



## Fuel injection and Ignition control system

### K-Motronic

With the introduction of the 1989 model year specification, turbocharged cars are equipped with a Bosch K-Motronic engine management system.

The K-Motronic system brings together the benefits of digital\* fuel injection and ignition control systems into a single electronic control unit (ECU). Other features of the system include cold start and warm-up enrichment, idle speed regulation, and automatic correction of any long term mixture strength deviations.

On cars fitted with catalytic converters the K-Motronic system also provides an 'on-board' self diagnostic facility.

**Note** \*Digital refers to an electronic data system where the information used is in discrete or quantized form (data in the form of digits), not continuous as with an analogue system.

The exhaust emission control systems (if fitted) include three catalytic converters (one warm-up converter and twin main converters), and air injection.

The fuel evaporative emission control system (if fitted) includes a charcoal absorption canister which is purged during specific engine operating modes.

A crankcase emission control system is fitted to all cars.

This section contains service information relating specifically to the K-Motronic digital system. Details for the other emission control systems are provided within their respective chapter (refer to the Contents page).

#### K-Motronic digital engine management system

The engine is equipped with several sensors that continuously monitor operating parameters such as engine speed, coolant temperature, and load (see fig. B4-19). The sensors are connected to a digital ECU which is programmed with characteristic data for the following functions, mixture strength control, ignition timing, idle speed control, purging of the evaporative emission control canister, and operation of the air injection system.

A separate electronic control unit is used for the boost pressure control system.

#### Fuel injection system

The Bosch KE3-Jetronic continuous fuel injection system incorporates certain components from the KE2-Jetronic system. In addition to digital electronic correction of the air/fuel mixture, the system also incorporates electronic regulation of the idle speed.

When the engine is running in the naturally aspirated mode, fuel delivery is directly proportional to intake air flow. During turbocharged modes of operation, electronic correction factors provide boost pressure compensation.

Control of the air/fuel ratio is provided by a

mixture control unit, comprising an air meter and a fuel distributor (see fig. B4-2).

Multi-point, mechanical fuel injectors are fitted.

Electronic correction of the air/fuel ratio is provided for start and warm-up phases of engine operation.

To achieve compliance with strict emission control regulations, cars fitted with catalytic converters require adjustment to the air/fuel ratio during part load engine operation. This is achieved by using a 'closed-loop' (lambda) control system. In this system a heated oxygen sensor measures the oxygen content of the exhaust gases and continuously adjusts the fuel flow to maintain a stoichiometric air/fuel ratio.

**Note** Components within the system may look similar to those used on other systems. However, visual inspection should not be used to identify replacement parts, as internal calibrations may be different.

#### Air flow sensing

The air meter consists of an air venturi (cone) in which moves an air flow sensor plate mounted on a pivoted lever (see fig. B4-3).

When the engine is operating the sensor plate is deflected into the air cone; the deflection being dependent upon the volume of air passing through the cone (i.e. throttle plates opening). The air deflects the sensor plate until a state of hydraulic balance exists; this being due to the force of the air pressure acting across the sensor plate area and the primary fuel pressure acting over the control piston area.

The weight of the air sensor plate and connecting lever are balanced by a counterweight on the fuel distributor side of the lever.

Any movement of the air sensor plate and lever about the pivot pin is transmitted to the control piston in the fuel distributor and the ECU by a potentiometer.

The movement of the control piston and its horizontal control edge (see fig. B4-5) either increases or decreases the open area of the eight metering slits (one for each engine cylinder) in the fuel distributor.

Differential pressure valves (one for each cylinder) located within the fuel distributor, maintain a constant pressure drop across the metering slits.

The air flow sensor plate and the control piston are operated by the same lever. Therefore, the rate of basic fuel discharge is proportional to the deflection of the air sensor plate within the calibrated cone, as governed by throttle plate opening.

Idle CO (idle mixture strength) is set during manufacture. Adjustment should not be necessary but can be achieved by removing the tamperproof

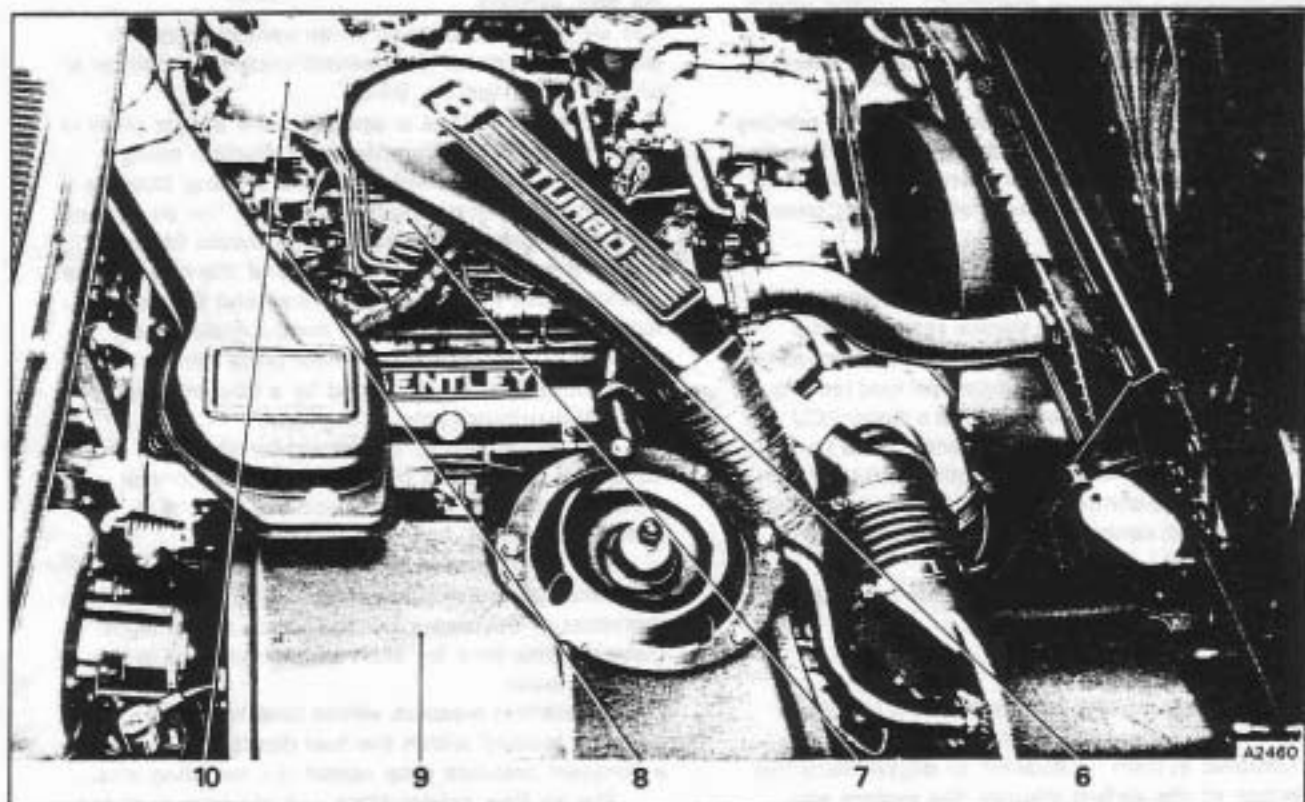
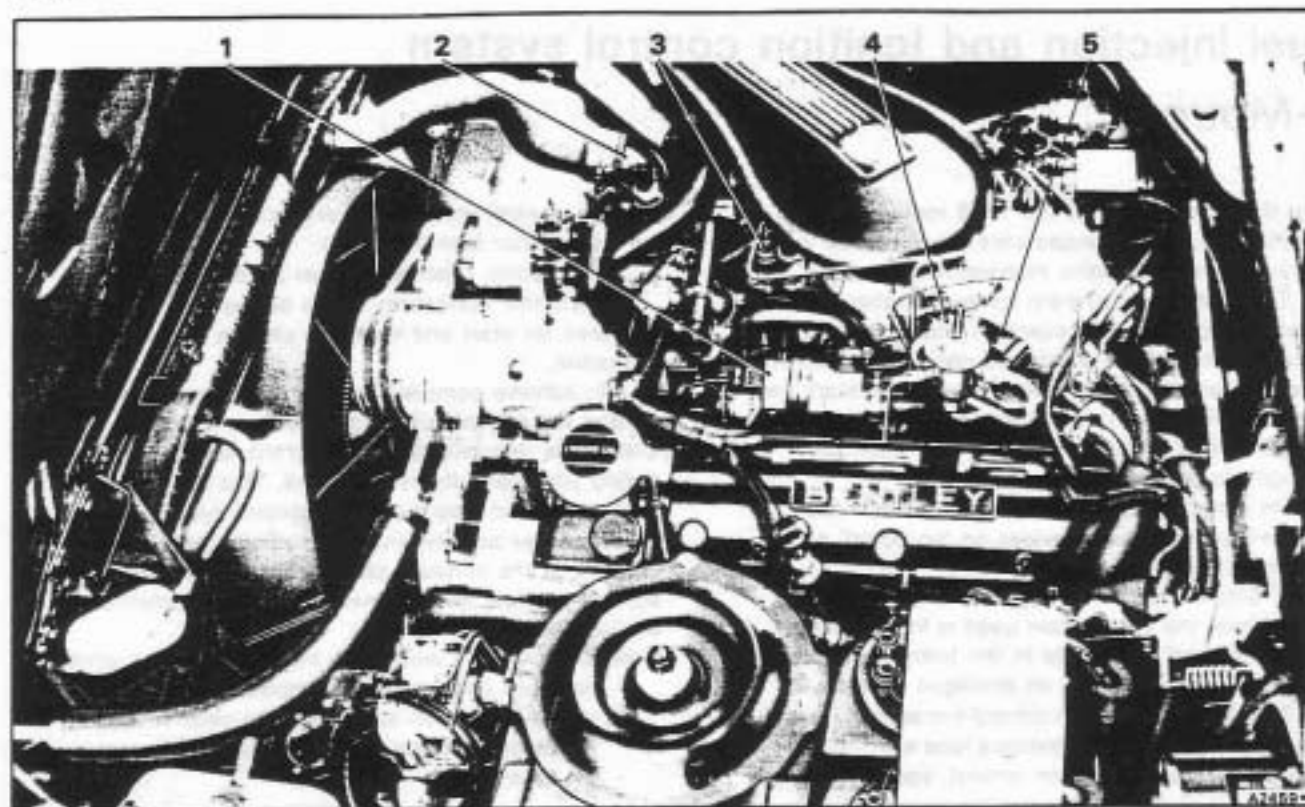


Fig. B4-1 Engine compartment details

- |                              |                           |
|------------------------------|---------------------------|
| 1 Idle speed actuator        | 6 Air intake              |
| 2 Thermostat housing outlet  | 7 Air meter               |
| 3 Cold start injector        | 8 Air pressure transducer |
| 4 Fuel pressure regulator    | 9 ECU compartment cover   |
| 5 Electro-hydraulic actuator | 10 Fuel distributor       |

plug and rotating the idle mixture screw. The tamperproof plug should then be replaced and no further mixture adjustment should be necessary.

This basic adjustment alters the relationship of the air flow sensor plate position to that of the control piston in the barrel of the fuel distributor.

#### Fuel circuits

Fuel pressures within the KE3-Jetronic fuel circuit are as follows.

Primary pressure	6,2 bar to 6,4 bar (89.9 lbf/in <sup>2</sup> to 92.8 lbf/in <sup>2</sup> )
Differential pressure valves (lower chambers)	5,7 bar to 5,9 bar (82.65 lbf/in <sup>2</sup> to 85.55 lbf/in <sup>2</sup> )
Fuel injector pressure	4,0 bar to 4,1 bar (58.0 lbf/in <sup>2</sup> to 59.4 lbf/in <sup>2</sup> )

#### Primary fuel circuit

Primary fuel pressure is controlled by the fuel pressure regulator (see figs. B4-4 and B4-9).

An electrically driven pre-pump, mounted inside the fuel tank, supplies fuel to the inlet of the main pump. Fuel delivery to the fuel distributor is then via a pressure damper, a fuel accumulator, and a fine mesh filter.

Fuel initially enters passages in the fuel distributor where the pressure is held constant (primary system pressure) by means of a pressure regulator. Excess fuel from the regulator flows through a fuel cooler (incorporated with the vehicle's automatic air conditioning system) and a one-way valve as it returns to the tank via the fuel return line.

In the fuel distributor, movement of the control piston within the barrel allows metered fuel to pass through the fuel distributor slits, to the upper side of the diaphragm in each differential pressure valve (see fig. B4-5).

The fuel entering the upper chamber of a differential pressure valve, deflects the diaphragm away from the open end of the injector fuel line and thereby allows fuel to flow to the injector.

The fuel injectors have an opening pressure of between 4,0 bar and 4,1 bar (58.0 lbf/in<sup>2</sup> and 59.4 lbf/in<sup>2</sup>) and are designed to spray finely atomized fuel under all operating conditions.

The primary fuel circuit also feeds fuel to provide the hydraulic force that is applied above the control piston. This provides the hydraulic balancing force for the air load acting on the air sensor plate.

Primary fuel pressure is supplied to the cold start injector and to the electro-hydraulic actuator (EHA).

When the engine is stopped, the fuel pressure regulator allows system pressure to drop rapidly to a pressure governed by the fuel accumulator. This is just below fuel injector opening pressure.

The retention of fuel at this pressure during 'hot soak' conditions minimizes fuel vaporization.

A sudden drop in fuel pressure when the engine is stopped closes the injectors and prevents dieseling (the tendency of an engine to continue 'running-on')

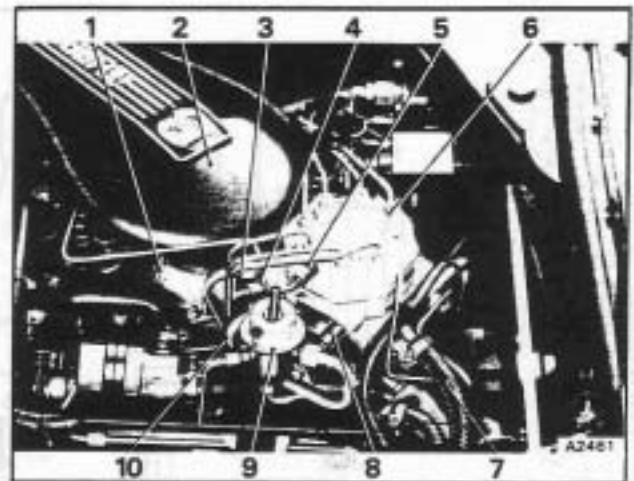


Fig. B4-2 Mixture control unit

- 1 Air meter
- 2 Air intake
- 3 Fuel supply to distributor
- 4 Fuel return to tank via pressure regulator
- 5 Fuel feed to cold start injector
- 6 Injector pipe
- 7 Hydraulic system pipes
- 8 Electro-hydraulic actuator
- 9 System pressure regulator
- 10 Fuel feed to pressure regulator

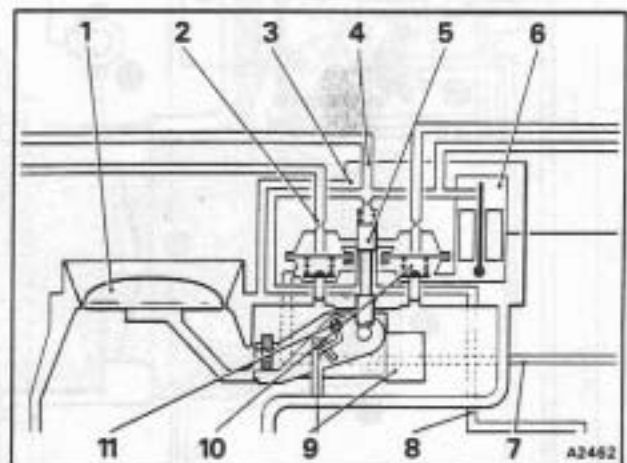


Fig. B4-3 Air flow sensor and fuel distributor (mixture control unit)

- 1 Air flow sensor plate
- 2 Fuel line to injector
- 3 Fuel distributor
- 4 Fuel line to cold start injector
- 5 Control piston
- 6 Electro-hydraulic actuator (EHA)
- 7 Fuel return line to pressure regulator
- 8 Fuel supply line
- 9 Counterbalance weight
- 10 Differential pressure valve
- 11 Pivot



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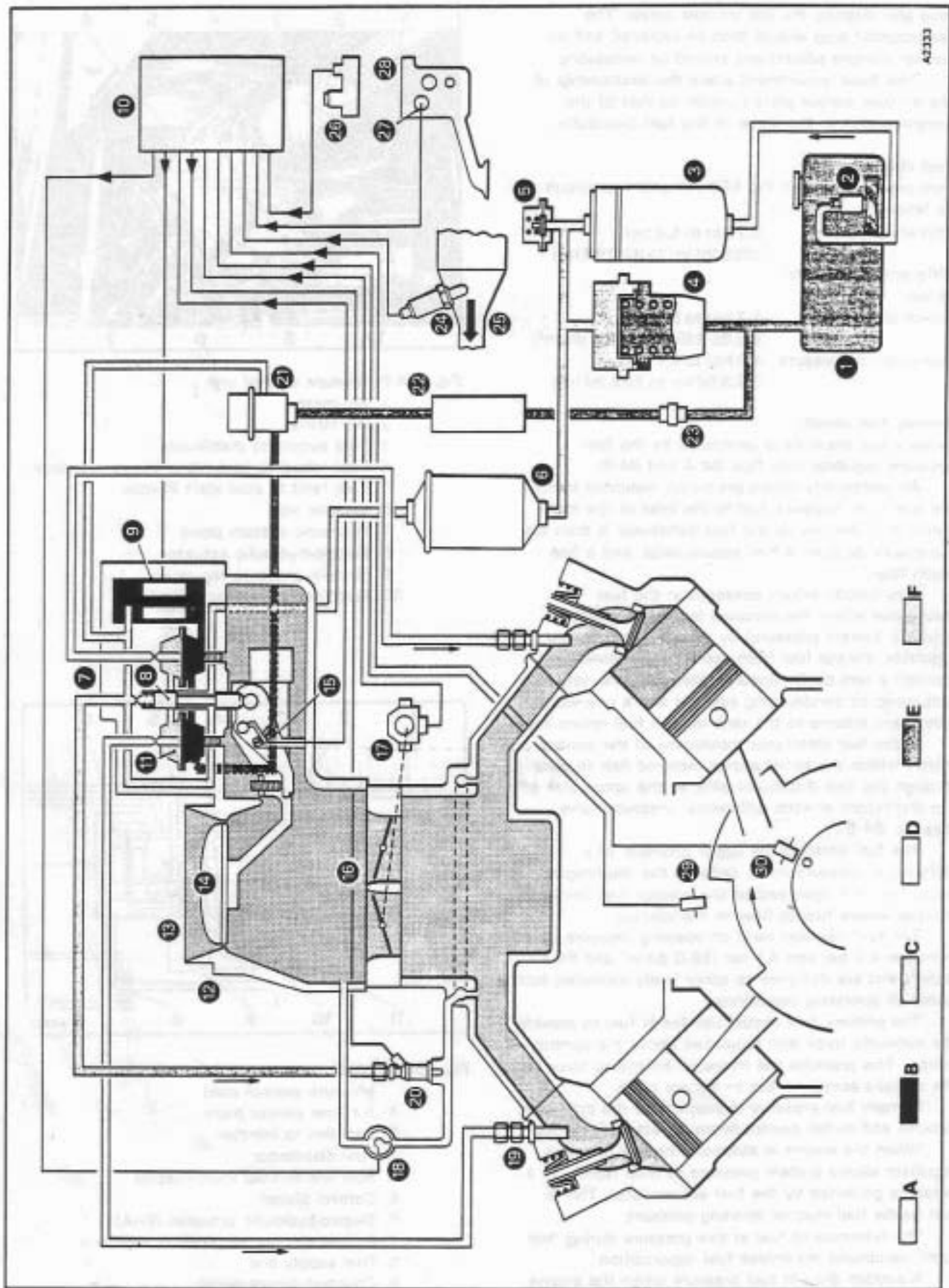


Fig. B4-4 Fuel injection system

**Key to fig. B4-4 Fuel injection system**

- 1 Fuel tank
- 2 Fuel pre-pump
- 3 Fuel pump
- 4 Fuel accumulator
- 5 Fuel pressure damper
- 6 Fuel filter
- 7 Fuel distributor
- 8 Control piston
- 9 Electro-hydraulic actuator (EHA)
- 10 Electronic control unit (ECU)
- 11 Differential pressure valve
- 12 Air cone
- 13 Air meter
- 14 Air sensor plate
- 15 Air flow sensor potentiometer
- 16 Throttle body
- 17 Throttle position switch
- 18 Idle speed actuator
- 19 Injector
- 20 Cold start injector
- 21 Fuel pressure regulator
- 22 Fuel cooler
- 23 Non-return valve
- 24 Heated oxygen sensor
- 25 Warm-up catalytic converter
- 26 Air pressure transducer (APT)
- 27 Temperature sensor
- 28 Thermostat housing
- 29 Engine speed sensor
- 30 Crankshaft reference sensor
- A Upper chamber pressure
- B Lower chamber pressure
- C Primary circuit pressure
- D Injection pressure
- E Unpressurized return line
- F Pre-pump pressure

**Note** Items 24 and 25 are only fitted to cars with catalytic converters

after the ignition has been switched off).

**Fuel distribution**

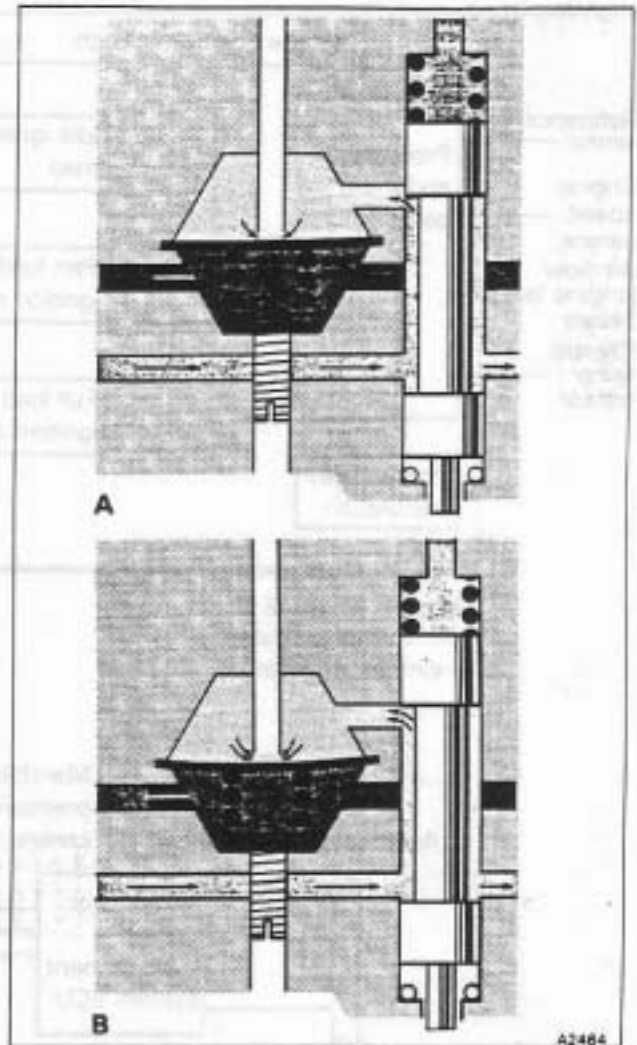
Fuel is distributed uniformly to the cylinders via an accurately machined control piston and barrel assembly (see figs. B4-4 and B4-8). This assembly operates by controlling the open cross sectional area of the metering slits machined in the barrel.

The barrel has one rectangular metering slit for each cylinder.

Depending upon the position of the piston in the barrel, the metering slits are opened a corresponding amount. This allows fuel to flow through the openings to the differential pressure valves.

Each metering slit has a differential pressure valve.

If the air flow sensor plate travel is small, the control piston will only be raised in the barrel a small amount. This only allows a small section of the metering slits to be opened for the passage of fuel.



**Fig. B4-5 Differential pressure valve**  
 A Low flow rate  
 B High flow rate

A hydraulic force is applied on top of the control piston and acts in opposition to the movement of the air flow sensor plate, lever, and control piston. A constant air/fuel pressure drop at the sensor plate is the result. This ensures that the control piston always follows the movement of the sensor plate lever.

A restrictor between the primary fuel circuit and the top of the control piston provides air sensor plate damping. This avoids small fluctuations of the air sensor plate, particularly during low engine speed operation when the air flow through the air meter is pulsating.

A spring is fitted above the control piston to assist the hydraulic force. It prevents the control piston being drawn upwards in the barrel due to a vacuum effect when the engine is stopped and the system cools down. If the control piston was drawn up in the barrel it could cause an excessively rich mixture when the engine is started again.

When the engine is switched off, the control piston sinks until it rests on the axial sealing ring.

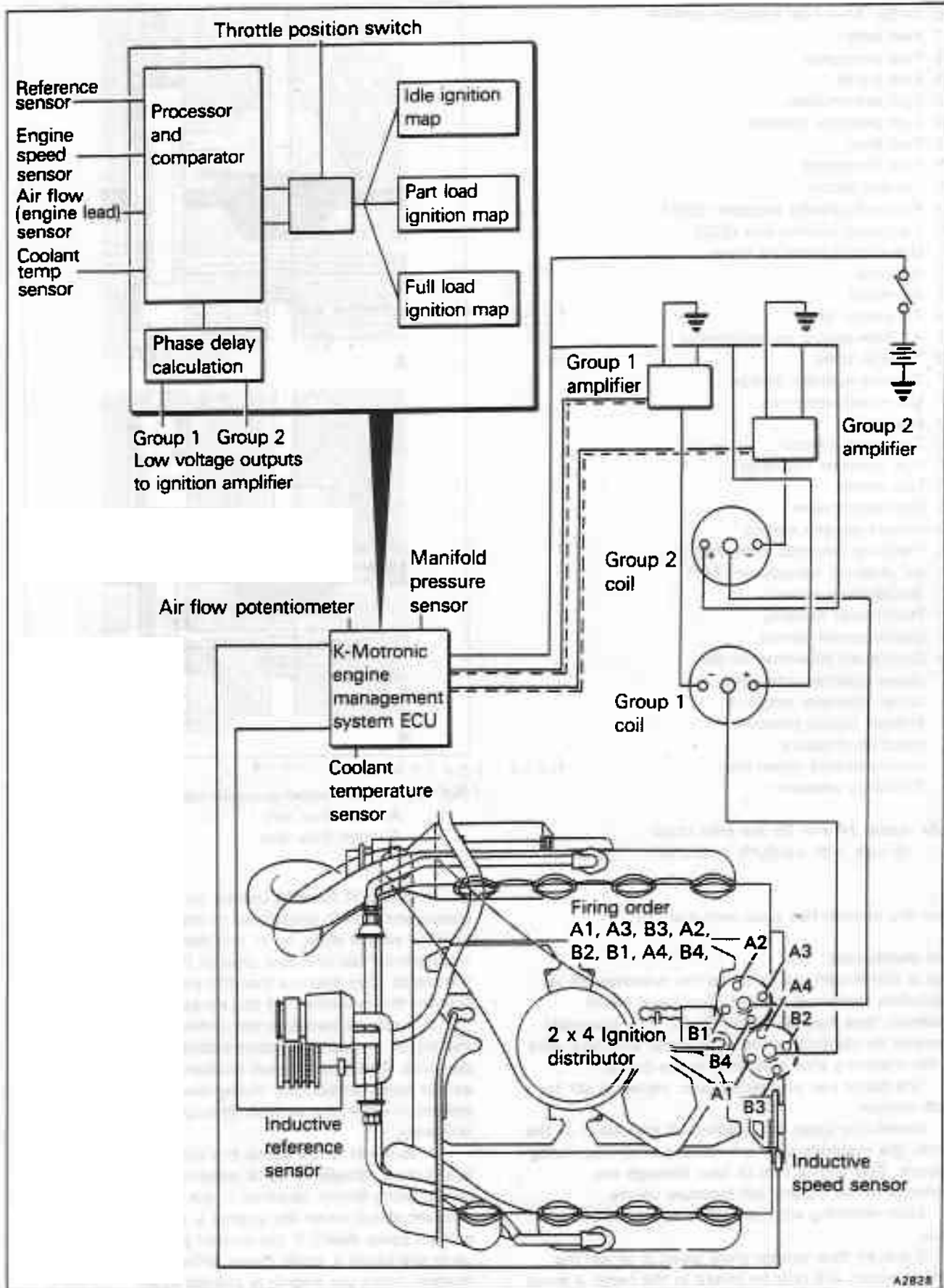


Fig. B4-6 Ignition control system



This position is set during manufacture and ensures complete closure of the metering slits when the piston is in the rest (zero lift) position. When the piston is resting on the sealing ring and the engine is switched off, the seal prevents primary system fuel leakage past the piston. This would otherwise allow fuel accumulator pressure to be lost too quickly.

#### Differential pressure valves

There is a differential pressure valve for each engine cylinder (see figs. B4-3 and B4-5).

These valves are a diaphragm type consisting of an upper and lower chamber with the diaphragm separating the two halves.

The purpose of these valves is to maintain a given pressure drop at the metering slits. The pressure differential between the two halves of the valve is maintained irrespective of the fuel flow.

The difference in fuel pressure between the upper and lower chambers (and therefore the metering slits) is approximately 0,2 bar (3 lbf/in<sup>2</sup>). Basically this is determined by the helical spring operating in the lower chamber of each valve.

The lower chambers are connected to one another by a ring main.

The upper chambers are completely sealed from one another but are connected to the metering slits. Each chamber contains a valve seat and is connected to its respective injector line.

If an increased fuel flow enters the upper chambers, the pressure is increased and the diaphragms are deflected downwards. This opens the outlet end of the injector lines allowing the fuel flow to increase until the preset differential pressure is restored.

If the fuel flow decreases, the pressure in the upper chambers will fall allowing the diaphragms to lift. This reduces the fuel flow to the injectors until the pressure differential again prevails.

The total travel of the diaphragm is only a few hundredths of a millimetre.

By varying the fuel pressure in the lower chambers of the differential pressure valves, fine control of the fuel flow rate (mixture strength) can be achieved.

In addition to the helical spring, the fuel pressure in the lower chambers is further affected by the operation of the EHA attached to the side of the fuel distributor. This is used to vary the fuel pressure in the lower chambers in response to signals from the ECU. In general, the mixture strength becomes richer with increasing current to the EHA.

An additional fuel filter incorporating a separator for ferromagnetic contamination is fitted in the fuel line to the EHA.

#### Ignition system

The ignition system is an integral part of the engine management K-Motronic system and consists of two driver stages which amplify ECU signals to the low tension side of the ignition coils. The coils generate high tension outputs which are distributed to the

sparkling plugs in two groups, via a twin rotor distributor assembly (four cylinders per rotor).

Part load ignition timing is dependent upon engine load and speed and is generated from a characteristic map. Engine load is sensed by the air meter potentiometer and engine speed by the engine speed sensor, mounted adjacent to the segment wheel at the rear of the engine.

The potentiometer is attached to the air flow sensor plate lever and reflects any change in the amount of metered air entering the induction system. The electrical signal generated within the potentiometer by the movement of the sensor plate is then transmitted to the K-Motronic ECU to become a measure of engine load.

The timing wheel fitted to the rear of the crankshaft, has four segments of equal length at its periphery, separated by four gaps which are also of equal length but longer than the segments. Rotation of the four segment timing wheel generates a fixed duty cycle which is sensed by the engine speed sensor and transmitted to the K-Motronic ECU.

The K-Motronic ECU also receives a signal from the crankshaft reference sensor located at the front of the engine. As a reference pin rotating with the crankshaft, passes the sensor it triggers A1 ignition and the subsequent firing order for the eight engine cylinders. Co-ordination with the segment wheel ensures the correct ignition timing.

Ignition angles for operation at idle and at full throttle are dependent upon engine speed. They are governed by separate characteristic curves programmed into the ECU.

Ignition timing during cold starting and warm-up is also dependent upon engine coolant temperature.

#### Sparkling plugs

NGK BPR 4EVX sparking plugs are used. The sparking plugs comprise a precious metal centre electrode surrounded by a ceramic insulating material whose relative positions are located by a metal housing. The central electrode and insulator are designed to project beyond the end of the metal housing to improve combustion efficiency. The ground electrode, attached to the leading edge of the housing, is extended to form an air gap across which the spark is induced to jump.

#### 'Closed-loop' mixture control system (lambda control system)

Cars fitted with catalytic converters also have a 'closed-loop' lambda control system.

The lambda control system is an addition to the KE3-Jetronic fuel injection system and is fitted to give increased control of the air/fuel ratio about the stoichiometric value.

With an ideal (stoichiometric) air/fuel mixture the air factor is identified by the value  $\lambda$  (lambda) = 1 (under boost and at full load = 0.83 to 0.95).

$$\lambda = \frac{\text{Actual air intake}}{\text{Theoretical requirement}}$$



In order to achieve optimum three-way catalytic conversion efficiency, a stoichiometric air/fuel ratio must be accurately maintained.

This is achieved by means of an oxygen sensor located in the exhaust system, in conjunction with the K-Motronic engine management system ECU (see fig. B4-7). The ECU provides a control signal to the EHA, oscillating between pre-set threshold limits and regulating the fuel pressure in the lower chambers of the differential pressure valves. Increased fuel flow through the EHA will increase the pressure in the lower chambers, simultaneously, the pressure in the upper chambers increases by the same amount. As a result, the pressure drop across the metering slits in the fuel distributor is decreased which in turn decreases the fuel flow to the injectors. Decreasing the flow through the EHA has the opposite effect.

#### Automatic altitude compensation

Cars fitted with catalytic converters also have automatic altitude compensation. Due to lower air density at high altitudes, the volumetric air flow measured by the air meter corresponds to a lower air mass flow than at low altitudes. Operation at high altitude would therefore, have a richening effect on the air/fuel mixture ratio. In practice however, this is initially compensated for by the lambda 'closed-loop'

control system. Also, the engine management system incorporates a function for permanent correction of any long term drift in mixture strength due to such variations as air density (refer to adaptive lambda pre-control).

Altitude compensation is therefore, available until both the above control functions are at the limit of their control range and is effective to an altitude of 4267 m (14 000 ft) above sea level.

#### Adaptive lambda pre-control

Cars fitted with catalytic converters also have adaptive lambda pre-control. This is a function of the engine management system which makes a permanent correction for any long term changes in mixture strength. It is integrated with the lambda 'closed-loop' system within the engine management system ECU and corrects for mixture strength deviations due to engine ageing, minor air leaks, altitude, environmental changes, and variations in fuel density.

This allows the lambda 'closed-loop' system to continue to operate around the centre of its control range and to maintain its full capability of correcting for any temporary variations in mixture strength.

The pre-control system operates by monitoring the output from the lambda 'closed-loop' integrator (i.e. the average EHA current required to maintain a

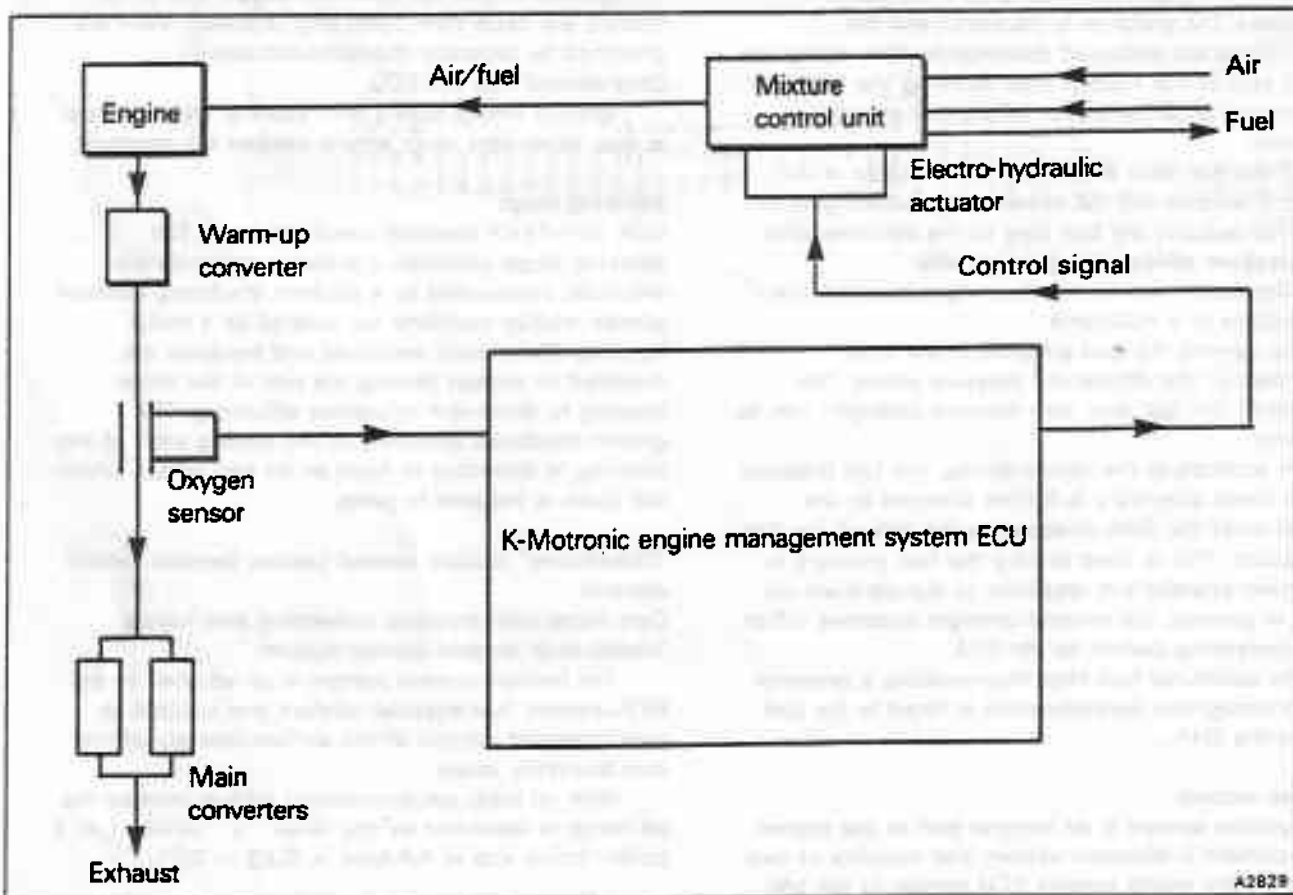


Fig. B4-7 'Closed-loop' mixture control system



stoichiometric air fuel ratio). If the average correction factor over a predetermined time period is different from the initial value, then the factors are stored in random access memories in the ECU and are subsequently used and updated during the next period of engine operation.

Lambda pre-control is active in two areas of engine operation, which are defined by air flow rate and engine speed thresholds. At low engine speeds and low air intake flow rates (i.e. at idle and small throttle openings) permanent additive corrections are made. In this area, malfunctions such as an induction system air leak or an incorrect idle mixture setting would be detected and necessary correction factor applied.

At higher engine speeds and loads (but not at full throttle) permanent multiplicative corrections are made. In this area corrections are made for variations in air and fuel density and for gradual changes due to engine wear.

If the K-Motronic ECU is disconnected for any reason (i.e. removal or battery isolation) it results in a loss of ECU stored memory. When the engine is started the ECU will have to go through its learning process again.

Lambda pre-control is only active during the engine operating modes described in the preceding paragraphs, when the 'closed-loop' mixture control system is functioning. It does not operate during a period of open loop fuelling control, such as a period following a cold start or when the engine management system is in failure mode. When the evaporative emission control canister is being purged, lambda pre-control is active but the correction factors are not stored.

#### On-board fault diagnosis capability

Cars fitted with catalytic converters also have an engine fault warning lamp on the vehicle instrument panel to alert the driver to a possible engine related fault. The lamp displays the message CHECK ENGINE and remains illuminated, whenever the ignition is switched on, until the malfunction has been diagnosed and corrected.

The engine management system ECU continuously monitors the inputs from sensors critical to emission control system operation. If a signal is outside the specified limits programmed into the ECU, the engine check lamp is illuminated and a fault message (in the form of a four digit code) is stored within the ECU and subsequently used to inform workshop personnel of the faulty component or system.

The warning lamp is not always illuminated when a fault is identified. In these instances however, the fault code is still stored in the ECU and can be retrieved in the usual manner during workshop diagnosis.

Diagnosis in the workshop can be made either with the engine idling or with the engine stationary and the ignition switched on. It is carried out by depressing a diagnostic button located on the vehicle

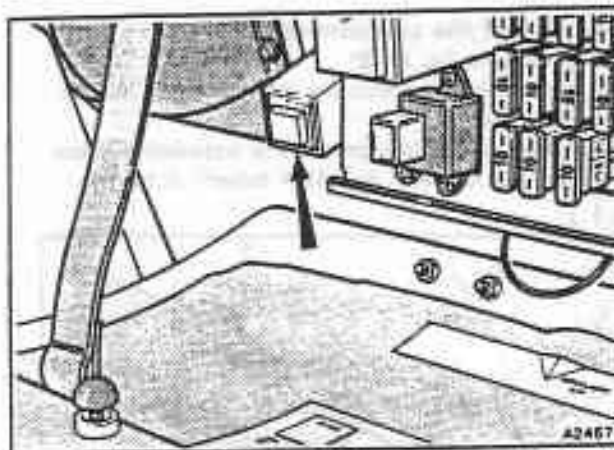


Fig. B4-8 Diagnostic button

fuseboard for a minimum of four seconds (see fig. B4-8). This provides a ground connection for ECU pin 13 which initiates a read-out programme, causing the stored fault codes to be sequentially displayed as blink codes on the engine check lamp. If there is more than one malfunction the system continues to display the first registered fault code until either the fault has been cleared or the system has been reset. Each blink code begins with a start signal of 2.5 seconds lamp on, 2.5 seconds lamp off. The lamp flashes on for 0.5 seconds and off for 0.5 seconds in accordance with the stored code. There is a lamp off period of 2.5 seconds between each digit.

Examples of blink codes are shown in the servicing section of this chapter.

If faults are not corrected and the vehicle continues to be used, the system can be returned to its monitoring role by raising the engine speed above 3000 rev/min. The check engine lamp will continue to be illuminated.

When a fault has been corrected, raising the engine speed above 3000 rev/min will extinguish the warning lamp.

When all fault codes have been shown during diagnosis, the output end code 1-1-1 is displayed. If no faults are detected then the code 4-4-4 is given.

#### Engine speed limiting

Engine speed is limited by interrupting the fuel flow to the injectors.

The engine management system ECU senses engine speed, by means of a signal from the inductive sensor at the rear of the engine.

When the speed of the engine reaches 4600 rev/min the signal triggers an ECU function which causes the current to the EHA to oscillate at a constant frequency between a fixed negative value and the last known positive value.

The negative EHA correction has the effect of increasing the pressure in the lower chambers of the fuel distributor. This raises the diaphragm of each differential pressure valve and stops the fuel flow to the injectors.



### Description of the components

#### Fuel injector (see fig. B4-9)

A fuel injector is fitted into the inlet port just behind each inlet valve.

The injector opening pressure is between 4,0 bar and 4,1 bar (58.0 lbf/in<sup>2</sup> and 59.4 lbf/in<sup>2</sup>). It has no

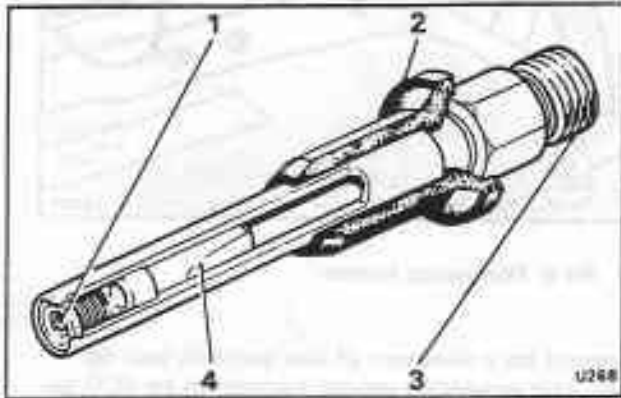


Fig. B4-9 Injector valve

- 1 Nozzle
- 2 Insulating sleeve
- 3 Fuel supply connection
- 4 Filter

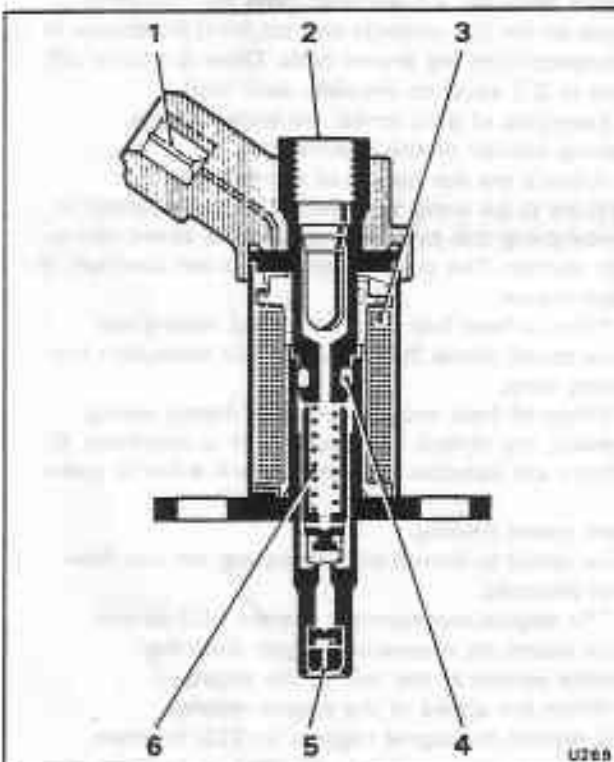


Fig. B4-10 Cold start injector

- 1 Electrical connection
- 2 Fuel inlet
- 3 Magnetic coil
- 4 Sealing ring
- 5 Swirl nozzle
- 6 Armature

metering functions, its purpose being to continually spray finely atomized fuel under all running conditions.

The injector is supported in an insulating moulded rubber sleeve. It is pressed (not screwed) into position. The hexagonal section is provided to hold the injector while the fuel line is attached.

A retention plate is fitted over the injector and secured by two small setscrews, each plate retaining two injectors.

#### Cold start injector (see fig. B4-10)

Cold start injector control is computed by the ECU and sprays fuel into the induction manifold air galleries. The duration and quantity of fuel injected is dependent upon the engine coolant temperature. This is indicated by a temperature sensor in the thermostat housing (see fig. B4-14). The ECU is programmed with a coolant temperature dependent data characteristic curve from which it computes a duty cycle between 0% and 100%, and allows up to 10 seconds of injection time.

Under normal engine operation there is no cold start injection above a coolant temperature of 16°C (60°F). However, in high ambient air temperatures the cold start injector can provide hot start enrichment. A duty cycle of 10% is applied, providing a slow rate of injection, if the coolant temperature is above 100°C (212°F) and if the engine has not started after cranking for approximately two seconds.

The cold start injector incorporates a helical spring which presses a moveable armature and seal against the valve seat, closing the fuel inlet. When the armature is energized (and therefore drawn upwards) the fuel port is opened and the pressurized fuel flows along the sides of the armature to the swirl nozzle.

#### Air flow sensor plate (see fig. B4-3)

The sensor plate is housed in the cone of the air meter. Its function is described on page B4-1, under the heading of Air flow sensing.

A stabilizer is fitted on top of the air flow sensor plate. Its purpose being to improve the air flow around the sensor plate at high flow rates and provide sensor plate stability.

#### Differential pressure valves (see fig. B4-5)

The differential pressure valves (one for each engine cylinder) are housed in the fuel distributor. Their function is described on page B4-7 under the heading of Differential pressure valves.

#### Fuel distributor (see fig. B4-3)

The fuel distributor forms part of the mixture control unit. Its function is described in the section relating to fuel distribution on page B4-5.

#### Control piston (see fig. B4-11)

This is a cylindrical plunger type of valve that moves vertically in the fuel distributor. It is operated by a lever connected to the air flow sensor plate.