control valve to control the rail pressure. When the pressure-control valve is triggered, the energized electromagnet forces the armature up against the seal seat and the valve closes. The high-pressure and low-pressure side are sealed off from each other and the rail pressure increases.
In the non-energized mode, the electromagnet no longer exerts force on the armature and the pressure-control valve opens so that some of the fuel from the rail can flow back to the tank through a collector line. The rail pressure drops.
It is possible to vary the pressure by pulsing (pwm) the triggering current. The degree to which the pressure-control valve is opened or closed depends on the pulse rate (duty cycle).

Glow control unit

The glow control unit is responsible for ensuring efficient cold starting. It also shortens the warm-up period, a fact which is highly relevant for exhaust emissions. The preheating time is a function of the coolant temperature. The further glow phases during engine start or when the engine is actually running are determined by a number of parameters which include engine speed and injected fuel quantity. Glow control utilises a power relay.

INTEGRATED DIAGNOSIS

Sensor monitoring

For sensor monitoring, the integrated diagnosis facility checks whether they are being supplied with power, and whether their O/P signals are plausible (within the permitted range, e.g. temperature between -40 und 150° C). Where possible, the redundancy principle is applied for important signals. That is, in case of malfunction a switch is made to another similar signal.

Monitoring module

In addition to the microcontroller, the ECU also incorporates a monitoring module.
The ECU and the monitoring module monitor each other. If a malfunction is detected, either of them can switch off the injection independent of the other.

Malfunction detection

Malfunction detection is only possible within the monitoring range of a given sensor. A signal path is classified as faulty when an error is present for longer than a predefined period. In such cases, the error is stored in the ECU's error memory together with details of the environmental conditions which prevailed when the error/malfunction occurred (e.g. coolant temperature, engine speed etc.). For a large number of errors/malfunctions, it is possible for the "OK again" status to be established. Here, the signal path must be identified as intact for a defined period of time.

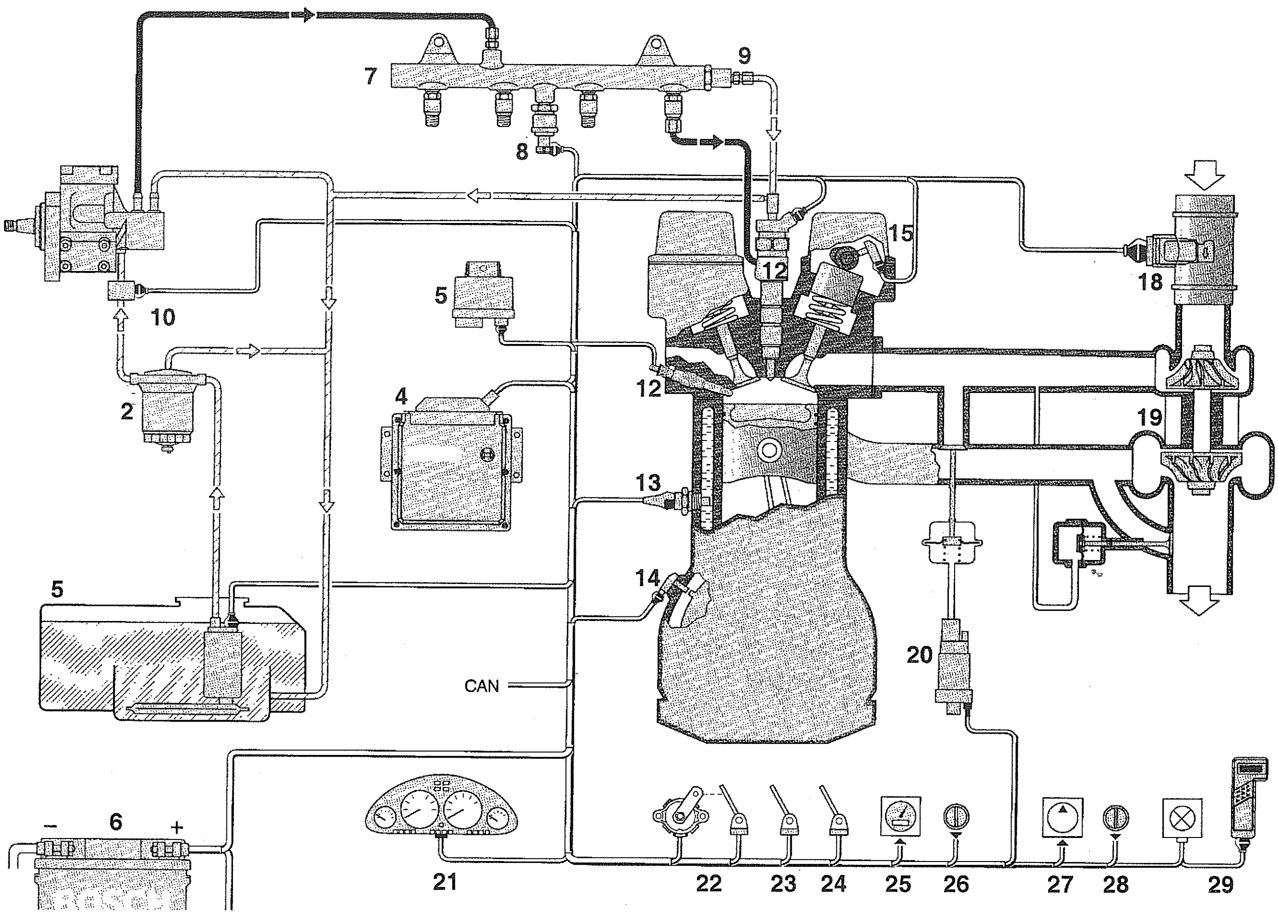
Error procedure

If a sensor' s permitted output-signal range is violated, a switch is made to a substitute value. This procedure is applied for the following input signals:

- Battery voltage,
- Coolant, air, and lube-oil temperature,
- Charge-air pressure,
- Atmospheric pressure and intake-air quantity.

In addition, in case of non-plausible signals from the accelerator-pedal sensor and/or the brakes, a substitute accelerator-pedal sensor signal is applied.

[Fig. 12]



System overview of a Common Rail injection system and a variety of system components

1. High-pressure pump
2. Fuel filter
3. Fuel tank with preliminary filter and presupply pump
4. ECU
5. Glow control unit
6. Battery
7. High-pressure accumulator (rail)
8. Rail-pressure sensor
9. Pressure limiter valve
10. Fuel-temperature sensor
11. Injector
12. Sheathed-element glow plug
13. Coolant-temperature sensor
14. Crankshaft sensor
15. Camshaft sensor
16. Intake-air temperature sensor
17. Boost-pressure sensor (BPS)
18. Air-mass meter
19. Turbocharger
20. EGR positioner
21. Instrument panel with display for fuel consumption, engine speed etc.
22. Accelerator-pedal sensor
23. Brake contacts
24. Clutch switch
25. Road-speed sensor
26. Operator unit for vehicle-speed controller
27. Air-conditioner compressor
28. Air-conditioner operator unit
29. Diagnosis display with connection for diagnostic unit

EFHB411A

ELECTRONIC DIESEL CONTROL - EDC

TECHNICAL REQUIREMENTS

The reduction of fuel consumption along with an increase in power output or torque, are the decisive factors behind present-day developments in the diesel fuel-injection field. In the past years this has led to an increase in the use of direct-injection (DI) diesel engines. Compared to prechamber or whirl-chamber engines, the so-called indirect-injection (IDI) engines, the DI engine operates with far higher injection pressures. This leads to improved mixture formation, and fuel combustion is more complete.
In the DI engine, the improved mixture formation and the fact that there are no overflow losses between prechamber/whirl chamber and the main combustion chamber results in a fuel-consumption reduction of 10...15% compared to the IDI engine.
In addition, modern-day engines are subject to more severe requirements with regard to exhaust-gas and noise emissions.
This has led to higher demands being made on the injection system and its control:

- High injection pressures,
- Structured rate-of-discharge curve,
- Variable start of injection,
- Pilot injection,
- Adaptation of injected fuel quantity, boost pressure, and injected fuel quantity to the given operating state,
- Temperature-dependent start quantity,
- Load-independent idle-speed control,
- Cruise control,
- Closed-loop-controlled exhaust-gas recirculation (EGR), and
- Reduced tolerances and higher accuracy throughout the vehicle' s useful life.

Conventional mechanical (flyweight) governors use a number of add-on devices to register the various operating conditions, and ensure that mixture formation is of high quality. Such governors, though, are restricted to simple open-loop control operations at the engine, and there are many important actuating variables which they cannot register at all or not quickly enough.

SYSTEM OVERVIEW

In the past years, the marked increase in the computing power of the micro-controllers available on the market has made it possible for the EDC (Electronic Diesel Control) to comply with the above-named stipulations.
In contrast to diesel-engined vehicles with conventional in-line or distributor injection pumps, the driver of an EDC controlled vehicle has no direct influence, for instance through the accelerator pedal and Bowden cable, upon the injected fuel quantity. On the contrary, the injected fuel quantity is defined by a variety of actuating variables, e.g. operating state driver input, pollutants emission, etc. This of course means that an extensive safety concept must be implemented that detects errors and malfunctions and, depending upon their severity, initiates appropriate countermeasures (e.g. limitation of torque, or emergency (limp-home) running in the idle-speed range) EDC also permits the exchange of data with other electronic systems in the vehicle (e.g. with the traction control system (TCS), and with the electronic transmission-shift control). This means that it can be integrated in the overall vehicle system.

EDC DATA PROCESSING

Input signals

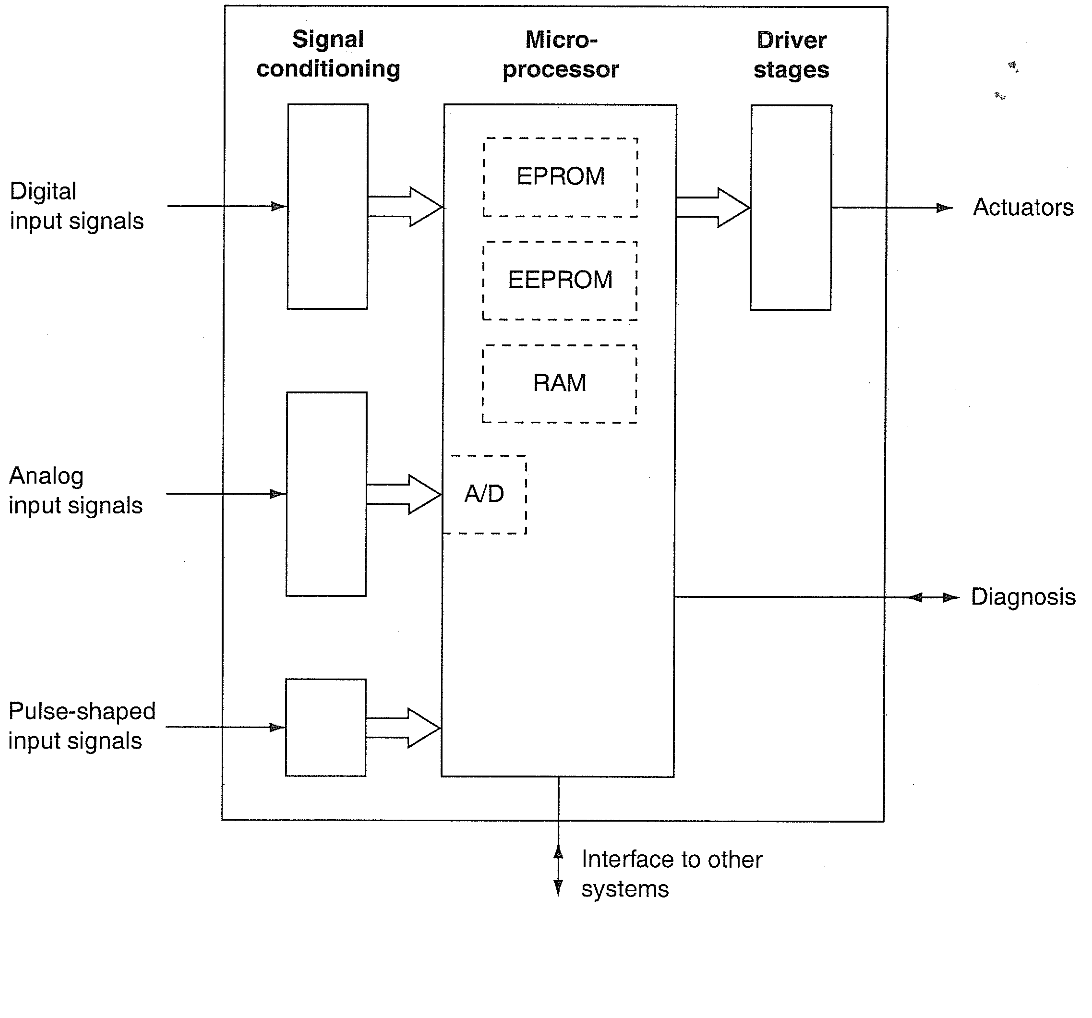
Together with the actuators, the sensors represent the interface between the vehicle and its data-processing unit the ECU.
The signals from the sensors are passed to the ECU (or to several ECU' s) via protective circuitry and, where necessary, via signal transducers and amplifiers (Fig. 1):

- Analog input signals (e.g. information from analog sensors on the quantity of air drawn in by the engine, engine and intake-air temperatures, battery voltage, etc.) are converted to digital values by an A/D converter in the ECU microprocessor.
- Digital input signals (e.g. On/Off switching signals, or digital sensor signals such as the rotational-speed pulses from a Hall sensor) acan be processed directly by the microprocessor.
- In order to suppress interference pulses, the pulse-shaped input signals from inductive sensors which carry information on engine speed and reference mark are conditioned by a special circuit in the ECU and converted to square-wave from.

Depending upon the level of integration, signal conditioning can take place completely or partially in the sensor. The operating conditions encountered at its installation point determine the sensor' s loading.

[Fig. 1]

Signal processing in the ECU



SIGNAL CONDITIONING

Protective circuitry is used to limit the incoming signals to a maximum voltage level. The effective signal is freed almost completely of superimposed interference signals by means of filtering, and is then amplified to match it to the ECU input voltage.

SIGNAL PRESSING IN THE ECU

The ECU microprocessors (Fig. 1) mostly process the input signals digitally, and therefore need a special program. This is stored in a Read Only Memory (ROM or Flash-EPROM).

In addition, engine-specific curves and engine-management maps are stored in a Flash-EPROM. Immobilizer data, calibration and manufacturing data, as well as data on errors/malfunctions which may have occurred during operation are stored in a non-volatile read/write memory (EEPROM).
Due to the large number of engine and equipment variants, the ECU' s are provided with a so-called variant code. Using this code, a selection of the maps stored in the Flash-EPROM takes place at the manufacturer or in the workshop, in order to provide the specific functions required for the vehicle variant in question. This selection is also stored in the EEPROM.
Other ECU variants are designed so that complete data sets can be programmed into the Flash-EPROM at the end of vehicle production. This reduces the number of different ECU types required by the vehicle manufacturer.

A volatile random access memory (RAM) is needed to store variable data such as calculations data and signal values. In order to function correctly, the RAM requires a permanent power supply. In other words, it loses its complete data stock when the ECU is switched off via the ignition switch or when the vehicle battery is disconnected. In such cases, the adaptation values (values which have been learnt regarding engine and operating conditions) would have to be re-established when the ECU is switched on again. To prevent this, the adaptation values are stored in an EEPROM and not in a RAM.

OUTPUT SIGNALS

With their output signals, the microprocessors trigger output stages which usually are powerful enough for direct connection to the actuators. The triggering of the individual actuators is dealt with in the particular system decription. These output stages are proof against short-circuit to ground or to battery voltage, as well as against destruction due to electrical overload. Such faults are recognized by the output stages and reported to the microprocessor. This also applies to conductor open-circuits.
In addition, a number of the output signals are transmitted through interfaces to other systems in the vehicle.

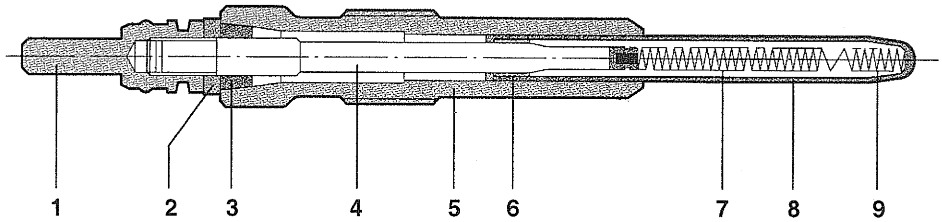
START-ASSIST SYSTEMS

Sin leakage and heat losses reduce the pressure and the temperature of the A/F mixture at the end of the compression stroke, the diesel engine is more difficult to start and the mixture more difficult to ignite than it is when hot. These facts make it particularly important that start-assist systems are used. The minimum starting temperature depends upon the engine type. Pre-chamber and swirl-chamber engines are equipped with a sheathed-element glow plug (GSK) in the auxiliary combustion chamber which functions as a "hot spot". On small direct-injection (DI) engines, this "hot spot" is located on the combustion chamber' s periphery. Large DI truck engines on the other hand have the alternative of using air preheating in the intake manifold (flame start) or special, easily ignitable fuel (Start Pilot) which is sprayed into the intake air. To day, the start-assist systems use sheathed-element glow plugs practically without exception.

SHEATHED-ELEMENT GLOW PLUG

The sheathed-element glow plug' s tubular heating element is so firmly pressed into the glow-plug shell that a gas-tight seal is formed. The element is a metal tube which is resistant to both corrosion and hot gases, and which contains a heater (glow) element embedded in magnesium-oxide powder (Fig. 1). This heater element comprises two series-connected resistors: the heater filament in the glow-tube tip, and the control filament. Whereas the heater filament maintains virtually constant electrical resistance regardless of temperature, the control filament is made of material with a positive temperature coefficient (PTC). On newer-generation glow plugs (GSK2), its resistance increases even more rapidly with rising temperature than was the case with the conventional S-RSK glow plug. This means that the newer GSK2 glow plugs are characterized by reaching the temperature needed for ignition far more quickly (850°C in 4s). They also feature a lower steady-state temperature (Fig. 2) which means that the glow plug' s temperature is limited to a non-critical level. The result is that the GSK2 glow plug can remain on for up to 3 minutes following engine start. This post-glow feature improves both the warm-up and run-up phases with considerable improvements in noise and exhaust-gas emissions.

[Fig. 1]



Sheathed-element glow plug GSK2

1. Electrical connector terminal
2. Insulating washer
3. Double gasket
4. Terminal pin
5. Glow-plug shell
6. Heater seal
7. Heater and control filament
8. Glow tube
9. Filling power

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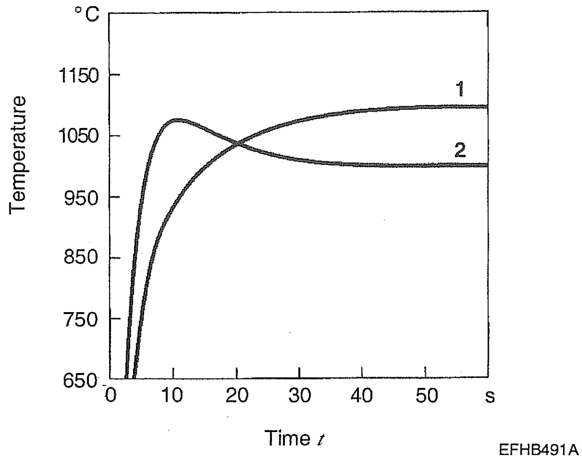
[Fig. 2]

Sheathed-element glow plugs: Temperature-time diagram

1. S-RSK
2. GSK2



FLAME GLOW PLUG

The flame glow plug burns fuel to heat the intake air. Normally, the injection system' s supply pump delivers fuel to the flame plug through a solenoid valve. The flame plugs' s connection fitting is provided with a filter, and a metering device which permits passage of precisely the correct amount of fuel appropriate to the particular engine. This fuel then evaporates in an evaporator tube surrounding the tubular heating element and mixes with the intake air. The resulting mixture ignites on the 1000° C heating element at the flame-plug tip.

GLOW CONTROL UNIT

For triggering the glow plugs, glow control unit (GZS) is provided with a power relay and a number of electronic switching blocks. These, for instance, control the glow duration of the glow plugs, or have safety and monitoring functions. Using their diagnosis functions, more sophisticated glow control units are also able to recognise the failure of individual glow plugs and inform the driver accordingly. Multiple plugs are used as the control inputs to the ECU. In order to avoid voltage drops, the power supply to the glow plugs is through suitable threaded pins or plugs.

FUNCTIONAL SEQUENCE

The diesel engine' s glow plug and starter switch, which controls the preheat and starting sequence, functions in a similar manner to the ignition and starting switch on the spark-ignition (SI) engine. Switching to the " ignition on" position starts the preheating process and the glow-plug indicator lamp lights up. This extinguishes to indicate that the glow plugs are hot enough for the engine to start, and cranking can begin. In the following starting phase, the droplets of injected fuel ignite in the hot, compressed air. The heat released as a result leads to the initiation of the combustion process (Fig. 3).

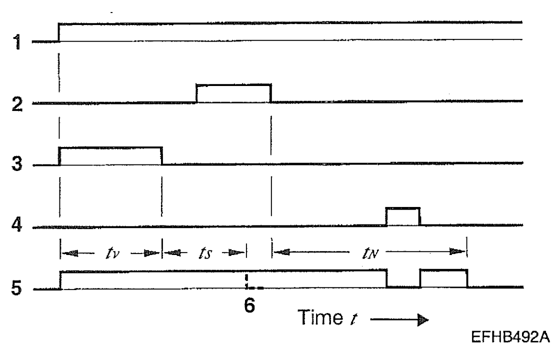
In the warm-up phase following a successful start, post-heating contributes to faultless engine running (no mis-firing) and therefore to practically smokeless engine run-up and idle. At the same time, when the engine is cold, preheating reduces combustion noise. A glow-plug safety switchoff prevents battery discharge in case the engine cannot be started.

The glow-control unit can be coupled to the ECU of the Electronic Diesel Control (EDC) so that information available in the EDC control unit can be applied for optimum control of the glow plugs in accordance with the particular operating conditions. This is yet another possibility for reducing the levels of blue smoke and noise.

[Fig. 3]

Typical preheating sequence

1. Glow-plug and starter switch
2. Starter
3. Glow-plug indicator lamp
4. Load switch
5. Glow plugs
6. Self-sustained engine operation, t_V Pre-heating time, ts Ready to start, t_N Post-heating time



GENERAL

SPECIFICATION

Input sensors	
Mass air flow sensor	HFM5 (Hot Film Sensor)
Intake air temperature sensor	Thermistor type
Resistance	2.22 ~ 2.82kΩ at 20°C (68°F)
	0.299 ~ 0.357kΩ at 80°C (176°F)
Engine coolant temperature sensor	Thermistor type
Resistance	2.31 ~ 2.59kΩ at 20°C (68°F)
	0.314 ~ 0.331kΩ at 80°C (176°F)
Vehicle speed sensor	Hall effect type
Camshaft position sensor	Hall effect type
Crankshaft position sensor	Hall effect type
Accel position sensor	Variable resistor type
Fuel pressure sensor	Piezo electricity type
Fuel temperature sensor	Thermistor type
Resistance	2.27 ~ 2.73kΩ at 20°C (68°F)
	0.322 ~ 0.298kΩ at 80°C (176°F)
Fuel tank capacity	SM : 65 liter
	FO : 65 liter
	XD : 55 liter
Fuel filter	High pressure type
Fuel pump	Electrical, in-tank type
Driven by	Electric motor
Fuel pressure at high pressure side	1350 bar.
Injectors	Electromagnetic type

SEALANT

Engine coolant temperature sensor	LOCTITE 962T or equivalent

SERVICE STANDARD

Curb idle speed (rpm)	N-range	A/CON: OFF	750 ± 40	SM
		A/CON: ON	750 ± 40	
	N-range	A/CON: OFF	780 ± 40	FO
		A/CON: ON	780 ± 40	
	N-range	A/CON: OFF	750 ± 40	XD
		A/CON: ON	800 ± 40	

TIGHTENING TORQUES

Item	Nm	Kg.cm	lb.ft
Delivery pipe (Common Rail) installation	18 - 23	180 - 230	12.6 - 15.4
Engine coolant temperature sensor	20 - 40	200 - 400	14 - 29
Throttle body - nut flange	7 - 11	70 - 110	4.9 - 9.9
Throttle body - bolt flange	4 - 6	40 - 60	2.8 - 4.2
Fuel filter mounting bolts	9 - 14	90 - 140	6.5 - 10
Accelerator arm bracket bolts	8 - 12	80 - 120	5.8 - 8.7
Pipe from rail to Injector 1/2/3/4	18 - 22	180 - 220	12.6 - 15.4
Rail pressure sensor	33 - 37	330 - 370	23.1 - 25.9
Clamp bolt for Injector	25 - 29	250 - 290	17.5 - 20.3
Retaining bolt for high pressure pump	13 - 18	130 - 180	9.1 - 12.6
Flang bolt - EGR Sonenoid valve	7 - 11	70 - 110	4.9 - 7.7
Self locking nut - EGR valve gasket	25 - 30	250 - 300	17.5 - 21
Bolt - EGR pipe gasket	20 - 30	200 - 300	14 - 21
CMP sensor mounting bolt	4 - 6	40 - 60	2.8 - 4.2
High pressure pump - bolt	13 - 18	130 - 180	9.1 - 12.6
CKP - bolt	4 - 6	40 - 60	2.8 - 4.2
Oil pressure switch	15 - 26	150 - 260	10.5 - 18.2

TROUBLESHOOTING

FUEL INJECTION SYSTEM

Symptom	Probable cause	Remedy
Engine does not start	Cranking speed too low	Repair starting system or charge or replace battery so that engine cranks at a minimum of 150 rpm.
	No voltage at fuel cut-off solenoid on injection pump	Check for voltage with test light. If necessary, replace fuse or faulty wires.
	Fuel cut-off solenoid on injection pump loose or faulty	Tighten solenoid. Check that solenoid clicks when key is turned off and on. Replace faulty solenoid.
	No voltage at glow plug bus	If test light shows no voltage at bus with key at "ON" position, test relay and wiring.
	Glow plug faulty	Test and, if necessary, replace glow plug.
	Air in fuel system	Bleed fuel system.
	Injection pump not delivering fuel	If no fuel emerges from a loosenes injection pipe during cranking, check timing belt and fuel supply from filter.
	Injection pipes misconnected	Connect pipes in correct location
	Injection timing incorrect	Adjust injection timing.
	Faulty injection	Check and, if necessary, replace injectors.
	Engine mechanical faults, as described earlier under this heading	Test compression and, if necessary, repair engine.
	Faulty injection pump	Try to start engine with new pump installed. If necessary, replace pump permanently. Check and, if necessary, adjust the idle speed.
Idle speed incorrect of idle rough or irregular	Idle speed incorrectly adjusted	Check that accelerator lever on pump is not loose, then adjust accelerator cable.
	Accelerator control binding	Replace hose of secure with clamps, bleed air from system.
	Loose fuel hose between filter and injection pump	Tighten, if necessary, and repair.
	Air in fuel system	Bleed fuel system.

Symptom	Probable cause	Remedy
Idle speed incorrect of idle rough or irregular	Inadequate fuel supply owing to clogged fuel filter, or fuel return line and injection pipes leaking, dirty, kinked, or squeezed at connections	Inspect and, if necessary, replace lines and hoses or replace fuel filter
	Faulty injection	Check and, if necessary, repair or replace injection injectors.
	Injection timing incorrect	Adjust injection timing.
	Engine mechanical faults, as described earlier under this heading	Test compression and, if necessary, repair engine.
	Faulty injection pump	Try engine at idle with new pump installed. If necessary, replace pump permanently.
	Engine lugging in too high a gear	Observe correct shift speeds.
Smoky exhaust (black, blue or white)	Engine not reaching correct operating temperature	Check and, if necessary, replace cooling system thermostat.
	Maximum rpm incorrect	Check and, if necessary, replace injection pump.
	Faulty injection nozzles	Check and, if necessary, repair or replace injection nozzles.
	Injection timing incorrect	Adjust injection timing.
	Restricted exhaust system	Check exhaust system for dents and obstructions
	Engine mechanical faults, as described earlier under this heading	Test compression and, if necessary, repair engine.
	Faulty injection pump	Observe exhaust with new pump installed if necessary, replace pump permanently.
Poor power output, slow acceleration (speedometer accurate, clutch not slipping)	Injection pump accelerator lever loose or not reaching maximum rpm adjusting screw	Tighten lever, check that accelerator pedal travel is not restricted, then adjust accelerator cable.
	Maximum rpm incorrect	Check and, if necessary, replace injection pump.
	Air cleaner filter dirty	Clean or replace air cleaner filter.
	Inadequate fuel supply owing to clogged fuel filter, or fuel return line and injection pipes leaking, dirty, kinked, or squeezed at connections	Inspect and, if necessary, replace lines and hoses, replaced fuel filter.
	Air in fuel system	Bleed fuel system.

Symptom	Probable cause	Remedy
Poor power output, slow acceleration (speedometer accurate, clutch not slipping)	Ice or solidified wax in fuel lines. (winter time only)	Move car to a warm garage until ice or wax has become liquid, then bleed fuel system.
	Faulty injection nozzles	Check and, if necessary, repair or replace injection nozzles.
	Injection timing incorrect	Adjust injection timing.
	Engine mechanical faults, as described earlier under this heading	Test compression and, if necessary, repair engine.
	Faulty injection pump	Check acceleration and speed with new pump installed. If necessary, replace pump permanently.
Excessive fuel consumption	Air cleaner filter dirty	Clean or replace air cleaner filter
	Fuel leaks	Check and, if necessary, replace or tighten all pipes, hoses and connections.
	Return pipe and hose blocked	Check return line for kinks and dents. Replace faulty lines. If line is clogged, blow it out with compressed air, then bleed fuel system.
	Idle speed too fast or maximum rpm too high	Check and, if necessary, adjust idle speed or replace injection pump.
	Faulty injection nozzles	Check and, if necessary, repair or replace injection nozzles.
	Injection timing incorrect	Adjust injection timing.
	Engine mechanical faults, as described earlier under this heading	Test compression and, if necessary, repair engine.
	Faulty injection pump	Check fuel consumption with new pump installed, if unnecessary, replace pump permanently.

ENGINE CONTROL

Symptom	Probable cause	Remedy
Excessive accelerator pedal effort required (Incomplete pedal return included)	Rusty pedal arm	Clean and lubricate
	Incorrect routing	Ensure bending radius of 150mm or more and correct excessively bent portion
	Rusty cable	Replace
	Shift throttle cable	Lubricate link and shaft
Broken accelerator control cable	Binding cable end	Remove rust and burrs from cable end
	Incorrect perpendicularity of cable end mounting point	Correct ends on the lever side
	Incorrect perpendicularity between cable end and cable	Correct or replace parts
Engine does not stop	Faulty starting switch operation	Correct or replace part
	Broken harness between starting switch and fuel cut solenoid	Replace harness

TROUBLESHOOTING

Trouble condition	Probable cause	Remedy
Engine will not crank	Battery charge low	Charge or replace battery
	Battery cables loose, corroded or worn	Repair or replace cables
	Transaxle range switch faulty (Vehicle with automatic transaxle only)	Adjust or replace switch
	Fusible link blown	Replace fusible link
	Starter motor faulty	Repair starter motor
	Injector switch faulty	Replace Injectors
Engine cranks slowly	Battery charge low	Charge or replace battery
	Battery cables loose, corroded or worn	Repair or replace cables
	Starter motor faulty	Repair starter motor
Starter keeps running	Starter motor faulty	Repair starter motor
	Starter switch faulty	Replace ignition switch
Starter spins but engine will not crank	Short in wiring	Repair wiring
	Pinion gear teeth broken or starter motor faulty	Repair starter motor
	Ring gear teeth broken	Replace flywheel ring gear or torque converter

FUEL TANK AND FUEL LINE

Symptom	Probable cause	Remedy
Engine malfunctions due to insufficient fuel supply	Bent or kinked fuel pipe or hose	Repair or replace
	Clogged fuel pipe or hose	Clean or replace
	Clogged fuel filter of in-tank fuel filter	Replace
	Water in fuel filter	Replace the fuel filter or clean the fuel tank and fuel lines
	Dirty or rusted fuel tank interior	Clean or replace
	Malfunctioning fuel pump (Clogged filter in the pump)	Replace
When the fuel filter warning lamp illuminates	Water has accumulated in the fuel filter	Remove the water accumulated in the fuel filter as below - Unscrew the mounting bolt on the fuel filter and raise fuel filter up (for SM) - Loosen the drair plug at the bottom of the fuel filter - Tighten the drain plug when water no longer comes out

TROUBLESHOOTING GUIDE CHART

Trouble symtoms / Check items	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 smothly, 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						

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 smothly, 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 In-mani. Leaking			6				13		

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 componenet (compression, valve clearance...)			7	7				
ECU defective					5			
TDC sensor								
Water Temp. Sensor	8	2	6	3			5	3
Loss of coolant				6				
Glow-plug system								

TROUBL-3

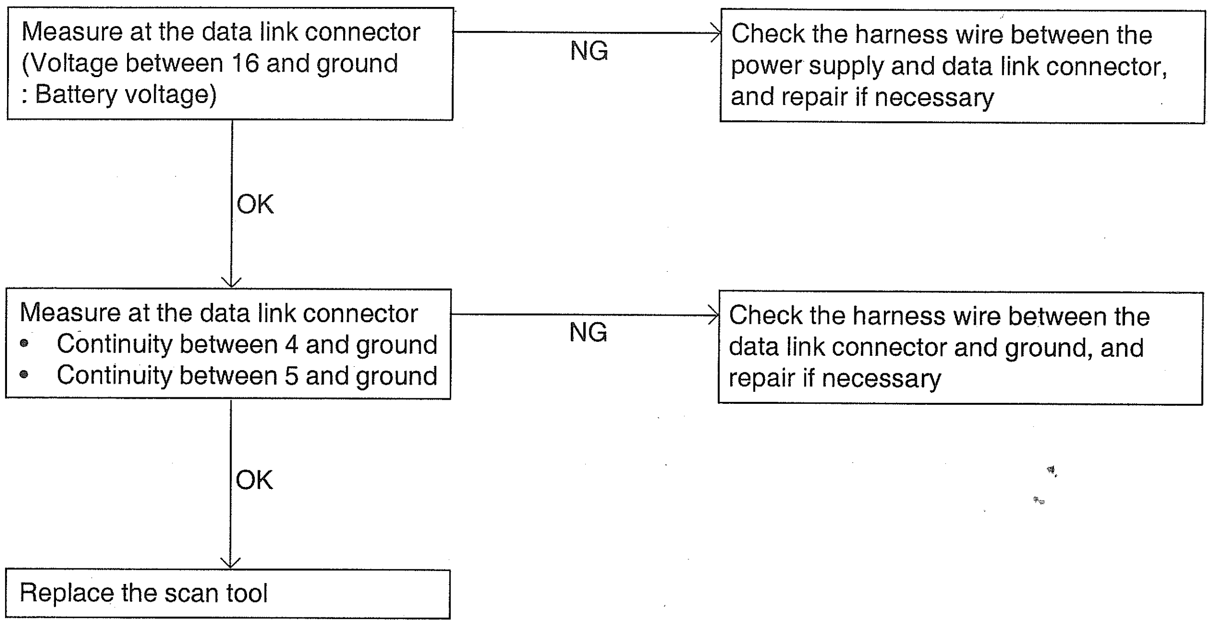
Check items \ Trouble symtoms	Engine overrun, Accel.	White/Blue smoke	Clouds of black smoke	Engine overheating	Can not shut off with IG key	Diagnosis lamp not go out or flickers	AC cannot be switched on	RAD. Fan constantly in operation
Rail Pressure Sensor								
Accel. Position Sensor	3						6	
Mechanical 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 In-mani. Leaking								

TROUBL-4

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 ↓

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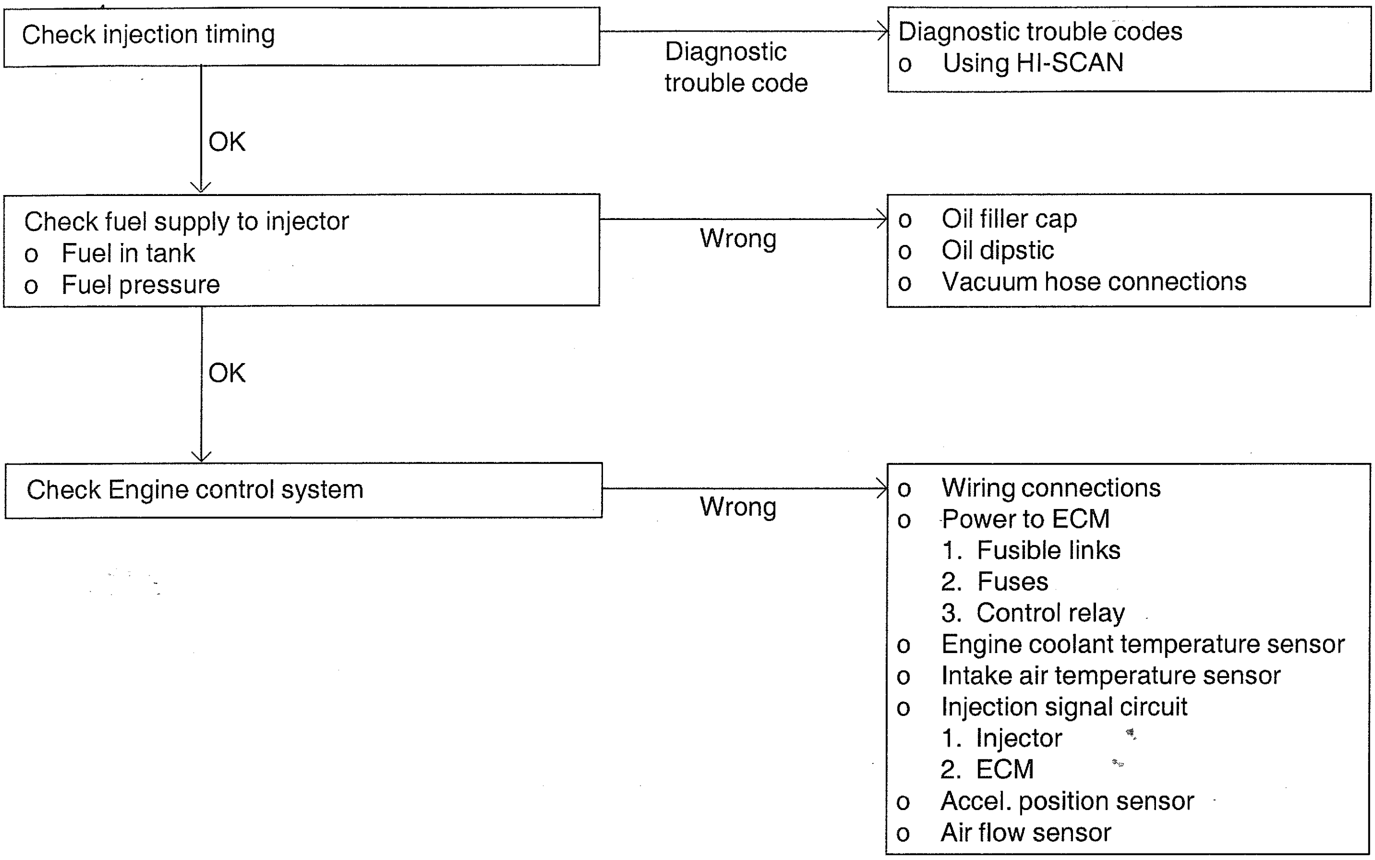

Check injection timing
Diagnostic trouble code
Diagnostic trouble codes
o Using HI-SCAN
OK
Check fuel supply to injector
o Fuel in tank
o Fuel pressure
Wrong
o Oil filler cap
o Oil dipstic
o Vacuum hose connections
OK
Check Engine control system
Wrong
o Wiring connections
o Power to ECM
1. Fusible links
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

Check self-diagnosis
- Wrong → Diagnostic trouble codes
  - o Using HI-SCAN
- OK ↓

Check for vacuum leaks
- Wrong →
  - o Oil filler cap
  - o Oil dipstic
  - o Vacuum hose connections
- OK ↓

Check fuel supply to injector
- o Fuel in tank
- o Fuel pressure
- Wrong →
  - o Fuel line (leakage, deformation)
  - o Fuses
  - o Fuel pump
  - o Fuel filter
  - o Fuel pressure regulator
- OK ↓

Check air cleaner filter
- Wrong → Filter-clean or replace
- OK ↓

Check idle speed
Standard : 750 ± 40rpm (SM)
: 780 ± 40rpm (FO)
: 750 ± 40rpm (XD)
- Wrong → Idle speed-adjust
- OK ↓

Check injection timing
- Wrong → Inspect the fuel system
- OK ↓

Continued next page

From the previous page

Check fuel pressure → Wrong:
- o Fuel pump
- o Fuel filter
- o Fuel pressure regulator

OK ↓

Check injectors → Wrong: Injection condition

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 Injection signal circuit
  1. Injector wiring
  2. ECM

Engine hesitates or accelerates poorly

Check clutch or brakes → Wrong:
- o Clutch-slip
- o Brake-drag

OK ↓

Check vacuum leaks in intake air line → Wrong:
- o Oil filler cap
- o Oil dipstic
- o Hose connections

OK ↓

Check air cleaner filter → Wrong: Clean-filter or replace

OK ↓

Check self-diagnosis → Wrong: Diagnostic trouble codes
- o Using HI-SCAN

OK ↓

Continued next page

From the previous page

↓

Check injection timing Actual : 12° ± 5° BTDC	Wrong →	Inspect the fuel system
↓ OK		
Check fuel pressure	Wrong →	o Fuel pump o Fuel filter o Fuel pressure regulator
↓ OK		
Check injectors	Wrong →	o Injector condition
↓ OK		
Check the compression	Wrong →	o Compression check
↓ 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 Injection signal circuit 1. Injector wiring 2. ECM

INSPECTION CHART FOR DIAGNOSTIC TROUBLE CODES

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P0601	**EEPROM and configuration**		
	Adjusting values (EEPROM) checksum	C020	Adjusting values (EEPROM) checksum
	EEPROM Communication	C019	Line open circuit
	EEPROM Writer error	C021	Code word incorrect or mission
	Different variation number	C021	Code word incorrect or mission
	Code word incorrect or missing	C021	Code word incorrect or mission
P0335	**Engine speed sensor (CKP)**		
	Dynamic plausibility	C004	Plausibility error
	Overspeed recognition	C002	Signal : SRC above upper limit
P0340	**Increment sensor (IAT)**		
	Flow quantity limiter switched on		
	Cam signal frequency too high	C002	Signal : SRC above upper limit
	IAT failure	C003	General error
	IAT dynamic inplausible	C004	Plausibility error
	Cam signal statically defect	C001	Signal : SRC below lower limit
	Main injection correction too late		
P1645	**Capacitor 1 voltage**		
	Booster voltage too high	C002	Signal : SRC above upper limit
	Booster voltage too low	C001	Signal : SRC below lower limit
P1647	**Threshold voltage**		
	Calculated booster voltage too high	C002	Signal : SRC above upper limit
	Calculated booster voltage too low	C001	Signal : SRC below lower limit
P0190	**Rail pressure sensor (RPS)**		
	Signal : SRC below lower limit	C001	Signal : SRC below lower limit
	Signal : SRC above upper limit	C002	Signal : SRC above upper limit
	Supply : SRC below lower or above upper limit	C003	General error
	Plausibility of I_DRV and P_Rail	C004	Plausibility error

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P1181	**Fuel pressure monitoring**		
	Maximum pressure exceeded	C005	Maximum pressure exceeded
	Minimum pressure at engine speed too low	C006	Minimum pressure at engine speed too low
	Set value DRV too high/leakage overrun	C007	Correcting value DRV too great/leakage overrun
	DBE jammed	C008	Actuator sticks
	Leakage	C009	Leakage
	Governor deviation at engine speed too high	C010	Governor deviation at engine speed too high
	Correcting variable too high	C011	Governor output too great
	Leakage flow while idling	C012	Leakage during low idle
P0560	**Battery voltage**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
	Rail pressure limited over UBAT	C004	Plausibility error
P0120	**Accelerator pedal sensor (APS 1)**		
	Signal : SRC below lower limit	C001	Signal : SRC below lower limit
	Signal : SRC above upper limit	C002	Signal : SRC above upper limit
	Supply : SRC above upper or below lower limit	C003	General error
	PWG plausibility with brake signal BRE	C004	Plausibility error
P0220	**Accelerator pedal sensor (APS 2)**		
	Signal : SRC below lower limit	C001	Signal : SRC below lower limit
	Signal : SRC above upper limit	C002	Signal : SRC above upper limit
	Supply : SRC above upper or below lower limit	C003	General error
	Implausibility potentiometer 1/2	C004	Plausibility error
P1639	**Monitoring ADC**		
	Dynamic ADC-RAM test failed	C004	Plausibility error
	Ground connection PGS failed	C002	Signal : SRC above upper limit
	Test voltage from ADC failed	C003	General error
P0115	**Water temperature sensor (ECT)**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
	Operation temperature not attained	C004	Plausibility error
P0180	**Fuel temperature sensor (ETS)**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P0110	**Air temperature sensor (IAT)**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
P1170	**Atmospheric pressure sensor (in ECU)**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
P0100	**Airmass meter (HFM)**		
	HFM5 signal : SRC below lower limit	C001	Signal : SRC below lower limit
	HFM5 signal : SRC above upper limit	C002	Signal : SRC above upper limit
	Supply : SRC above upper or below lower limit	C003	General error
	Plausibility offset drift HFM5 1ms	C004	Plausibility error
	Plausibility positive range	C004	Plausibility error
	Plausibility	C004	Plausibility error
P1526	**Sensor supply 1 voltage**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
P1526	**Sensor supply 2 voltage**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
P1569	**Current of pressure control valve IDV**		
	SRC below lower limit	C001	Signal : SRC below lower limit
	SRC above upper limit	C002	Signal : SRC above upper limit
P1638	**Microcontroller**		
	RECOVERY occured	C022	RECOVERY occured
	Redundant overrun monitoring	C023	Redundant overrun monitoring
	Gate array quantity stop	C024	Gate array quantity stop
	Gate array communication	C025	Gate array communication
	Gate array communication not debounced	C025	Gate array communication
P0500	**Vehicle speed signal (VSS)**		
	CAN data invalid	C003	General error
	SRC above upper limit	C002	Signal : SRC above upper limit
	PEC frequency too high	C002	Signal : SRC above upper limit
	FGG plausibility	C004	Plausibility error

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P0403	**Vacuum Modulator**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
	Positive governor deviation	C010	Governor deviation at engine speed too high
	Negative governor deviation	C010	Governor deviation at engine speed too high
	EGR flow check		
P1613	**Regulator**		
	Lower regulator limit	C001	Signal : SRC below lower limit
	Upper regulator limit	C002	Signal : SRC above upper limit
P1635	**Water heated relay**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1325	**Glow relay**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1629	**Glow indicator lamp**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P0230	**Electric fuel pump relay**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
	Plausibility after ignition off operation	C004	Plausibility error
P1180	**Rail pressure regulator**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
	Power stage error	C003	General error
P1622	**Air-condition relay**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1624	**Radiator cooling fan**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P1625	**A/C condensor fan**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1623	**ENG. CHK lamp**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P0703	**Brake switch**		
	Parity error in CAN-message		
	Plausibility with redundant contact after initialization	C004	Plausibility error
	Plausibility with redundant contact	C004	Plausibility error
P0704	**Clutch switch**		
	Plausibility	C004	Plausibility error
P1616	**Main relay**		
	Switch off too early	C004	Plausibility error
	Switch off too late	C004	Plausibility error
P1652	**IG-switch**		
	K15 plausibility after initialization	C004	Plausibility error
P0600	**CAN-Diagnosis error path NPL**		
	CAN NPL M1 TCU	C019	Line : open circuit
	CAN NPL M2 ABS	C019	Line : open circuit
	CAN NPL M3 receipt message 3	C019	Line : open circuit
	CAN NPL M4 receipt message 4	C019	Line : open circuit
	CAN NPL M3 receipt message 5	C019	Line : open circuit
	CAN NPL M4 receipt message 6	C019	Line : open circuit
	CAN NPL mute	C019	Line : open circuit
	CAN NPL bus	C019	Line : open circuit

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P0600	**CAN-Diagnosis error path ERF**		
	CAN ERF M1 TCU	C019	Line : open circuit
	CAN ERF M2 ABS	C019	Line : open circuit
	CAN ERF M3 receipt message 3	C019	Line : open circuit
	CAN ERF M4 receipt message 4	C019	Line : open circuit
	CAN ERF M5 receipt message 5	C019	Line : open circuit
	CAN ERF M6 receipt message 6	C019	Line : open circuit
	CAN ERF mute	C019	Line : open circuit
	CAN ERF bus	C019	Line : open circuit
P1609	**Immobilizer**		
	Immo Line faulty	C013	Immobilizer smartra error
	Invalid Tester request	C014	Immobilizer antenna error
	EEPROM faulty-non plausible VSP data	C015	IFZ does not respond
	Transponder faulty	C016	Start command at locked IFZ
	SMATRA faulty	C017	IFZ responds with wrong code
	Authentication not succesful	C026	Authentication not successful
	EEPROM faulty for KEY ID block & Immo data block	C027	EEPROM faulty for KEY ID block & IMMO data block
P1530	**Maximum vehicle speed limiting**		
	Negative governor deviation	C003	General error
P0204	**Injector #4**		
	Over current LS	C018	Line : short circuit
	Over current HS	C018	Line : short circuit
	Load drop	C019	Line : open circuit
	SL error		
P0203	**Injector #3**		
	Over current LS	C018	Line : short circuit
	Over current Hs	C018	Line : short circuit
	Load drop	C019	Line : open circuit
	SL error		
P0202	**Injector #2**		
	Over current LS	C018	Line : short circuit
	Over current HS	C018	Line : short circuit
	Load drop	C019	Line : open circuit
	SL error		

DTC No.	Fault Item and Description	Detailed Code	Meaning (could also be used for tester display)
P0201	**Injector #1**		
	Over current LS	C018	Line : short circuit
	Over current HS	C018	Line : short circuit
	Load drop	C019	Line : open circuit
	SL error		
P1653	**Error check after ignition off**		
	Error at shutoff via zero quantity		
	Error at shutoff via injector power stage (OFF)		
P1623	**MIL-CARB lamp**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1633	**Immobilizer status indicator lamp**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1634	**Cruise control indicator lamp**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit
P1660	**Cruise control switch**		
	Signal : SRC below lower limit	C001	Signal : SRC below lower limit
	Signal : SRC above upper limit	C002	Signal : SRC above upper limit
	Supply : SRC out of limits	C003	General error
	Plausibility	C004	Plausibility error
P1190	**Throttle plate actuator output**		
	Short circuit	C018	Line : short circuit
	Open circuit	C019	Line : open circuit

TROUBLESHOOTING PROCEDURE

GENERAL

1. Test drive: Test drive means a cantain driving cycle or pattern that includes the ambient conditions when a fault was occured. Before driving, erase the stored fault code with Hi-scan.

2. Limp home mode : ECU switches to limp home mode in the event of failure of the important input/output signals.
   The result is as follows.
   - Reduced power and lower maximum speed.
   - EGR function disabled.

3. Emergency shut off
   For safety reasons, ECU effects emergency shut off of the engine if the following system components fail.
   - Injectors
   - Engine speed sensor
   - Pressure regulator
   - Fuel leakage

4. Attention
   Never work on injection system with engine running or within 30 seconds after shutting off the engine. High pressure pump, rail, injectors and high pressure pipes are subjected to high pressure even after the engine has been switched off.

5. Safety measures
   If it is necessary to run the engine for certain test steps (ex. Call up the actual values at the actuator test), the test equipment is to be set up such that mechanic does not have to be within possible range of high pressure jets when performing test.
   People who are using pacemakers should not be closer than 30cm to ECU or wiring harness within the engine is running, since the high currents in the CR system produce considerable magnetic fields.

   - Acutuator test can be performed only if engine speed is "ZERO".

ECU : ENGINE CONTROL UNIT

1. Possible DTC
   1) P0601 (Perform and configuration)
   2) P1647(Threshold voltage)
   3) P1639 (Monitoring ADC)
   - CC-CODE: C002
     Check the ground connection from APS ground to ECU pin
     (APS pin #6 - ECU pin #79)
     (APM pin #5 - ECU pin#79)
   4) P1526 (Sensor supply voltage 1 for APS1, AFS)
      P1527 (Sensor supply voltage 2, APS2, RPS)
   * Check the short circuit of sensor supply line to GND or Bat. ECU should not be exchanged for these errors.
   5) P1569 (Actual current of pressure regulator valve)
   6) P1638 (Microcontroller)
   7) P1613 (Voltage regulator monitoring of voltage regulator in 2 different tests)

2. If these faults are encountered, cancel the fault memory and perform the test drive. Replace ECU if fault code is stored again.

ECU : CAPACITOR VOLTAGE 1

1. Possible DTC : P1645

   Capacitor in ECU charges for activating the injectors. First check the wiring of injectors to ECU. Rectify the additionally stored faults. Cancel the fault memory and perform the test drive.
   Replace ECU if fault code is stored again.

CKP : CRANKSHAFT POSITION SENSOR

1. Possible DTC :P0335

2. Actual value for evaluation : Engine warm > 80°C, aircondition off
   - Required idling speed

     SM: 750 ± 40 rpm (M/T, A/T)
     FO: 780 ± 40 rpm (M/T, A/T)
     XD: 750 ± 40 rpm (M/T, A/T)

   - CC-CODE
   - Substitute reaction is performed anyhow.
   - NOTE : When excessive engine oil is filled up, for instance 2 times of normal amount, engine can be run more than 6000rpm (i.e. dieseling) in this case error can be memorized but this should be neglected.
   1) C004 (Plausibility error)
      - This error is reduntant to DTC340 can occur only if DTC340 CC-Code C004 occurred.
      - Measure the signal rate between present engine speed(k) and previous engine speed(k-1). If the rate is out of the standard, it is detected as an error.

- Possible causes of trouble:
  1) Contact resistance
  2) CKP defective
  3) Metal abrasion or dirt at sensor
  4) Incorrect installation position or sensor loose
  5) Wheel - CKP sensor

3. Measure the resistance of sensor at the detached plug pin1 to pin 2

650 - 1000Ω at 20°

4. Attach the plug.

5. Record the signal profile from pin1 to GND. Engine idling.
Using oscillocope : CMP signal
CKP signal

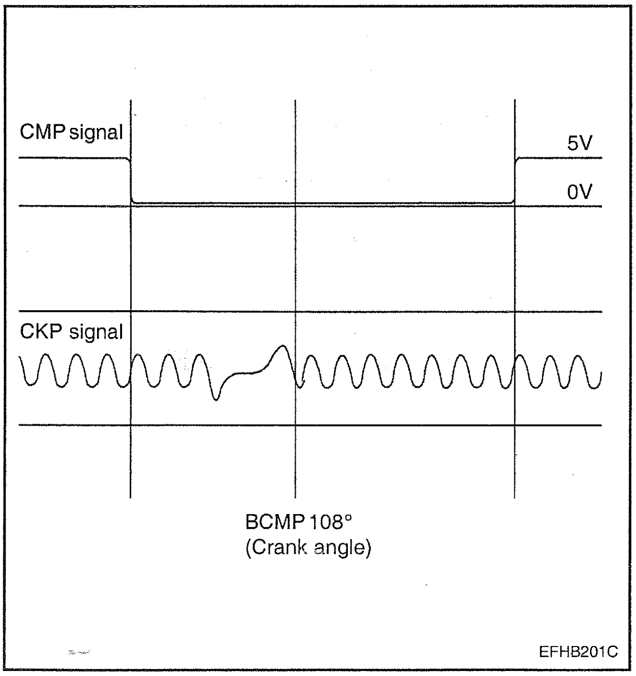
Wiring check:

ECU	CKP
Pin 69	Pin 1
Pin 100	Pin 2
Pin 101	Pin 3

6. If wiring is OK and signal profile doesn't correspond to set value (Min. 1.65V), check the sensor for dirt (possibly abrasion or some metallic parts), proper installation position and tight fit.
Measure the gap between sensor wheel and sensor:

1 ± 0.5 mm

Gap cannot be adjusted. Check the sensor wheel for damage.



CMP : TOP DEAD CENTER SENSOR

1. Possible DTC: P0340
   - CC-CODE
   1) C001 (Signal below the lower limit - No signal)
      - Possible causes of trouble:
      A. Open circuit. Broken line
      B. Short circuit to GND line
      C. CMP sensor defective
      E. Incorrect installation position or sensor loose
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. CMP sensor defective
      B. Inteference on signal line from other component (Alternator, Injector lines)
   3) C003 (General error)
      - 2 time turns of camshaft signal are exceed the upper or lower window limit of camshaft set signal, then error is detected.
      - Possible causes of trouble:
      A. CMP sensor defective
      B. Incorrect installation position or sensor loose
      C. Air gap between sensor to sensing wheel is too wide
   4) C004 (Plausibility error)
      - When the limit between angular velocity of crankshaft signal sensing stubs and frequency multiplier of inner ECU is exceed the set value, error is detected.
      - Possible causes of trouble:
      A. Contact resistance
      B. CMP sensor defective
      C. Incorrect installation position or sensor loose
      D. Camshaft and crankshaft misarrangement
      E. Inteference on signal line from other component (Alternator, Injector lines)

2. Measure the supply voltage of sensor pin 3 to pin 1

Set value : 8 - 15V

3. Use an oscilloscope to record signal profile from pin2 to GND. Engine idling.

Set value : Square wave (5V)

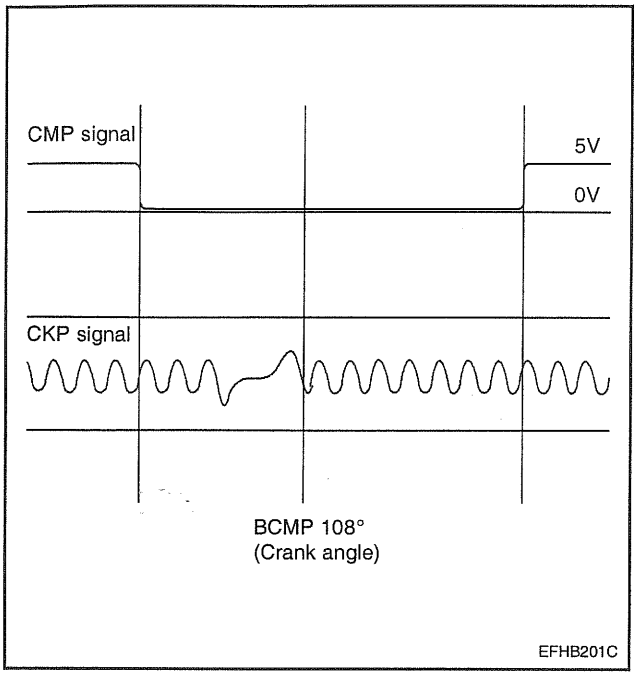
CMP signal
CKP signal

4. Check wiring if CMP sensor signal is not OK.

Wiring check:

ECU	CMP
Pin 104	Pin 1
Pin 103	Pin 2
B (+)	Pin 3

5. Check the camshaft and crankshaft arrangement if applicable at the present of CKP and CMP signal.



RPS : RAIL PRESSURE SENSOR

1. Possible DTC: P0190
   Actual value for evaluation : Engine warm at approx. 80°C. Engine idling.

   Set value: 220 - 300 bar
   Typical value: 260 bar

   Rail pressure in limp home mode (fault state) :

   approx. 400 bar

   Vehicle can be driven in limp home mode.

   - CC-CODE
   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Open circuit, contact resistance, or short circuit to GND line
      B. RPS defective
      C. ECU - sensor supply voltage 2 : DTC1527 C001
   1) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to Bat(+) line
      B. RPS defective
      C. ECU - sensor supply voltage 2 : DTC1527 C002
   3) C003 (General error)
      Rail pressure sensor error is determined by comparison of rail pressure regulator operation current value to rail pressure sensor output.
      Possible causes of trouble:
      A. Short circuit to Bat(+) line or to GND
      B. ECU - sensor supply voltage 2 : DTC1527
      The CC-Code from this error reports the error source.

2. Measure the supply voltage of RPS with ignition on. Pin 3(+) to pin 1(-)

   Set value : 4.5V - 5.5V

3. Signal voltage measurement
   If supply voltage set value is attained, measure the voltage from pin 2 to GND with ignition on.

   Set value : Approx. 0.5V
   Engine idling set value : 1V
   Voltage increases with increasing pressure:
   Max. 4.5V

4. If set values are attained : Ignition off, pull off the plug of control unit and sensor. Then check the following wiring for open/ short circuit.

ECU	Sensor
Pin 90	Pin 3
Pin 91	Pin 2
Pin 92	Pin 1

5. If the signal voltage set value is not attained, replace RPS.

6. Note the followings
   1) Always renew the sealing washer (soft iron sealing ring) even if the old sensor is re-used
   2) When removing seal, take care not to damage sealing surface.
   3) When installing RPS, apply sealing washer with grease if necessary.
   4) **Tightening torque** : 35 ± 2Nm

   - 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.

RAIL PRESSURE MONITORING

1. Possible DTC: P1181

2. Actual value for evaluation: Conform actual value of RPS

   - CC-CODE
   1) C005 (Max. pressure excceed)
      C008 (Actuator sticks in closed position)
      - Possible causes of trouble:

A. Rail pressure sensor (RPS) defective
B. Pressure regulator valve defective
C. Injectors defective
D. High pressure pump defective

2) C006 (Min.pressure at low engine speed)
C009 (Leakage), C010 (Governor deviation at high engine speed)
- Possible causes of trouble:
A. Rail pressure sensor (RPS) defective
B. Pressure regulator valve defective
C. Injectors defective
D. High pressure pump defective
E. Leakage

3. Any additionally stored faults are to be rectified first. Cancel the fault memory and then perform the test drive. Start by checking above-mentioned components if fault code is stored again.

4. Visually check the pipes, rail and connections for leakage.

5. Check the low pressure circuit.
- Possible causes of trouble: Leakage, fuel filter clogged, electric fuel pump
1) Connect the pressure gauge between fuel filter and high pressure pump. Ignition on. Fuel pump delivery for 30 seconds.

Pressure > 3.5 bar

Opening pressure at overflow valve of fuel filter is too high
Replacle the valve

Pressure < 1.5 bar

Block the hose between overflow valve and return flow collector

Pressure > 3.5 bar

Overflow valve defective

Pressure < 3.5 bar

Check the electric fuel pump

2) Connect the pressure gauge to the entire return fuel line toward the tank
Ignition on. (High pressure pump delivery)

Pressure < 1 bar : Return line clogged

3) Connect the pressure gauge to upstream of filter
Ignition on. (High pressure pump delivery)

Pressure > 2.8 bar : Filter or inlet clogged

6. Check the high pressure circuit
- Possible causes of trouble: Leakage, rail pressure sensor, regulator, injectors, high pressure pump
1) Visually inspect for leakage and check all connectors
2) Block the fuel return line of function block
3) Pull off the electric connector of all injectors. Connect the self-diagnosis tester (HI-SCAN)
4) Ignition on. Operate starting motor for 5 seconds

Actual value read out: Rail pressure
Actual value < 150 bar :
High pressure pump defective

BATTERY VOLTAGE

1. Possible DTC: P0560
- CC-CODE
1) C001 (Signal below the lower limit- No signal)
- Possible causes of trouble:
A. Open circuit in wiring / Short circuit to GND line
B. Contact resistance
C. Fuse defective
D. Plug contacts
E. Main relay
F. Battery defective
G. Alternator charge defective

2) C002 (Signal above the upper limit)
- Possible causes of trouble:
A. 24V battery connected
B. Alternator over-charging

3) C004 (Plausibility error)
- Possible causes of trouble:
A. Rail pressure sensor defective
B. Pressure regulator valve defective
C. Battery defective

2. Check ECU plug and wiring plug contact condition.
3. After ignition on, check the supply voltage of ECU pin 4 to GND and of ECU pin 5 to GND.

Set value: 8 - 15V

4. If set value is not attained, check the main relay of pin 30 to GND.

Set value: 8 - 15V

5. If set value is not attained, check fuses.

6. Measure the supply voltage of ECU pin 13 to GND

Set value: 8 - 15V

7. Check GND wires from ECU pin 1,2,3 for open and short circuit.

8. Check the battery voltage

9. Check the alternator charge condition

APS : ACCELERATION POSITION SENSOR 1

1. Possible DTC: P0120 (Accel position sensor 1)

   Actual value for evaluation : Ignition on

   Idle set value: 0%
   Full throttle : 100%

   - CC-CODE

   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Short circuit to GND line
      B. APS defective
      C. ECU defective (Sensor supply voltage): DTC P1526 C001
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to Bat line
      B. APS defective
      C. ECU defective (Sensor supply voltage): DTC P1526 C002
   3) C003 (General error)
      Possible causes of trouble:
      - Possible causes of trouble:
      A. ECU defective (Sensor supply voltage): DTC P1526
   4) C004 (Plausibility error with brake signal)
      When depressing accel pedal (not at idle), brake switch signal is shown "ON" for a certain time, error is detected.
      - Possible causes of trouble:
        A. Brake switch defective
        B. APS defective
        C. ECU defective (Sensor supply voltage); DTC P1526

2. Check the sensor supply voltage with ignition on.
   Sensor 1: Pin 2(+) and pin 3(-), Sensor 2 : Pin 1 (+) and pin 5(-) (with APM)

   Set value : 4.5 - 5.5V

   Sensor 1: Pin 4(+) and pin 5(-), Sensor 2 : Pin 1 (+) and pin 6(-) (with APM)

   Set value : 4.5 - 5.5V

3. If set value is not attained: Ignition off. ECU and sensor plug off. Check wiring for short or open circuit. Check the following wiring.
   1) With APS (XD/FO/SM-RHD)

ECU	APS 1
Pin 76	Pin 5
Pin 77	Pin 2
Pin 78	Pin 4

   2) With APM (LC/FC/SM-LHD)

ECU	APS 2
Pin 76	Pin 3
Pin 77	Pin 4
Pin 78	Pin 2

4. If connecting leads are OK, measure the signal voltage of sensor.
   1) With APM
      - Sensor 1:

      Pin 4(+) and pin 3(-) set value
      At idle : 0.6 - 0.9V
      At full throttle : 3.6 - 4.6 V

   2) With APS
      - Sensor 1:

      Pin 2(+) and pin 5(-) set value
      At idle : 0.6 - 0.9V
      At full throttle : 3.6 - 4.6 V

APS : ACCELERATION POSITION SENSOR 2

1. Possible DTC: P0220 (Accel position sensor 2)

2. Actual value for evaluation : Ignition on

   Idle set value: 0%
   Full throttle : 100%

   - CC-CODE

   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Short circuit to GND line
      B. APS defective
      C. ECU defective (Sensor supply voltage): DTC P1527 C001
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to Bat line
      B. APS defective

C. ECU defective (Sensor supply voltage): DTC P1527 C002
3) C003 (General error)
APS sensor operation power error (ECU)
- Possible causes of trouble:
A. ECU defective (Sensor supply voltage): DTC P1527
4) C003 (Plausibility error with brake signal)
When comperative value between accel pedal sensor signal and accel pedal sensor signal 2 exceed the set deviation, error is detected.
- Possible causes of trouble:
A. APS defective
B. ECU defective (Sensor supply voltage): DTC P1527

3. Check the voltage supply of sensors with ignition on Sensor 1: Pin 2(+) and pin 3(-), Sensor 2 : Pin 1 (+) and pin 5(-) (with APM)

Set value : 4.5 - 5.5 V

Sensor 1: Pin 4(+) and pin 5(-), Sensor 2 : Pin 1 (+) and pin 6(-) (with APS)

Set value : 4.5 - 5.5V

4. If set value is not attained: Ignition off. ECU and sensor plug off.
Check wiring for short or open circuit.
Check the following wiring.

1) With APS (XD/FO/SM-RHD)

ECU	APS 1
Pin 79	Pin 6
Pin 80	Pin 3
Pin 80	Pin 1

2) With APM (LC/FC/SM-LHD)

ECU	APS 1
Pin 79	Pin 6
Pin 80	Pin 5
Pin 81	Pin 1

If connecting leads are OK, measure the signal voltage of sensor.

1) With APM

Sensor2: Pin 6(+) and pin 5(-) set value
At idle : 0.25 - 0.6V
At full throttle : 1.6 - 2.5 V

2) With APS

Sensor2: Pin 3(+) and pin 6(-) set value
At idle : 0.25 -0.6V
At full throttle : 1.6 - 2.5 V

WTS : WATER TEMPERATURE SENSOR

1. Possible DTC: P0115
Actual value for evaluation: Set value, approx. 80°C (with engine warm)
Evaluation display:
A temperature reading < -40°C indicates an open circuit in the signal line
A temperature reading > 120°C indicates a short circuit to GND in the signal line

NOTE
Radiator fan starts up if temperature sensor is defective or plug pulled off.

- CC-CODE

1) C001 (Signal below the lower limit- No signal)
- Possible causes of trouble:
A. Short circuit to GND line
B. Contact resistance
C. WTS defective
D. ECU defective
2) C002 (Signal above the upper limit)
- Possible causes of trouble:
A. Short circuit to Bat(+) line, open circuit in wiring
B. WTS defective
C. ECU defective
3) C004 (Plausibility error)
After ignition on, cooling water temperature is not arrived at the set value within set time, error is detected.
- Possible causes of trouble:
A. Contact resistance
B. WTS defective
C. ECU defective
D. Thermostat defective

2. Measure the resistance of sensor at pin 1 (+) and pin 3 (-)

Set value at 0 - 40 : 1.1 - 5.8 kΩ
Set value at 60 - 100 : 180 - 590Ω

3. Repeat the measurement directly at sensor if set values are not attained.

4. If set values are attained at sensor, check wiring from ECU pin 84 and pin 85 to sensor.

FTS : FUEL TEMPERATURE SENSOR

1. Possible DTC: P0180
   * CC-CODE
   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Short circuit to GND line
      B. Contact resistance
      C. FTS defective
      D. ECU defective
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to Bat(+) line, Open circuit in wiring
      B. WTS defective
      C. ECU defective

2. Measure the resistance of sensor at pin 1 (+) and pin 2 (-)

   Set value at 0 - 40°C : 1 - 7 kΩ
   Set value at 70 - 90°C : 390 - 240Ω

3. Repeat the measurement directly at sensor if set values are not attained.
   If set values are attained at sensor, check wiring from ECU pin 82 and pin 83 to sensor

ATS : AIR TEMPERATURE SENSOR

1. Possible DTC: P0110 (Air temperature sensor)

   Air temperature sensor is integrated into HFM5.
   Actual value for evaluation: Set value., Ambient temperature
   Evaluation display:

   A temperature reading < -40°C indicates an open circuit in the signal line
   A temperature reading > 120°C indicates a short circuit to GND in the signal line

   - CC-CODE
   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Short circuit to GND line
      B. Contact resistance
      C. HFM5 defective
      D. ECU defective
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to Bat line, Open circuit in wiring
      B. ATS in HFM5 defective
      C. ECU defective

2. Measure the resistance of temperature sensor at the detached ECU plug.

   Set value at 0 - 30°C : 1.5 - 6kΩ
   Set value at approx. 50°C : 750 - 920kΩ

3. If set values are not attained , repeat the measurement at temperature sensor in air flow sensor pin 1 to pin 3.
   If set values are attained at sensor, check wiring from ECU pin 86 to sensor pin 1 and ECU pin 88 to sensor pin 3

4. Replace HFM5 if set value is not attained at air temperature sensor

APS : ATMOSPHERIC PRESSURE SENSOR

1. Possible DTC: P1170

   Set value :
   Atmospheric pressure tolerance : +/- 30hPa

   Possible actual value : approx. 1000hPa at sea level

   NOTE
   Atmospheric pressure sensor is located in ECU

   - CC-CODE
   1) C001 (Signal below the lower limit- No signal), C002 (Signal above the upper limit)
      Possible causes of trouble: Defective atmospheric pressure sensor in ECU

2. Call up the actual values

3. Cancel the fault memory and perform the test drive

4. Replace ECU if fault memory cannnot be cancelled or if fault is set again.

HFM5 (AIR FLOW SENSOR)

1. Possible DTC: P0100 (Air flow sensor)

   Actual value for evaluation: Engine idling, or enine warm at approx.80°C

   Set value:
   450 - 510 mg/stroke (without EGR)
   280 - 360mg/stroke (without EGR)

   - CC-CODE
   1) C001 (Signal below the lower limit- No signal)
      - Possible causes of trouble:
      A. Short circuit to GND line or Open circuit in wiring
      B. Contact resistance
      C. HFM5 defective
      D. ECU defective (Sensor supply voltage) : DTC P1526 C001
   2) C002 (Signal above the upper limit)
      - Possible causes of trouble:
      A. Short circuit to GND line or Open circuit in wiring
      B. HFM5 defective

C. ECU defective (Sensor supply voltage) : DTC P1526 C002
3) C003 (General error)
Sensor operation power (from ECU) error
- Possible causes of trouble:
A. Open circuit in wiring / short circuit
B. ECU defective (Sensor supply voltage)

2. Check the HFM5 supply voltage

Pin 2 - GND / Pin 2 - Pin 3 : 8 - 15V
Pin 4 - GND / Pin 4 - Pin 3 : 4.5 - 5.5V

3. If set values are not attained : Ignition off, pull off ECU plug.
Check the following wiring

ECU	Sensor
Pin 97	Pin 2, Pin 4
Pin 89	Pin 5
Pin 88	Pin 3

4. Measure the signal voltage of sensors if connecting leads are OK.

5. Measure the voltage of plug pin 5 to pin 3 at idle.

Set value (engine warm) : 1.7 - 2.2 V
Throttle burst set value : Voltage increases

6. Replace HFM5 if signal voltage set values are not attained.

VEHICLE SPEED SIGNAL

1. Possible DTC: P0500

- CC-CODE
1) C001 (Signal below the lower limit- No signal)
- Possible causes of trouble:
A. Interference from other component
B. Vehicle speed sensor defective
2) C004 (Plausibility error)
While injection fuel and engine rpm is supported by above the upper limit, if vehicle speed is below the set value error is detected.
- Possible causes of trouble:
A. Clutch switch defective
B. Vehicle speed sensor defective

2. Check wiring between ECU pin 49 and vehicle speed sensor.

SOLENOID VALVE FOR EGR VALVE

1. Possible DTC : P0403
- CC-CODE
1) When feedback governing exceeds the set value in comparison of aim value with the actual value.
- Possible causes of trouble:
A. Solenoid valve sticks
B. Vacuum source/ pipe/ hose
2) C018 (Line : Short circuit)
- Possible causes of trouble:
A. Short circuit to Bat line, Open circuit in wiring
3) C019 (Line : Open circuit)
- Possible causes of trouble:
A. Short circuit to GND line

2. Check wiring between ECU pin 16 and solenoid valve.

3. Check wiring between supply voltage line and solenoid valve.

4. Check for leaks in vacuum hose to EGR valve and solenoid valve.

5. Pull off the plug of solenoid valve, measure the resistance of solenoid valve.

Set value : 14 - 17Ω

6. Measure the frequency of control voltage :

300 Hz

7. Check whether vacuum is provided by vacuum source.
Check mode : Keep engine at 1500rpm for 20 seconds and then conduct the measurement as it is.

Set value > 650 mmHg

8. Pull off the vacuum hose from EGR valve.
Check for presence of vacuum.

9. Check the mechanical components of solenoid valve if vacuum is present but engine speed does not change.

10. If valve stick is in closed position or C019 occurs, then black smoke arises.

ADDITIONAL WATER HEATER

1. Possible DTC: P1635

   - CC-CODE

   1) C018 (Line : Short circuit)
      - Possible causes of trouble:

      A. Short circuit to Bat line, Open circuit in wiring
      B. Fuse defective
      C. Open circuit. Contact resistance
      D. Additional water heater relay defective

   2) C019 (Line : Open circuit)
      - Possible causes of trouble:

      A. Short circuit to Bat line, Open circuit in wiring
      B. Fuse defective
      C. Contact resistance
      D. Additional water heater relay defective

2. Measure the voltage at relay pin 85 to GND.

   Set value :
   8 - 15V (OFF)
   0V(ON)

3. Check the additional water heater relay wiring

4. Measure the supply voltage at relay pin. 87 to GND.

   Set value : 8 - 15V

5. Check the additional water heater relay wiring

6. Check wiring between ECU pin 23 and additional water heater relay.

7. If wiring and fuse is OK, replace the additional water heater relay.

   NOTE :
   FO vehicle of which mounting combustive heater reveals the above trouble code normally. So please ignore the code.

GLOW RELAY AND GOLW LAMP

1. Possible DTC: P1325 (Glow relay) P1329 (Glow indicator lamp)

   - CC-CODE

   1) C018 (Line : Short circuit)
      - Possible causes of trouble:

      A. Short circuit to Bat line, open circuit
      B. Fuse defective
      C. Contact resistance
      D. Glow time control
      E. Glow plug indicator lamp

   3) C019 (Line : Open circuit)
      - Possible causes of trouble:

      A. Short circuit to GND line
      B. Fuse defective
      C. Contact resistance
      D. Glow time control
      E. Glow plug indicator lamp

   NOTE
   Golw plug idicator lamp lights briefly for self test when Ignition switch is turned on.

2. Activate the lamp by way of actuator diagnosis
   If check lamp does not flash: Check the fuse
   Check glow lamp wiring

3. Activate the lamp by way of actuator diagnosis
   If relay is not switched : Check the fuse
   Measure the supply voltage at relay pin. 2 to GND.

   Set value : 8 - 15V

   Check glow lamp wiring
   Measure the supply voltage at relay pin. 3 to GND.

   Set value : 8 - 15V

   Check glow lamp wiring.

4. If wiring and fuse is OK, replace the glow relay.

5. After replace the glow relay, perform the test again.

EFP : ELECTRIC FUEL PUMP

1. Possible DTC: P0230

   - CC-CODE

   1) C004 (Plausibility error)
      After run mode or fuel cut off mode, if rail pressure does not drop below the set value within set time, error is deteced.
      - Possible causes of trouble:

      A. Contact resistance
      B. EFP relay defective
      C. EFP defective

   2) C018 (Line : Short circuit)
      - Possible causes of trouble:

      A. Short circuit to Bat line, open circuit in wiring
      B. EFP relay defective
      C. EFP defective

   3) C019 (Line : Open circuit)
      When EFP runs for a second or longer and ignition switch is turned on :
      Line to EFP relay was short circuit to GND
      Measure the sensor resistance of pin 1 (+) and pin 2 (-)
      - Possible causes of trouble:

      A. Short circuit to Bat line, Open circuit in wiring
      B. Contact resistance

C. EFP relay defective
D. EFP defective
E. ECU power stage short circuited

2. EFP runs for approx. 1 second after switching on ignition. (Delivery noise can be heard)

3. Check the fuse in engine compartment if EFP does not run.

4. Ignition off. Check wiring between ECU pin 24 and EFP relay pin 86.
   Jump pin 30 and pin 87 at relay frame with fused measurement lead.
   Ignition on. EFP must run for apporx. 1 second.

5. Replace the relay if EFP runs.

6. Check the supply voltage of EFP.
   Voltage is applied to EFP for approx. 1 second when ignition switch is turned on.

   Set value : 8 - 15V

7. Replacle the EFP if set value is attained

PRV : PRESSUE REGULATOR VALVE

1. Possible DTC: P1180
   Feature: Depending on the rail pressure to be set, PRV is actuated by ECU with a PWM (Pulse with modulated).

2. When PRV is replaced

   Tightening torque : 5 ± 1Nm

   * 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.

   • CC-CODE
   1) C003 (General error)
      After run mode or fuel cut off mode, if rail pressure does not drop below the set value within set time, error is deteced.
      - Possible causes of trouble:
      A. Short circuit
      B. Contact resistance
      C. PRS defective
      D. EFP relay continuously active
      E. Pressure regulator valve defective
      F. High pressure pump
      G. ECU
   2) C018 (Line : Short circuit)
      - Possible causes of trouble:
      A. Short circuit to Bat line, Open circuit in wiring
      B. WTS defective
   3) C019 (Line : Open circuit)
      - Possible causes of trouble:
      A. Short circuit to GND line, Open circuit

3. Pull off PRV plug
   Check wiring between ECU pin 108, pin 109 and PRV.

4. Measure the resistance of PRV

   Approx. set value : 2.3 ± 0.23Ω

5. Check RPS if preceding test is OK.

6. Examine the system for leaks if rail pressure sensor is OK.

7. Check the high pressure circuit
   1) Visually inspect for leakage and check all connectors.
   2) Block the fuel return line of the function block.
   3) Pull off the electirc connector from all injectors and connect the self diagnosis tester (HI-SCAN).
   4) Ignition on, and operate starting motor for 5 seconds.
   - Actual value read out : Rail pressure
   - Actual value < 100 bar : High pressure pump defective or air in the system

A/C COMPRESSOR RELAY

1. Possible DTC : P1622

   • CC-CODE
   1) C018 (Line : Short circuit)
      - Possible causes of trouble:
      A. Short circuit to Bat line
      B. A/C compressor relay defective
   2) C019 (Line : Open circuit)
      - Possible causes of trouble:
      A. Short circuit to GND line, Open circuit
      B. A/C compressor relay defective
      C. Pressure switch defective
      D. A/C compressor magnetic clutch

2. Ignition on
   Measure the voltage at compressor relay (A/C compressor) pin 86 to GND.

   Set value : 8 - 15V

3. If set value is not attained , check the fuse

4. Measure the voltage at compressor relay (A/C compressor) pin 30 to GND.

Set value : 8 - 15V

If set value is not attained, check the supply voltage.

5. Check wiring from compressor relay pin 87 to plug of compressor.
Check wiring between relay pin 85 to ECU pin 21.

6. Check wiring between pressure switch to ECU pin 51, pin 52.

7. Check A/C compressor magnetic clutch if proceeding tests do not reveal the cause of trouble.

COOLING FAN

1. Possible DTC : P1624 P1625

- CC-CODE

1) C018 (Line : Short circuit)
   - Possible causes of trouble:
   A. Short circuit to Bat line
   B. Fuse defective
   C. Relay defective
   D. Resistance continuity defective
   E. Fan motors defective
2) C019 (Line : Open circuit)
   - Possible causes of trouble:
   A. Short circuit to GND line, Open circuit
   B. Fuse defective
   C. Relay defective
   D. Series resistors defective
   E. Fan motors defective

The fan relays are in 3 kinds
The first relay (FAN 1): Speed 1 (both fans)
The second and thrid relays : Speed 2 (each fan)

Fan speed 1:
Measure the supply voltage at relay pin 85 to the ground with ignition on.

Set value : 8 - 15 V

Check the fuse, if set value is not attained.
Ignition off.
Check wiring between ECU pin 20 and relay pin 85 if wiring is OK, check the relay.

2. Measure the series resistances.

3. If fans do not start up despite actuation, check the fuse.

4. Measure the resistance of wiring between relay pin 87 and GND.

5. Fan speed 2
Additional checks.
Measure the supply voltage of relays pin 85 to GND with ignition on.

Set value : 5 - 15V

6. Ignition off
Check wiring of relays pin 86 to ECU PIN 19.
Check wiring of relays pin 87 to GND.

ENGINE CHECK LAMP

1. Possible DTC :P1623

- CC-CODE

1) C018 (Line : Short circuit)
   - Possible causes of trouble:
   A. Short circuit to Bat line
2) C019 (Line : Open circuit)
   - Possible causes of trouble:
   A. Short circuit to GND line, Open circuit

2. Perform the actuator diagnosis.

3. If lamp does not flash, measure the supply voltage at engine check lamp to GND with ignition on.

Set value : 8 - 15V

4. Check the fuse if set value is not attained.

Check the actuation lead of fault lamp.
Check wiring between engine check lamp and ECU pin 110 for open circuit and short circuit.
Lamp is defective if all preceding tests are OK.

BRAKE SWITCH

1. C004 (Plausibility error)

- CC-CODE

1) C004 (Plausibility error)
   After ignition on, brake signal 1, and signal 2 are different each other, error is detected.

Without being concerned with brake signal 1, if only brake signal 2 is turned on continuously for set time, error is detected.
- Possible causes of trouble:
A. Open circuit in wiring , Short circuit
B. Fuse defective
C. Poor connection
D. Switch defective

Brake switch 1
Measure the supply voltage at switch pin 2 to GND with ignition on.

Set value : 8 - 15V

Check the fuse if set value is not attained.

2. Ignition off
Measure the supply voltage at the detached plug.
Depress the brake.

3. Check wiring between switch pin 1 and ECU pin 59.

Brake switch 2 (Redundant brake switch)
Measure the supply voltage at switch pin 4 to GND with ignition on.

Set value : 8 - 15V

Check the fuse if set value is not attained.

5. Ignition off
Measure the resistance of switch at the detached plug.
Depress the brake.

6. Check wiring between switch pin 3 and ECU pin 4.

CLUTCH SWITCH

* MT vehicle Only

1. Possible DTC: P704

- CC-CODE

1) C004 (Plausibility error)
Without changing of clutch signal, if vehicle speed is above the set value , error is detected.
- Possible causes of trouble:
A. Open circuit in wiring, Short circuit
B. Fuse defective
C. Poor connection
D. Switch defective

Measure the voltage at switch pin (ECU side) to GND with ignition on.

Set value : 8 - 15V

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3. Check wiring if set value is not attained.
Ignition off
Measure the resistance of switch at the detached plug.

Set value : ---- > 1 MΩ

Depress the clutch pedal.

Set value : 0 - 1Ω

---

4. Check wiring between switch and ECU pin 61.

5. Clutch disengage
Clutch engage // Signal on

MAIN RELAY

1. Possible DTC: P1616

- CC-CODE

1) C004 (Plausibility error)
Without changing of ignition switch position "ON" → "OFF", If main relay is turned off, error is detected.
Before ECU is shut off, if ignition switch and main relay are turned off, error is detected
- Possible causes of trouble:
A. Open circuit in wiring, Short circuit
B. Contact resistance
C. Fuse defective
D. Main relay defective

2. After ignition on, check the supply voltage of ECU pin 4 to GND and ECU pin 5 to GND.

Set value : 8 - 15V

---

3. If set value is not attained , check wiring an fuses.

4. If wiring and fuses are OK, replace the main relay.

IGNITION SWITCH

1. Possible DTC : P1652

- CC-CODE

1) C004 (Plausibility error)
After ignition off, if ignition switch signal keeps "OFF" continuously, error is detected.
- Possible causes of trouble:
A. Open circuit in wiring, Short circuit
B. Contact resistance
C. Fuse defective
D. Switch defective

2. Measure the voltage at switch from ECU pin 58 to GND with ignition on.

Set value : 8 - 15V

Check wiring and fuse if set value is not attained.
Ignition off
Measure the resistance of switch at the detached plug.

MAXIMUM VEHICLE SPEED LIMITATION

1. Possible DTC: P1530

   1) C003 (General error)
   In comparision of maximum vehicle speed set value with actual vehicle speed , if it exceeds set value, error is detected.
   - Possible causes of trouble:
   A. Vehicle speed sensor defective
   B. ECU defective

2. Check wiring between ECU pin 49 and vehicle speed sensor.

INJECTOR

1. Possible DTC: P0201 (Sylinder #1 Injector)
   P0202 (Sylinder #2 Injector)
   P0203 (Sylinder #3 Injector)
   P0204 (Sylinder #4 Injector)

   • CC-CODE
   1) C018 (Line : Short circuit)
   Engine can be severely damaged due to continuous fuel injection.
   - Possible causes of trouble:
   A. Short circuit of high side line to Bat
   B. Shrot circuit of low side line to GND
   C. Injectors
   D. Injector voltage (ECU)
   2) C019 (Line : Open circuit)
   - Possible causes of trouble:
   A. High side line or low side line broken
   B. Contact resistance
   C. Injectors
   D. Injector voltage (ECU)

2. Ignition off. Check wiring between ECU and injectors.

	Injector 1	ECU	Injector 2	ECU
Pin NO.	1	114	1	121
Pin NO.	2	117	2	118

	Injector 3	ECU	Injector 4	ECU
Pin NO.	1	120	1	119
Pin NO.	2	118	2	117

Measure the resistance of injectors with plug disconnected.

Set value : 0.3 - 0.6 ohm (at room temperature)

3. Check the actuation of injectors with clip- on ammeter of Motortester.
   Clip-on ammeter must satisfy the following conditions.

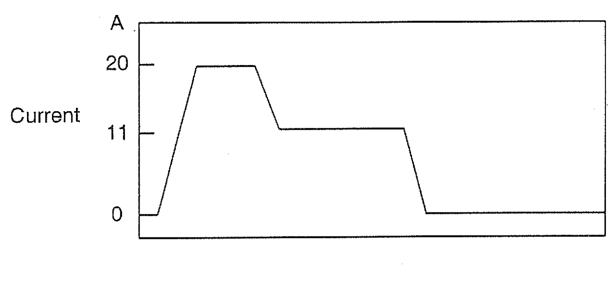
   Measuring range >25A
   Bandwidth >100 kHz

4. Attach the plug to injector
   Fasten clip-on ammeter around lead to pin 2 of corresponding injector.
   Allow the engine to idle. Set value : Refer to the following Fig. Injector set value(current) on next page.

   NOTE
   1) Length of holding current phase (Max. 12A) is governed by engine speed, injection time, and changes on acceleration.
   2) The first current curve shows the pre-injection.

5. Check whether injector injects fuel. To do so, pull off the injector plug in each case and connect to replacement injector.
   If change to engine running results, injector is injecting.
   If no change to engine running results injector is not injecting.

   This test cannot however establish whether an injetor is injecting correct quantity.
   If necessary, all injectors have to be replaced.



[Injector set value (Current)]

AFTER RUN TEST

1. After run test conditions
   1) Ignition switch : "ON" → "OFF".
   2) Engine rpm is within set value.
   3) Actual vehicle speed is below the set value.
   4) Rail pressure sensor and vehicle speed sensor is OK.

2. Possible DTC: P1653
   - When energizing time is "0" after run test mode, if engine rpm is not below the set value within set time , error is detected.
   - When injector power stage is shut off, if engine rpm is not below the set time within set time, error is detected.
   - Possible causes of trouble:
     A. Open circuit in wiring, or Short circuit
     B. Poor connection
     C. ECU

   Several tests are implemented in ECU after switching off the Ignition.
   This fault entry occurs if ECU detects any faults during these tests.

3. Start by rectifying any other stored faults.

   Then cancel the fault memory and perform the test drive.

4. Measure the supply voltage at ECU pin 114 (Cylinder #1 injector), pin 119 (Cylinder # 4 injector) to ECU Pin 117 and ECU pin 120 (Cylinder # 3 injector), pin 121 (Cylinder # 2 injector) to ECU Pin 118 with ignition off.

   Set value : 0 V

   Check wiring if set value is not attained.

5. If wiring is OK , replace ECU.

REMOVAL AND INSTALLATION OF INJECTOR

ATTENTION

1) **Fuel system is subject to extremely high pressure (1350 bar).**
2) **Never perform any work on injection system with engine running or within 30 seconds after stopping the engine.**
3) **Always pay attention to safety precautions.**
4) **Ensure the absolute cleanliness.**
5) **Never remove the injectors.**

1. Removal
   1) Disconnect the negative battery (-) terminal.
   2) Pull off the injector electric connector.
   3) Unfasten the high pressure pipe at rail and injector.
   4) Press in clip to back leak rail by hand and pull out back leak rail.
   5) Attach the connection of back leak rail. Never fit without clip.
   6) Remove the copper sealing ring.

2. Before re-installing injector, clean the cylinder head bore and sealing surface.
   1) Insert the brush.
   2) Clean the sealing surface and blow out.

3. Installaion
   1) Insert a new copper sealing ring (if necessary, apply small quantity of grease to bond it to injector).
   2) Install the injector (do not touch the nozzle tip) and sliding clamp with clamp bolt.
   3) Screw the clamp bolt .

   Tightening torque : 2.7 ± 0.2 kg· m

   4) Install the high pressure pipes.

   Tightening torque : 1.8 - 2.3 kg· m

   * When mounting the high pressure pipes, fix the hexagon component of high pressure fuel injection parts not to squeeze heavily the high pressure fuel injection parts.

   5) Attach the connection of back leak rail. Never fit without clip.
   6) Check the tighteness of back leak rail by tugging it.
   7) Attach the electric connector.
   8) Re-connect the negative battery(-) terminal.
   9) Start the engine and check the high pressure circuit for leaks.

4. Read out the fault memory and cancel the faults stemming from the detached injector plug.

HIGH PRESSURE PUMP

ATTENTION

1) **Fuel system is subject to extremely high pressure (1350 bar).**
2) **Never perform any work on injection system with engine running or within 30 seconds after stopping the engine.**
3) **Always pay attention to safety precautions.**
4) **Ensure the absolute cleanliness.**

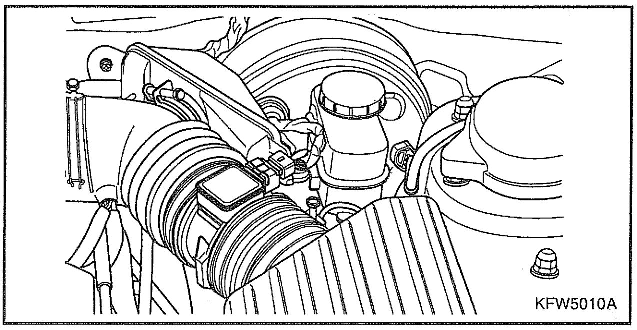
INSTALLATION

1) **Insert the coupling into the pump**
2) **Lightly apply the grease to O-ring and install the pump in cylinder head. At this time, turn the pump until the shaft stub of the pump engages the camshaft.**
3) **Apply the medium- strength screw locking compound to the bolt threads**
4) **Install the retaining bolts with washers and tighten to**

1.3 - 1.8 kg· m

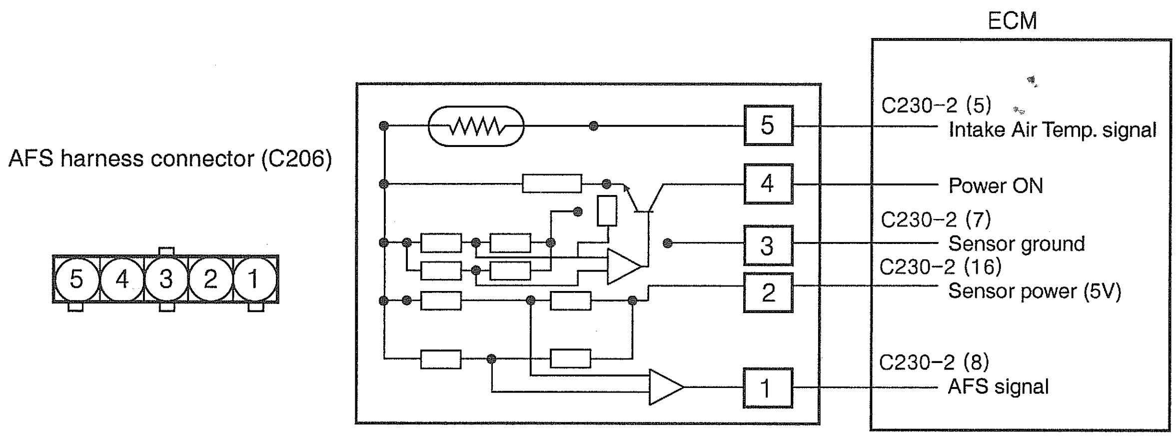
EDC COMPONENT INSPECTION

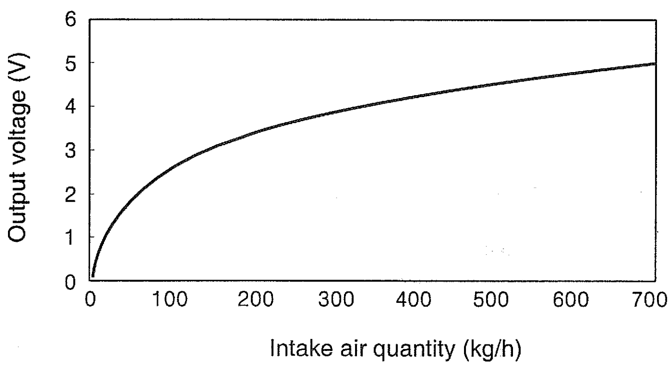
AIR FLOW SENSOR (AFS)



AFS uses the features of sensor heater, after HOT FILM units calculate the intake air quantity, then send the signal to ECM.
ECM decides the fuel quantity and ignition timing, and recognizes uphills and helps fuel quantity and overrun airconditioner compensation, idle speed actuator AFS might be combined to measure the intake air temperature.

[CIRCUIT DIAGRAM]

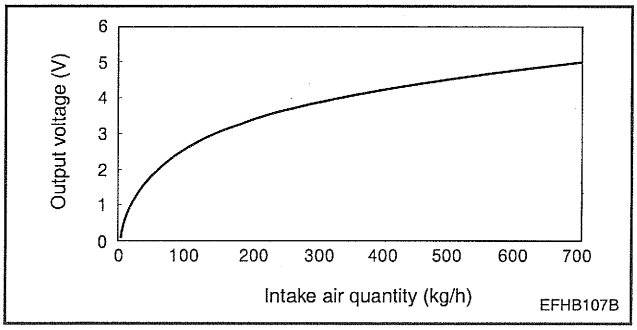




EFHB106B / EFHB107B

[HOT FILM AFS OUTPUT FEATURES]

Air quantity (kg/h)	Output voltage (V)
8	1.248 - 1.265
10	1.318 - 1.339
15	1.474 - 1.500
30	1.820 - 1.856
60	2.302 - 2.347



TEST PROCEDURE

- o Engine state : Operating
- o Fault code : P0100

YES ↓

- o Check wiring and ECM for poor connection.
- o Connection is OK?

NO → o Repair wire or connector.

YES ↓

- o Check the AFS.
- o Is it OK?

NO → o Repair sensor.

YES ↓

- o Cancel the stored error code.
- o Is there still existing error code after rechecking?

YES ↓

- o Replace the ECM.

TROUBLESHOOTING HINTS

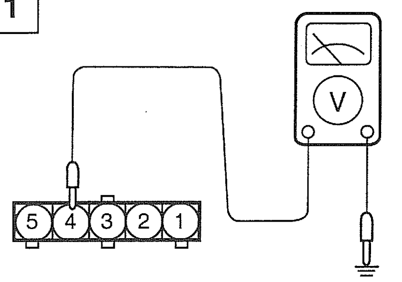
1. If engine is intermittently starting, after starting the engine, shake AFS harness up. Inspect the contact troubles of AFS connetor, if engine stops.
2. When Ignition switch is turned on, if AFS output voltage is not "0" (engine stops), inspect the malfunction of AFS and ECM.
3. Even though AFS output voltage is abnormal, if engine is at idle ,inspect the following conditions.
   1) Chect the poor attachment of airflow, cut air duct, and air cleaner filter branched from AFS.
   2) Bad combustion in the cylinder or fault injector.
4. Even it no AFS malfunction occurs, check the mounting direction of AFS.

NOTE

1. **In case of new vehicle (mileage : below 500km) AFS air quantity is above approx.10%.**
2. **Use correct digital voltmeter.**
3. **Before inspection, warming up the engine till the engine coolant temperature is up to 80~90°C.**

AFS HARNESS INSPECTION PROCEDURES

1



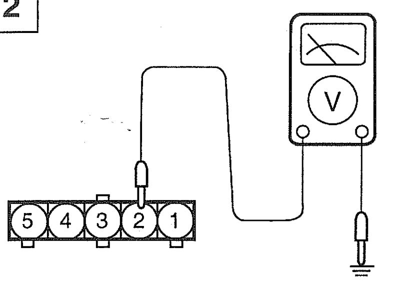
Measure the power supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : Battery voltage

OK ⇒ **2**

NG ⇒ Repair the harness

EFHB108B

2



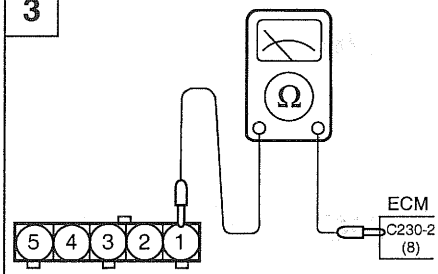
Measure the sensor power voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.8 - 5.3V

OK ⇒ **3**

NG ⇒ Repair the harness

EFHB109B

3



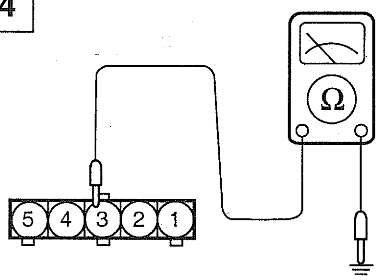
Check for a short wiring, or a short circuit between AFS and ECM harness
- o Connector : Disconnected

OK ⇒ **4**

NG ⇒ Repair the harness

EFHB110B

4



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

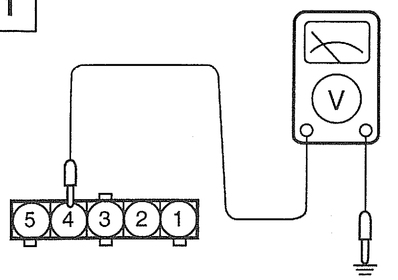
OK ⇒ **END !**

NG ⇒ Repair the harness

EFHB111B

INTAKE AIR TEMPERATURE SENSOR HARNESS INSPECTION PROCEDURE

1



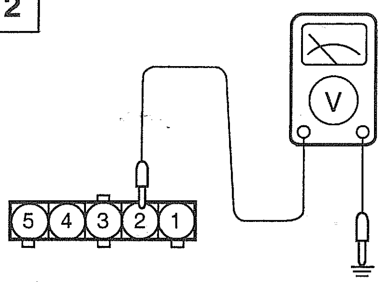
Measure the power supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : Battery voltage

OK ⟹ **2**

NG ⟹ Repair the harness

EFHB108B

2



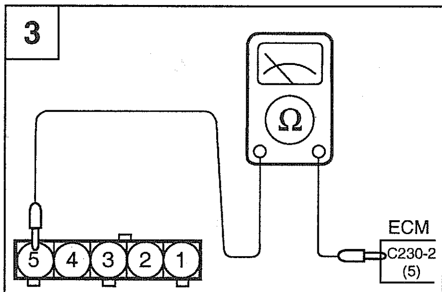
Measure the sensor power voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.8 - 5.3V

OK ⟹ **3**

NG ⟹ Repair the harness

EFHB109B

3



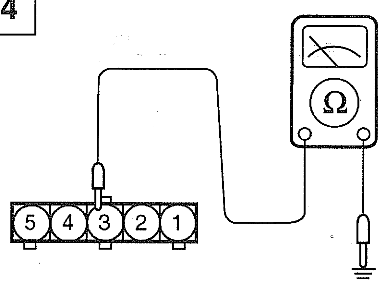
Check for a short wiring, or a short circuit between ECM and intake air temperature sensor
- o Connector : Disconnected

OK ⟹ **4**

NG ⟹ Repair the harness

EFHB114B

4



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

OK ⟹ **END !**

NG ⟹ Repair the harness

EFHB111B

TEST PROCEDURE (INTAKE AIR TEMPERATURE SENSOR)

- o Engine : Operating
- o Fault code : P0110

YES ↓

- o Check the harness or connector.
- o Is it normal?

NO → o Repair the harness or connector.

YES ↓

- o Check the intake air temperature sensor.
- o Is it normal?

NO → o Replace the sensor.

YES ↓

- o Cancel the stored error code.
- o Is there still existing error code after re-checking?

YES ↓

- o Replace the ECM.

SENSOR INSPECTION

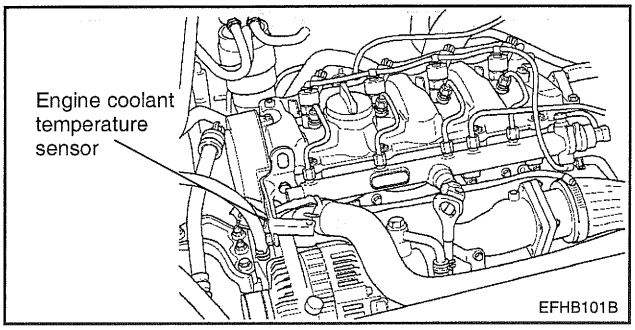
1. Inspect the resistance of sensor using a multi-tester.
2. Measure the resistance between intake air temperature sensor and terminal.

CONDITION	TEMPERATURE (°C)	RESISTANCE (kΩ)
Ignition switch ON	0	5.12 - 5.89
	20	2.29 - 2.55
	40	1.09 - 1.24
	80	0.31 - 0.37

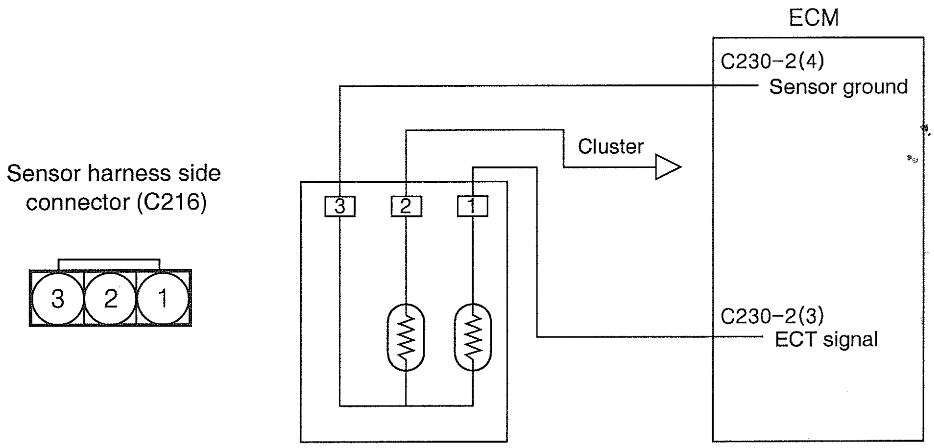
3. If resistance value is out of standard, replace the intake air temperature sensor assembly.

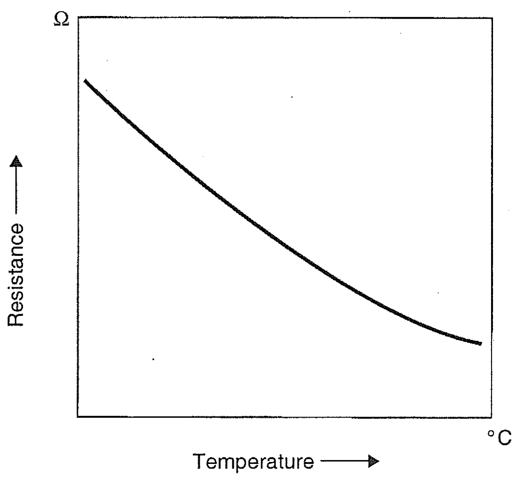
ENGINE COOLANT TEMPERATURE SENSOR (ECT)

The engine coolant temperature sensor located in the engine coolant passage of the cylinder head. It detects the engine coolant teperature and relays signals to the ECU. It employs a thermistor, which is sensitive to changes in temperature. The electric resistance of a thermistor decreases in response to temperature rise. The ECU judges engine coolant temperture by the sensor output voltage and provides optimum fuel enrichment when the engine is cold.



[CIRCUIT DIAGRAM]

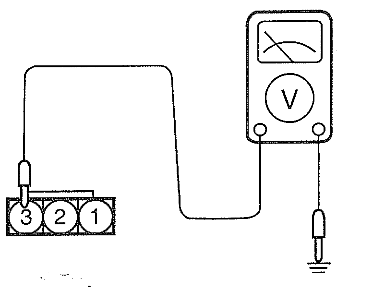
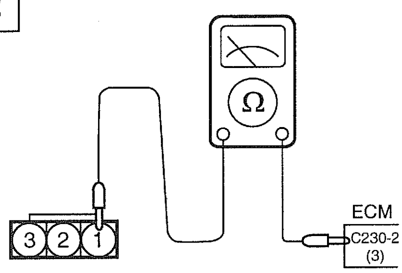




TROUBLESHOOTING HINTS

When idling speed is not appropriate or blacksmoke arises it is likely to be a defect of engine coolant temperature sensor.

HARNESS INSPECTION PROCEDURES

1		Check for continuity of the ground sensor o Connector : Disconnected	OK ⇨ NG ⇨	2 Repair the harness
2		Check for a short wiring or a short circuit between ECM and ECT sensor o ECM Connector : Disconnected o ECT sensor Connector : Disconnected	OK ⇨ NG ⇨	END ! Repair the harness

EFHB117B

EFHB118B

SENSOR INSPECTION

USING HI-SCAN

Check item	Data display	Check conditions	Coolant temp.	Set value (HI-SCAN)
Engine coolant temperature sensor	Sensor temperature	• Ignition switch : ON or engine running	-20°C	-20°C
			0°C	0°C
			20°C	20°C
			40°C	40°C
			80°C	80°C

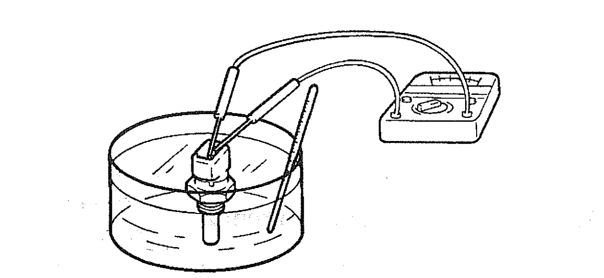
USING MULTITESTER

1. Remove the engine coolant temperature sensor from the engine coolant passage of the cylinder head.
2. With the temperature sensing portion of the engine coolant temperature sensor immersed in hot water, check resistance.
   1) ECT sensor

Temperature (°C)	Resistance (kΩ)
-20	14.13 ~ 16.83
0	5.790
20	2.31 ~ 2.59
40	1.148
60	0.586
80	0.322

   2) Gauge unit

Temperature (°C)	Resistance (Ω)
60	125
85	42.6 ~ 54.2
110	22.1 ~ 26.2
125	15.2


EFDA711C

3. If the resistance deviates from the standard value greatly, replace the sensor.

INSTALLATION

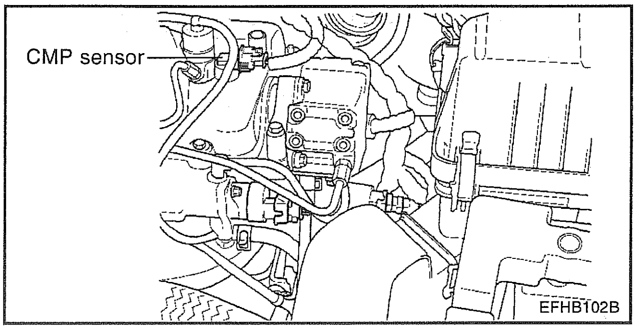
1. Apply sealant LOCTITE 962T or equivalent to threaded portion.
2. Install engine coolant temperature sensor and tighten it to specified torque.

Tightening torque : 2.0 ~ 4.0kg· m

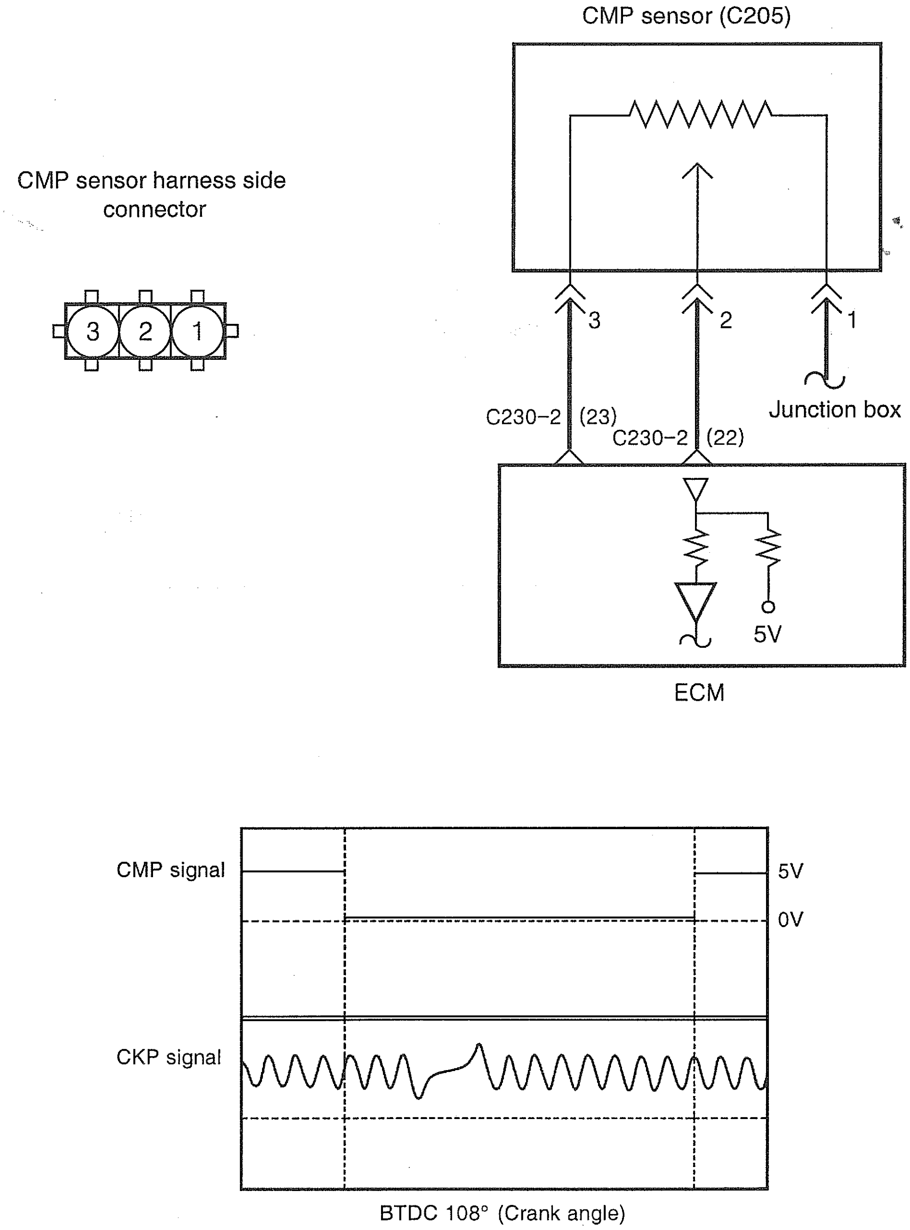
3. Connect the harness connector securely.

CAMSHAFT POSITION SENSOR (CMP)

CMP senses the CMP(Camshaft Position Sensor) point of NO.1,4 cylinder on its compression stroke. Its signal is fed to ECM to be used to determine the sequence of fuel injection.
Crank angular sesor senses the crank angular of each cylinder, and input the pulse signal to ECM. Its signal is fed to ECM to be used to determine the engine speed and adjust the fuel injection timing and ignition timing.



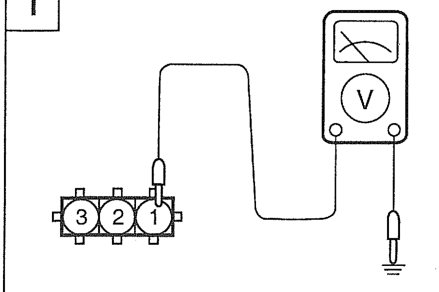
[CIRCUIT DIAGRAM]



EFHB119B / EFHB120B

HARNESS INSPECTION PROCEDURES

1



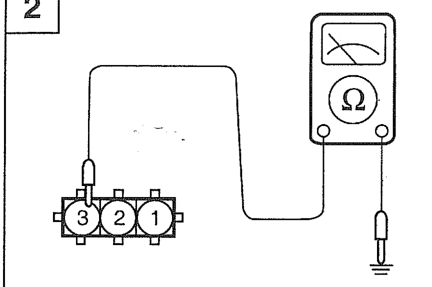
Measure the power supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : Battery voltage

OK ⇒ 2

NG ⇒ Repair the harness

EFHB121B

2



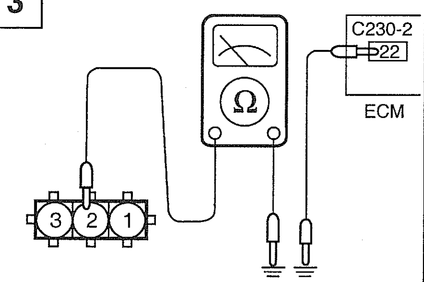
Check for continuity of the ground sensor
- o Connector : Disconnected

OK ⇒ 3

NG ⇒ Repair the harness

EFHB122B

3



Check for a short wiring or a short circuit to ground between TDC sensor and ECM.
- o Connector : Disconnected

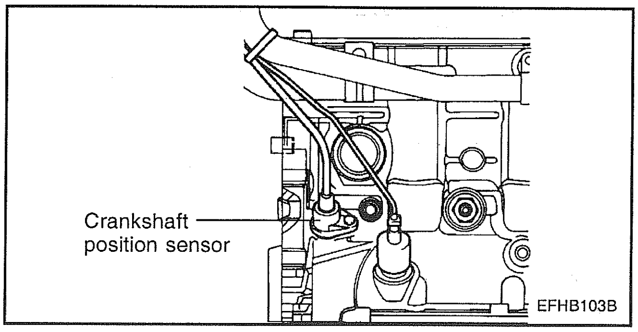
OK ⇒ END !

NG ⇒ Repair the harness

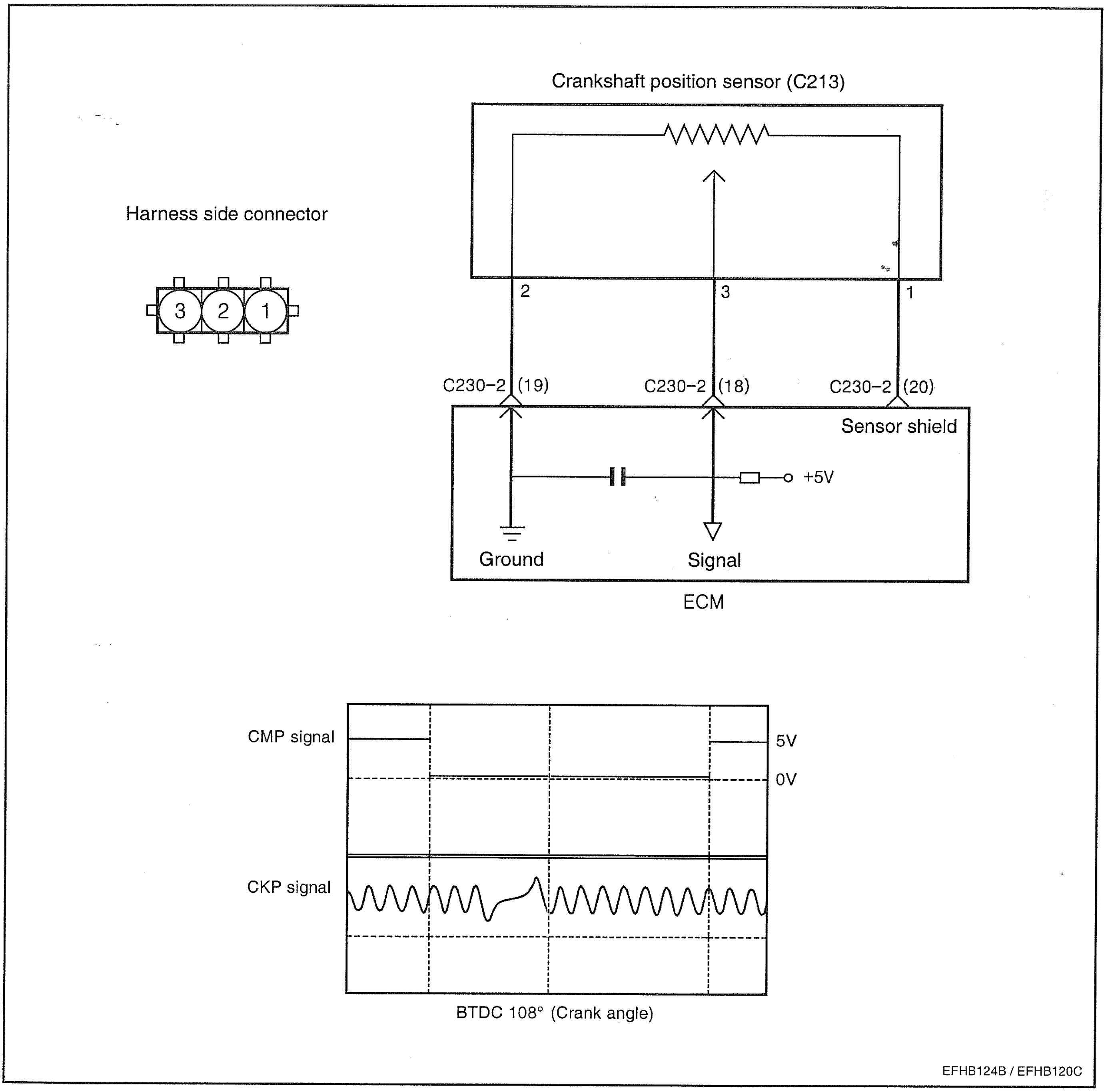
EFHB123B

CRANKSHAFT POSITION SENSOR (CKP)

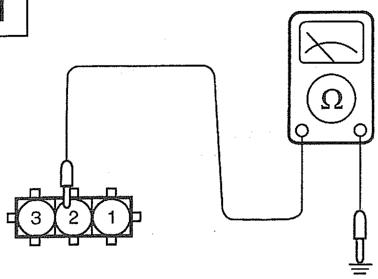
Piston position on combustion chamber is the substantial to define the starting of injection timing. All engine pistons are connected to crankshaft by connecting rod. Sensor on crankshaft can supply the informations concerning all piston positions, revolution speed is defined by revolutin per minute of crankshaft. Prior input variable is determined at ECM by using signal from induced crankshaft speed sensor.



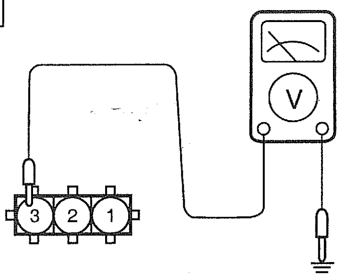
[CIRCUIT DIAGRAM]



HARNESS INSPECTION PROCEDURES

1		Check for continuity of the ground sensor o Connector : Disconnected	OK ⇨ NG ⇨	2 Repair the harness

EFHB125B

2		Measure the power supply voltage o Connector : Disconnected o Ignition switch : ON o Voltage(V) : 4.8 - 5.2V	OK ⇨ NG ⇨	END ! Repair the harness

EFHB126B

SENSOR INSPECTION

1. Remove the crankshaft position sensor connector.
2. Measure the resistance between terminal NO.1 and NO.2.

Standard value : 0.65 ~ 1.00kΩ

3. If the resistance deviates from the standard value greatly, replace the sensor.

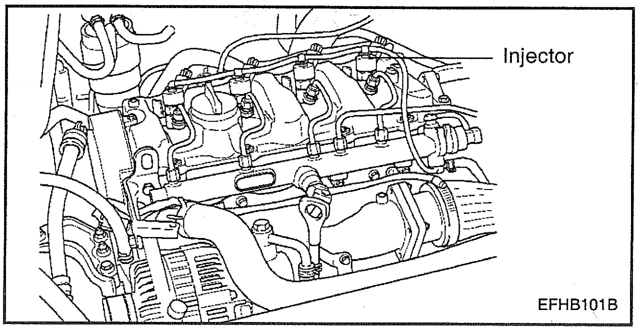
Clearance between crankshaft position sensor and CKP wheel : 0.5 ~ 1.5mm

4. Install the sensor observing the specified torque.

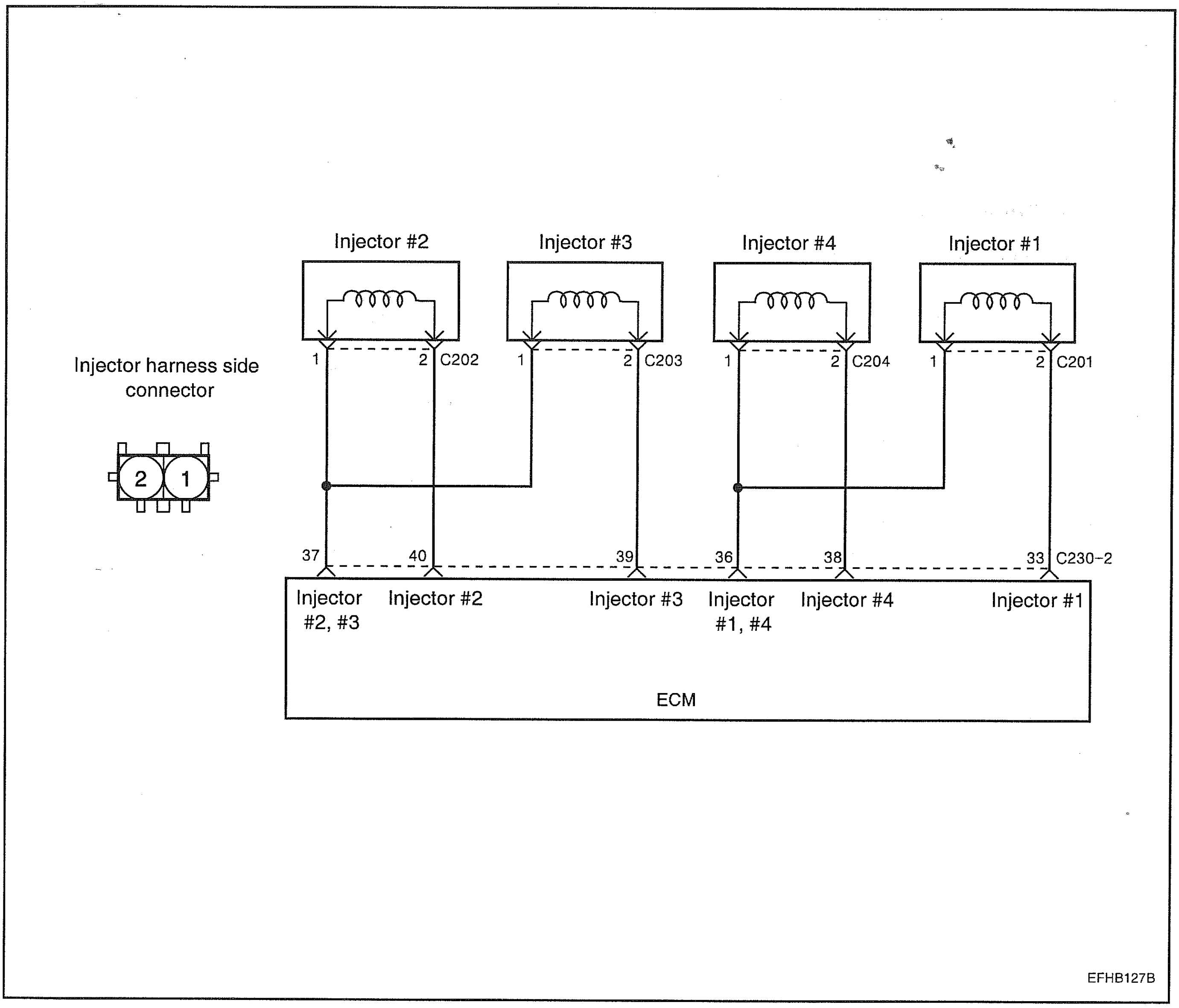
Specified torque : 0.4 ~ 0.6kg· m

INJECTOR

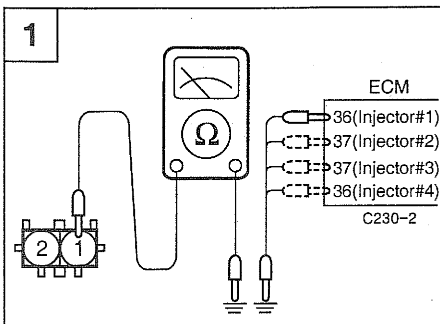
Special injectors with hydraulic servo-system and electrical triggering element (solenoid valve) are used with the Common Rail system in order to achieve efficient start of injection and precise injected fuel quantity. At the start of injection, a high pickup current is applied to the injector so that the solenoid valve opens quickly. As soon as the nozzle needle has travelled its complete stroke, and the nozzle has opened completely, the energizing current is reduced to a lower holding value. The injected fuel quantity is now defined by the injector opening time and the rail pressure. Injection is terminated when the solenoid valve is no longer triggered and closes as a result.



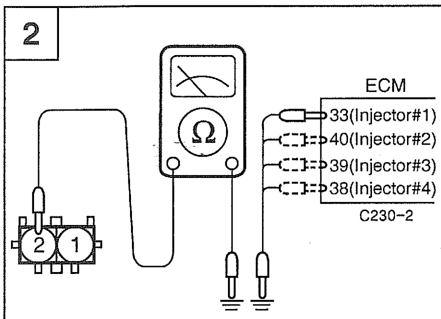
[CIRCUIT DIAGRAM]



HARNESS INSPECTION PROCEDURES

1 	Check for an open-circuit, or a short-circuit between ECM and injector o ECM Connector : Disconnected o Injector connector : Disconnected o Ignition switch : OFF	OK ⇒	2
		NG ⇒	Repair the harness

EFHB128B

2 	Check for an open-circuit, or a short circuit between ECM and injector o ECM Connector : Disconnected o Injector connector : Disconnected o Ignition switch : OFF	OK ⇒	END !
		NG ⇒	Repair the harness

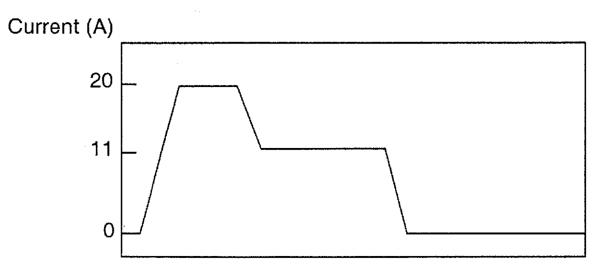
EFHB128C

INJECTOR OPERATION INSPECTION

1. Using a clip-on ammeter of motor tester, check actuation of injector. Clip-on ammeter must satisty the following conditions.

Measuring range > 25A
Bandwidth > 100kHz

2. Attach the plug to the injector. Fasten clip-on ammeter around lead to pin.2 of corresponding injector. Allow engine to be at idle.
   Refer to the set value(current) as following figure.



EFHB201D

NOTE

1. **Length of holding current phase (max.12A) is governed by engine speed, injection time and changes on velocity.**
2. **The first current curve shows the pre-injection.**

3. Check the injector for injecting of fuel. As checking procedure, detach the injector plug from each boxes and connect to replaced injector.

   If change to enine running results, injector is injecting. If no change to engine running results, injector is not injecting.

   This test cannot however establish whether an injector is injecting an correct quantity.
   If necessary, all injectors have to be replaced.

AFTER RUN TEST

1. After run test
   1) Ignition switch : ON → OFF.
   2) Engine rpm is within set value.
   3) Actual vehicle speed is below set value.
   4) Rail pressure sensor and vehicle speed sensor have no error.

2. Possible DTC:P1653
   1) When energizing time is "0" at after run test mode, if engine rpm is not below the set value within set time, error is detected.
   2) When injector power stage is shut off, if engine rpm is not below set value within set time, error is detected.
   3) Possible causes of trouble
      - Open circuit in wiring or short circuit
      - Poor connection
      - ECM

   Several tests are implemented in the ECM after switching off the ignition. This fault entry occurs if ECM detects and faults during these tests.

3. Start by rectifying any other stored faults. Then cancel the fault memory and perform the test drive.

4. Measure the supply voltage at ECM pin 33(Cylinder #1 Injector), pin 38(Cylinder #4 Injector) to pin 36 and pin 39(Cylinder #3 Injector), pin 40(Cylinder #2 Injector) to pin 37 with ignition OFF.

Set value : 0V

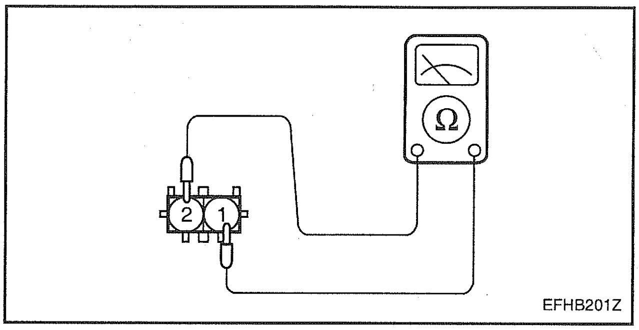
5. Check wiring if set value is not attained. If wiring is OK, replace the ECM.

MEASURE THE RESISTANCE BETWEEN TERMINALS

1. Detach the connector from injector.

2. Measure the resistance between terminals.

Specified value : 0.3 ~ 0.6Ω (at 20°C)

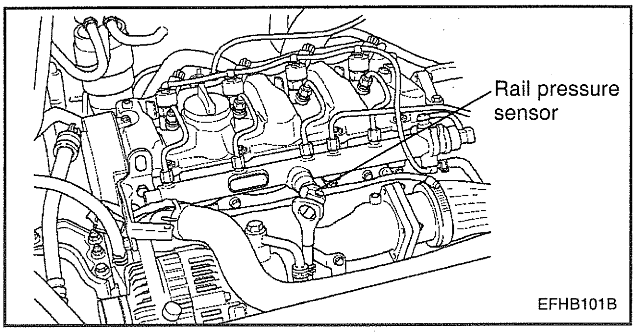


EFHB201Z

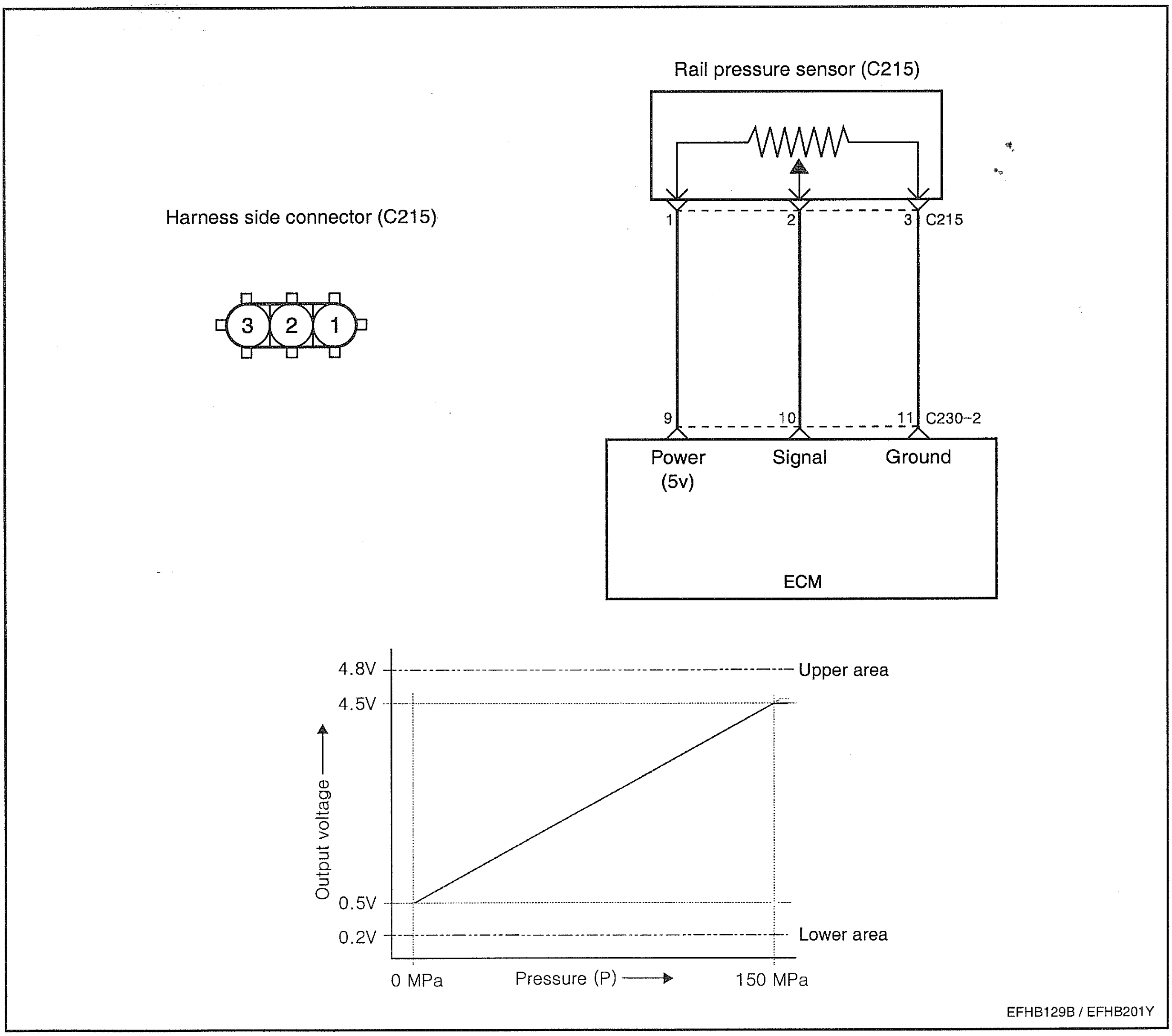
3. Connect the connector to the injector.

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]



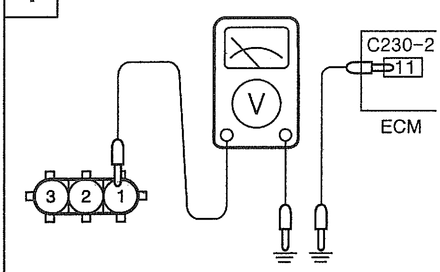
SENSOR INSPECTION

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



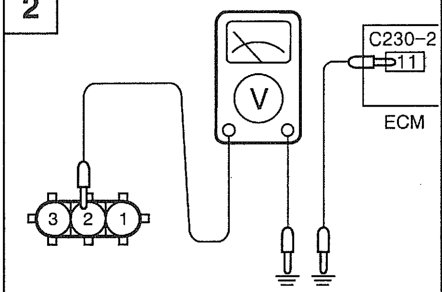
Measure the power supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.5 - 5.5V

OK ⇒ 2

NG ⇒ Repair the harness

EFHB130B

2



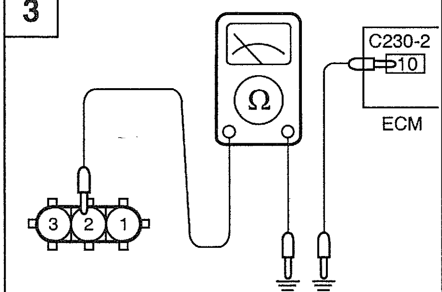
Measure the voltage of RPS harness side connector #2 terminal to the ground with ignition on.
- o Set value : 0.5V
- o Engine idling set value : 1V
- o Voltage increases with inereasing pressure : Max. 4.5V

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.

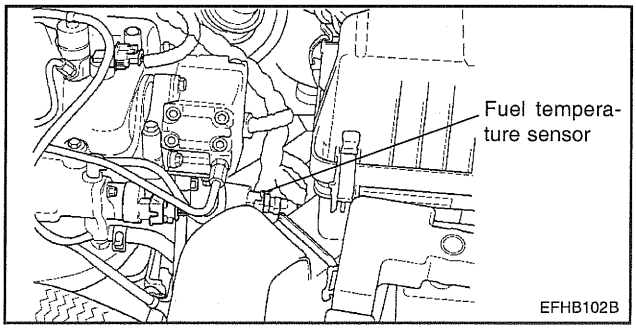
2. Note the followings.
   1) Always renew the sealing washer (soft iron sealing ring) even if old sensor is re-used.
   2) When removing seal, take care not to damage sealing surface.
   3) When installing RPS, provide the sealing washer with grease if necessary.
   4) Tightening torque is 35 ± 2 Nm.

NOTE

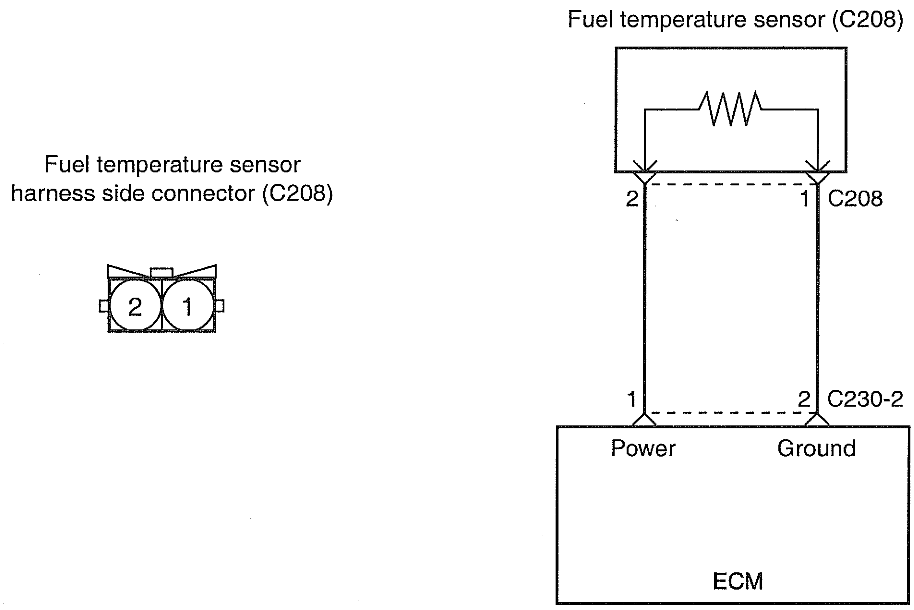
Replace the faulty fuel rail assembly in case of new model vehicle within a year, or replace the faulty parts of vehicle of which model year is more than a year.

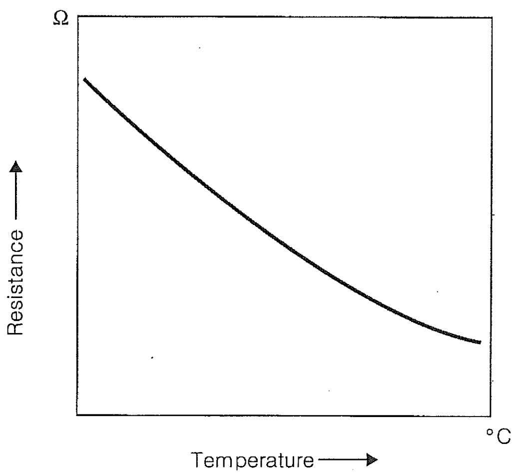
FUEL TEMPERATURE SENSOR (FTS)

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]





EFHB132B / EFHB322A

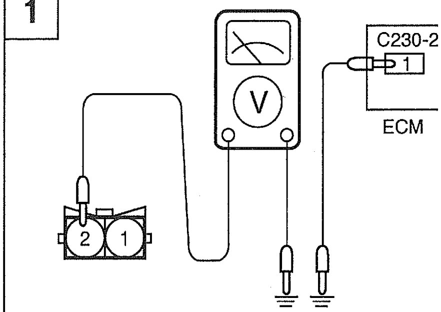
SENSOR INSPECTION

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



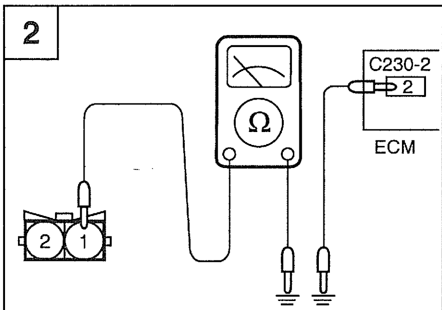
Measure the supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage : 4.8 - 5.2V

OK ⇨ **2**

NG ⇨ Repair the harness

EFHB133B

2



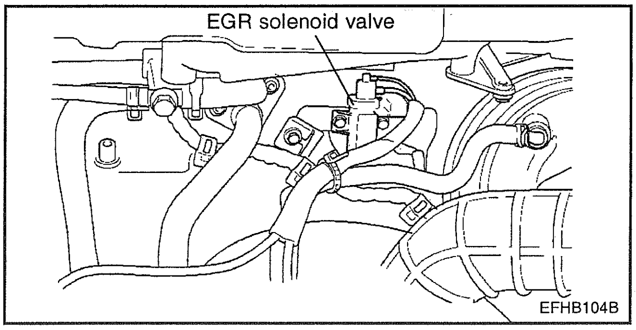
Check for an open circuit, or a short circuit to the ground between ECM and fuel temperature sensor.
- o ECM Connector : Disconnected
- o Fuel temperature sensor connector : Disconnected

OK ⇨ **END !**

NG ⇨ Repair the harness

EFHB134B

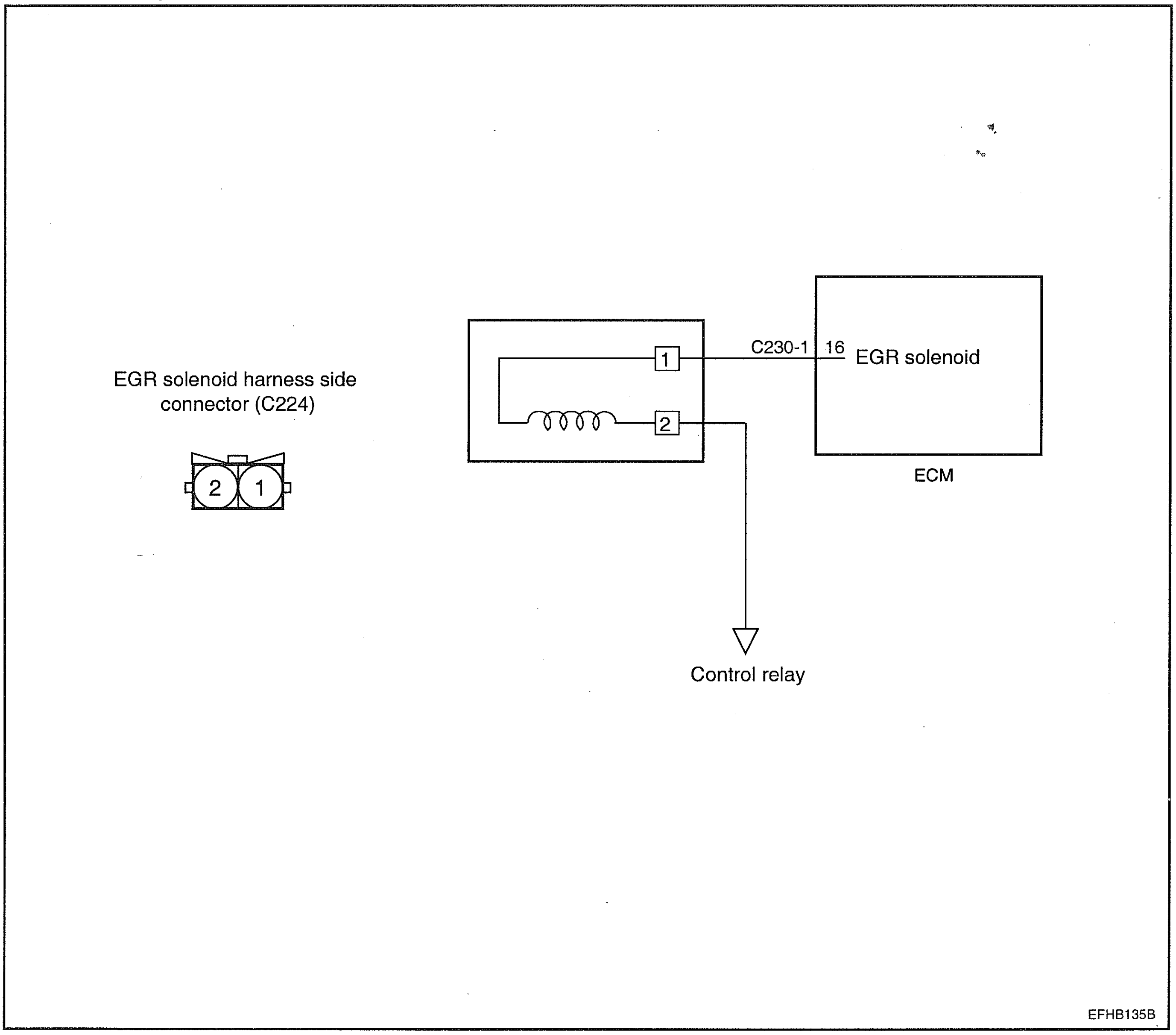
EGR SOLENOID VALVE



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.

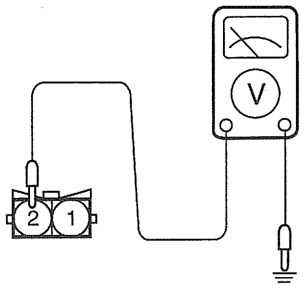
For ECM control, the actual drawn-in fresh-air mass is measured and compared at each operating point with the air-mass setpoint value. Using the signal generated by the control circuit, the EGR valve opens so that exhaust gas can flow into the intake tract.

[CIRCUIT DIAGRAM]



HARNESS INSPECTION PROCEDURES

1



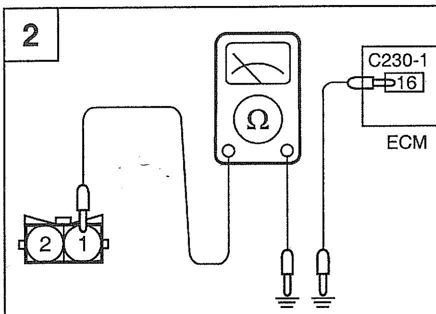
Measure the supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : Battery voltage

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

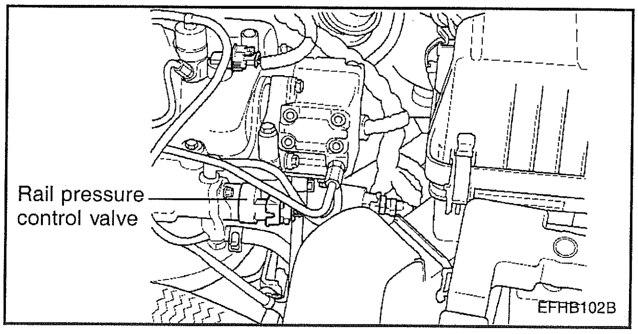
Check item	Check condition	Engine condition	Standard value
EGR solenoid valve	solenoid valve OFF → ON	Ignition switch : ON	Check the sound for proper operation

USING VOLTMETER

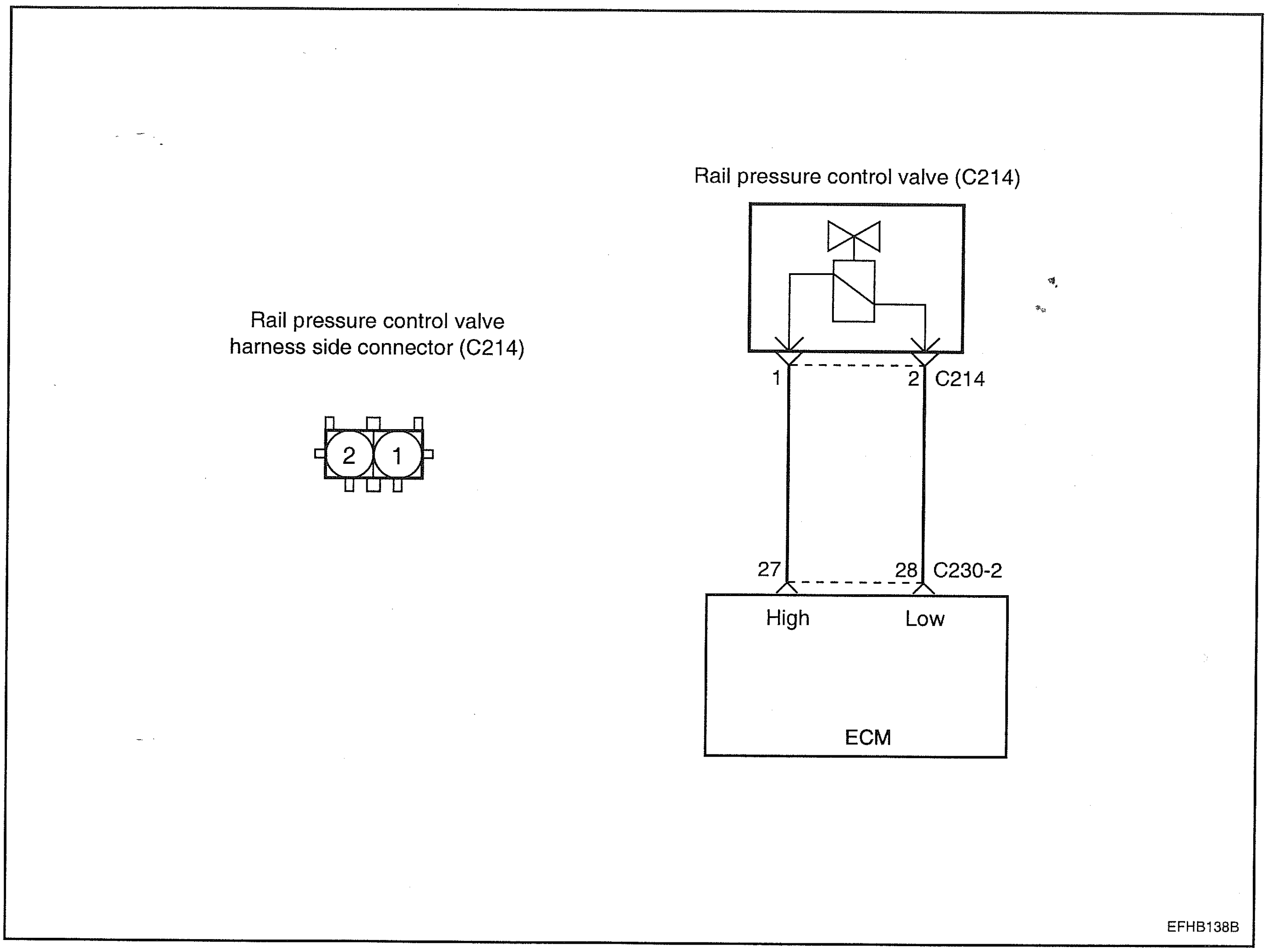
Check item	Specified value
EGR solenoid valve resistance	14 ~ 17Ω

RAIL PRESSURE CONTROL VALVE

The rail pressure-control valve sets the correct pressure in the rail as a function of engine loading, and maintains it at this level.
If the rail pressure is excessive, the pressure-control valve opens and a portion of the fuel returns from the rail to the fuel tank via a collector line.
If the rail pressure is too low, the pressure-control valve closes and seals off the high-pressure stage from the low-pressure stage.



[CIRCUIT DIAGRAM]



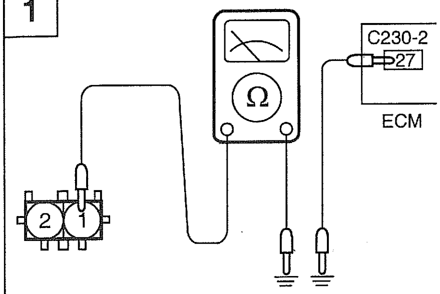
TROUBLESHOOTING HINTS

At after run test mode or fuel cut mode, if within set time engine rpm is not dropped below the lower set value, error is detected.

The reasons are short circuit, connecting resistance, faulty rail pressure sensor, continuity of fuel pump relay, faulty rail pressure control valve, defective high pressure pump, ECM fault, etc.

HARNESS INSPECTION PROCEDURES

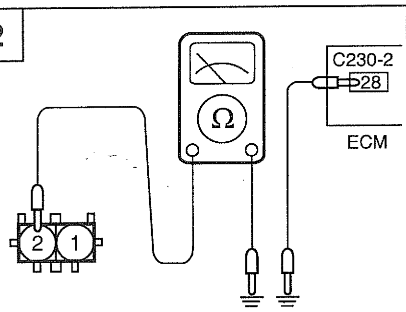
1



Check for an open circuit, or a short circuit to the ground between ECM and pressure control valve. o Connector : Disconnected	OK ⇨	2
	NG ⇨	Repair the harness

EFHB139B

2



Check for an open circuit, or a short circuit to the ground between ECM and pressure control valve. o Connector : Disconnected	OK ⇨	END !
	NG ⇨	Repair the harness

EFHB140B

RAIL RPRESSURE CONTROL VALVE INSPECTION

USING VOLTMETER

Check item	Set value (Ω)
Rail pressure control valve resistance	2.07 ~ 2.53Ω

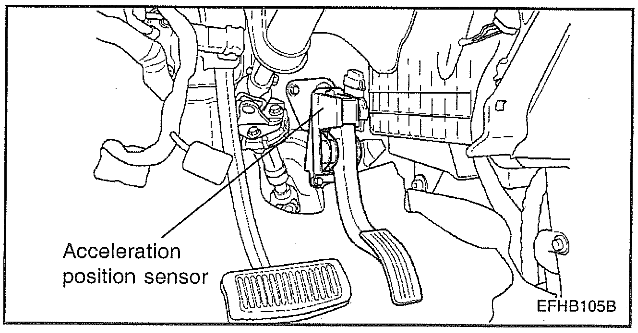
RAIL PRESSURE CONTROL VALVE REPLACEMENT

1. Replace the rail pressure control valve if signal voltage exceeds the set value.
2. Tightening torque for this replacement is 5 ± 1Nm.

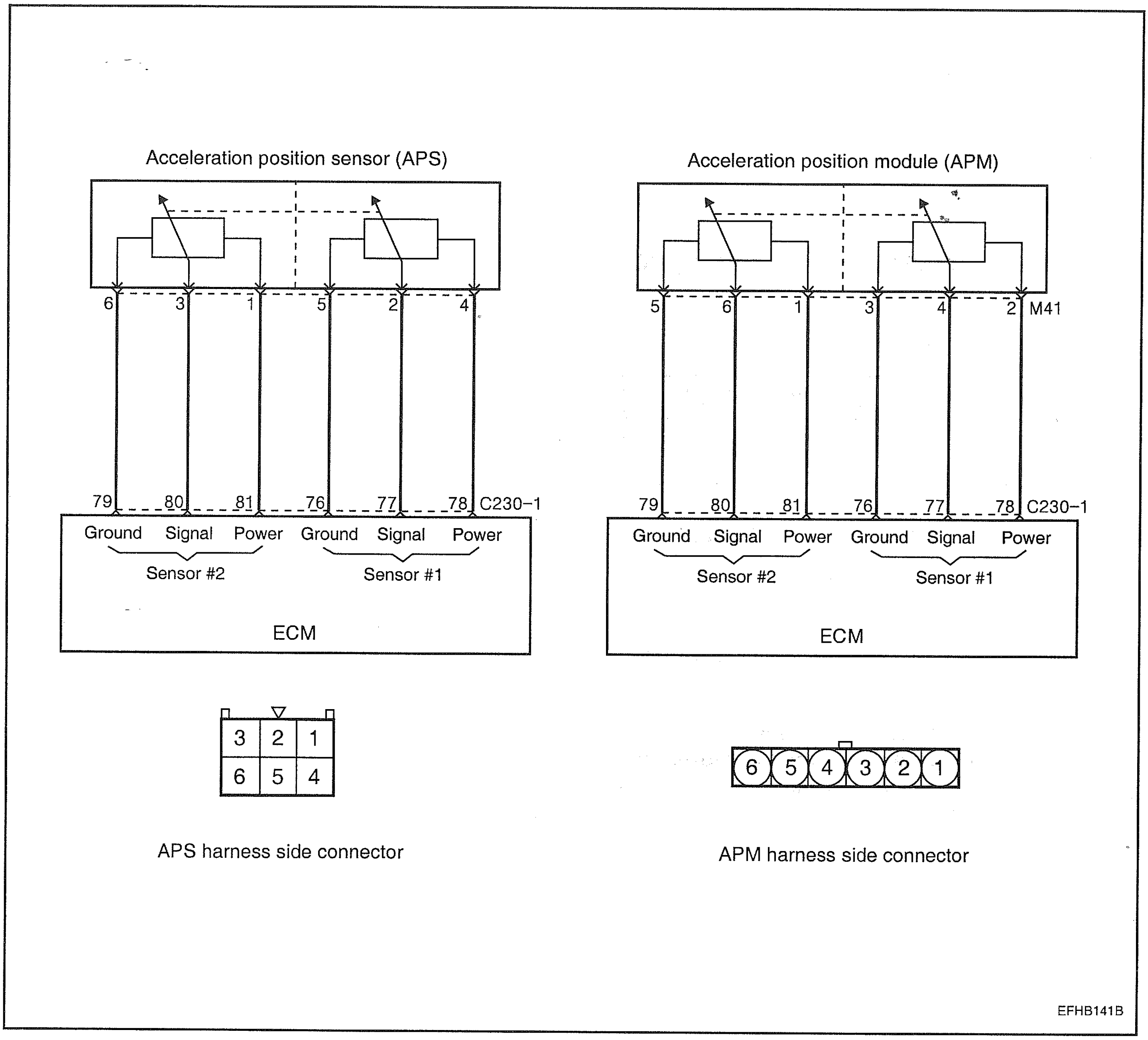
   NOTE
   Replace the faulty fuel rail assembly in case of new model vehicle within a year, or replace the faulty parts of vehicle of which model year is more than a year.

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.



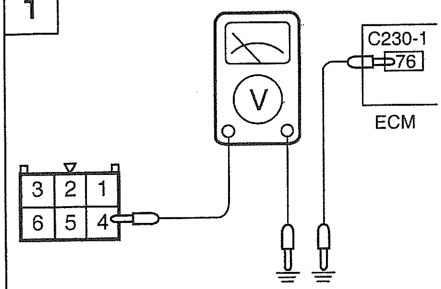
[CIRCUIT DIAGRAM]



HARNESS INSPECTION PROCEDURES

1. APPLYING ACCELERATION POSITION SENSOR (APS)

1



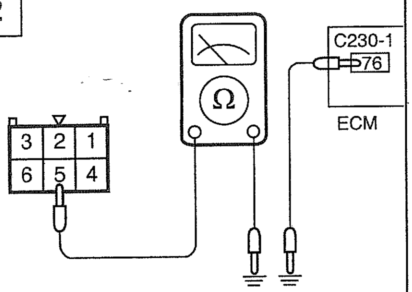
Measure the sensor supply voltage
- o Connector : Disconnected
- o Ignition switch : ON
- o Voltage(V) : 4.5 - 5.5V

OK ⇨ 2

NG ⇨ Repair the harness

EFHB142B

2



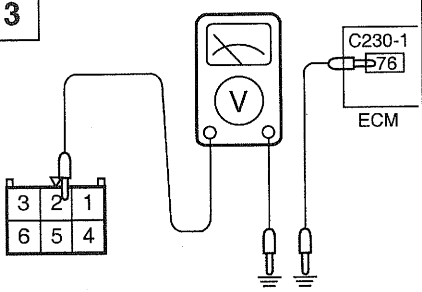
Check for an open circuit, or a short circuit between ECM and acceleration position sensor
- o Connector : Disconnected
- o Ignition switch : OFF

OK ⇨ 3

NG ⇨ Repair the harness

EFHB143B

3



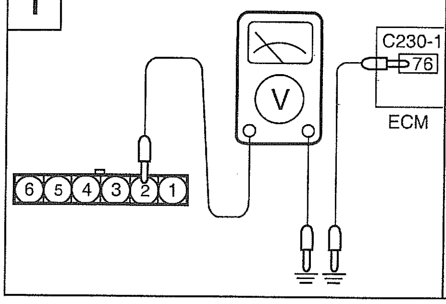
If contact lead is OK, measure the sensor signal voltage
- o at idle : 0.6 - 0.9V
- o at full throttle : 3.6 - 4.6V

OK ⇨ **END !**

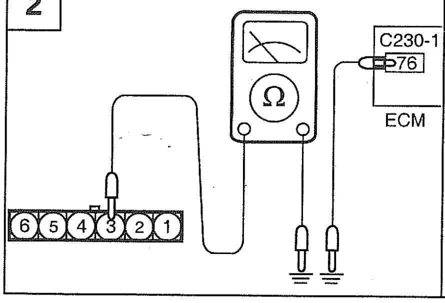
NG ⇨ Repair the harness

EFHB144B

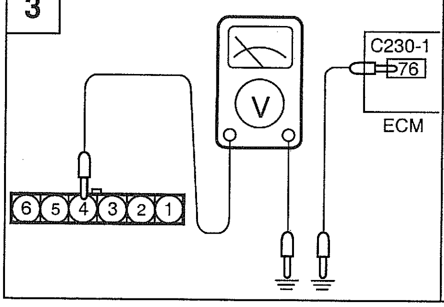
2. APPLYING ACCELERATION POSITION MODULE (APM)

1 	Measure the sensor supply voltage o Connector : Disconnected o Ignition switch : ON o Voltage(V) : 4.5 - 5.5V	OK NG	2 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 NG	3 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 NG	END ! Repair the harness

EFHB147B