EFI-D and EFI-L

Electronically Controlled Fuel Injection

● Reliability
Fuel injection is by no means a recent development. To the contrary, aircraft engines were first fitted with fuel injection systems more than 60 years ago. Development of higher-performance aircraft engines made flight possible at higher altitudes, under more severe weather conditions, as well as under operating conditions when a reliable fuel supply using conventional carburetor systems was not always guaranteed. Fuel injection employing injection pumps, however, made it possible to solve these problems completely.

● Increase in engine performance
During the 1950's, the racing cars manufactured by Daimler-Benz, the legendary "Silver Arrows", achieved victory after victory. The basis for these victories was the reliable and high-power racing engines equipped with fuel injection systems. Consistent and continued development of these injection systems, based on experience gained with injection systems designed for Diesel engines, resulted in the attainment of maximum engine performance under the extreme conditions of racing.

The high costs of a fuel injection system employing injection pumps in the years that followed justified use of this type of fuel injection system only in racing cars or in luxurious touring limousines. Fuel injection was still too expensive for the mass-produced motor vehicle.

● Fuel economy
Using the conventional type of fuel metering it was not possible to lower fuel consumption without a loss in engine performance. The continuous rise in the world market prices for petroleum products, however, dictated that a solution to this problem be found. When fuel injection is used, the fuel can be metered in exact proportion to the actual fuel requirement of the engine under the most widely varying conditions of load. Exact matching of the fuel to operating conditions results in a reduction in the specific fuel consumption.

● Clean exhaust gases
An additional problem which greatly influenced the development of fuel injection systems was the proportion of unhealthy components in exhaust gases. The proportion of these components can only be reduced by exact maintenance of a certain air-fuel ratio. Here also the fuel injection system, with the possibility it presents of exact fuel metering, was of assistance to engineers.

Electronically controlled fuel injection
New areas of technology have made it possible to develop an injection system for use in the manufacture of mass-produced motor vehicles.

In this system, detecting elements sense the operating condition of the engine and pass this information in the form of electric signals to an electronic control unit. Processing these signals, the control unit not only determines the amount of fuel required by the engine but also controls the injection valves which inject this required amount of fuel into the engine.

After much intensive research and experimentation, an electronically controlled fuel injection system designed for series production was developed in 1967.

During the development of electronically controlled fuel injection differing goals were pursued. On the one hand, there was a requirement to reduce the concentration of noxious components in exhaust gases with no reduction in engine power, while on the other hand there was also a requirement to increase engine performance, in part simultaneously with the detoxication of the exhaust gases. Proceeding on the basis of experience gained with fuel injection systems in regard to meeting regulations governing purification of exhaust gases – regulations which are constantly becoming more stringent – it has always been possible to stay within the limiting values specified.

The increase in torque is attained mainly by optimum design of the intake system. The associated rise in the torque curve at low and high engine speeds increases the elasticity of the engine to a clearly perceptible degree.

In comparison with the fuel system employing a carburetor, consumption of fuel by the injection system is less during general driving, while the fuel savings during city driving, depending on traffic conditions and driving characteristics, are even greater.

Mixture Formation

In the spark-ignition engine the air-fuel mixture is compressed to a mixture ratio suitable for ignition and combustion, and is then ignited by an electric spark. Formation of the air-fuel mixture begins when the fuel is added to the air drawn into the engine. The amount of this mixture which is led to the cylinders is determined by the changing operating characteristics of the engine.

The function of fuel metering is therefore to match the quantity of fuel to the quantity of air drawn into the engine at all times. Basically, this can be done in two ways: the correct quantity of fuel is metered by either the carburetor or the injection system.

The decision whether a carburetor or an injection system will be used for mixture formation depends mainly on the requirements established regarding maintenance of air purity, but this decision also depends on requirements relating to engine power and fuel consumption as well.

Most important, reduction in the noxious components in the exhaust gases necessitates exact maintenance of the air-fuel ratio for every driving condition.

One of the possibilities which exist to reduce emission of noxious gases is electronically controlled fuel injection as developed by Bosch.

Air-fuel Ratio

Proper ignition and combustion of the air-fuel mixture can only take place within a certain range of air-fuel ratios. When gasoline is used, the average ratio for full combustion of the fuel (the so-called stoichiometric air-fuel ratio) is 14 : 1. This means that about 14 kg of air are required for complete combustion of 1 kg of fuel. In this stoichiometric air-fuel ratio, the air factor, $\lambda = 1$.

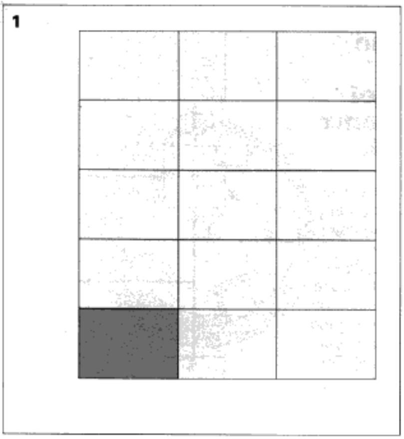


Fig. 1
Air-fuel mixture when gasoline is used (14 kg of air are required for complete combustion of 1 kg of fuel).

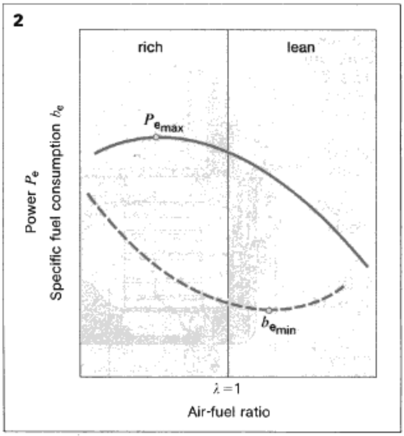


Fig. 2
Engine power and specific fuel consumption as a function of the air-fuel ratio.

This value, λ (Lambda), is determined as follows:

$$\lambda = \frac{\text{actual volume of air drawn into engine}}{\text{theoretical requirement of air}}$$

$\lambda = 0.9$
means a rich mixture, i. e., a deficiency of air – the intake of air is less than the theoretical requirement.

$\lambda = 1.1$
means a lean mixture, i. e., a surplus of air – the intake of air is greater than the theoretical requirement.

Spark-ignition engines develop the greatest power at a 0 . . . 10 % air deficiency ($\lambda = 0.95 \ldots 0.9$) and consume the least fuel at about a 10 % air surplus ($\lambda = 1.1$).

When there is an air deficiency, the fuel is not utilized adequately, and the concentration of unburned noxious components in the exhaust gas is higher. With a surplus of air, the power developed by the engine is lower, and the temperatures of the engine and exhaust gas are higher because of the slower combustion.

The air-fuel ratio of the mixture drawn into the spark-ignition engine must lie between $\lambda = 0.7$ and 1.3 regardless of whether the engine is fitted with a carburetor or a fuel injection system.

Operating Principle of the Electronically Controlled Fuel Injection Systems EFI-D and EFI-L

The electronically controlled fuel injection systems EFI-D and EFI-L are intermittently operating low-pressure injection systems.

In both systems the quantities representative for the fuel requirement of the engine are sensed by detecting elements and converted to electric signals which are sent to the electronic control unit. This control unit processes these signals and derives the fuel requirement of the engine from them. The control unit generates electric pulses which are sent to the injection valves; these pulses correspond to the quantity of fuel calculated. The injection valves are electro-magnetically opened and spray the amount of fuel calculated in front of the intake valves in the engine.

The EFI-D and EFI-L consist of the following basic components:

- fuel system – delivery, pressure generation, pressure regulation, cleaning, injection valves.
- detecting elements – collect all engine operating data necessary for calculation of exact fuel metering.
- electronic control unit – processes the data provided by the detecting elements, determines the duration of injection, controls the injection valves.

Components used in both systems will be described in the sections of this booklet immediately below, while components used in either the EFI-D or EFI-L alone will be discussed in the later sections of this booklet where each of these systems is described separately.

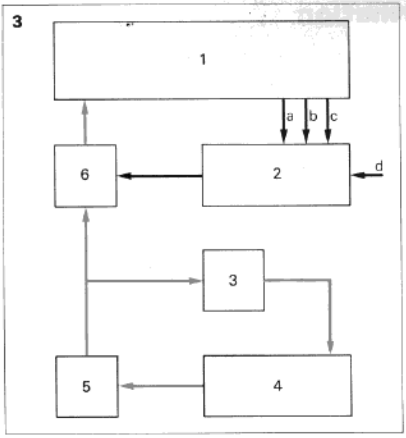


Fig. 3
Principle of the EFI-D and EFI-L

1 Engine
2 Control unit
3 Fuel-pressure regulator
4 Fuel tank
5 Fuel pump
6 Injection valves
a Compensation factors (engine)
b Engine speed
c Intake manifold pressure/air quantity
d Compensation factors (environment)

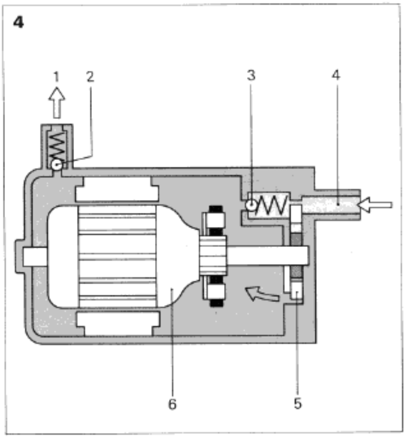


Fig. 4
Electric fuel pump

1 Pressure side
2 Non-return valve
3 Relief valve
4 Suction side
5 Roller-cell pump
6 Armature of electric motor

Fuel System

In the fuel circulation system a fuel pump draws the fuel from the tank and delivers it through a closed pipeline and its branches to the solenoid-operated injection valves. The fuel pressure at the valves is held constant by a fuel-pressure regulator.

Excess fuel flows under no pressure back to the tank. A fuel filter between the electric fuel pump and the injection valves prevents impurities in the fuel reaching other parts of the system.

Electric Fuel Pump

A roller-cell pump driven by a permanent-magnet series-wound electric motor is used as the fuel-supply pump. The rotor disc, mounted eccentrically in the pump housing, has metal rollers fitted into recesses around its edge which are pushed outward by centrifugal force and act as a rotating seal.

The fuel is carried through the cavities which form between the rollers and is then forced into the fuel injection tubing. In this design, the fuel flows directly around the electric motor. There is no danger of explosion, however, because there is never an ignitable mixture inside the engine-pump housing. The pump delivers more fuel than the maximum requirement of the engine so that the pressure in the fuel circulation system can be maintained under all operating conditions.

The excess fuel flows under no pressure back to the fuel tank. As a result, cool fuel is delivered at all times and formation of vapor bubbles in the fuel circulation system is prevented.

When the ignition is switched on, the pump only operates as long as the starting switch is activated. When the engine starts to operate, the electronic control unit switches the pump on. As a result of this safety circuit, flooding of a particular cylinder with fuel is prevented in event of a possible defective injection valve when the ignition is switched on (cylinder-flooding protection).

5

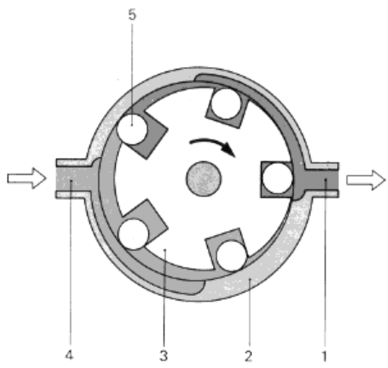


Fig. 5
Roller-cell pump

1 Pressure side
2 Pump housing
3 Pump rotor
4 Suction side
5 Roller

Fuel-pressure Regulator

The fuel pressure is held constant by a pressure regulator. This pressure regulator consists of a metal housing in which a spring-loaded diaphragm opens the inlet to an overflow channel if the set pressure should be exceeded. In the EFI-D the regulator can be adjusted, and the system pressure is 2 . . . 2.2 bar. In the EFI-L the pressure is set at the factory, depending on the engine type, to either 2.5 or 3 bar.

"bar" is the international measurement unit for pressure. For practical purposes,

$$1 \text{ bar} \approx 1 \frac{\text{kgf}}{\text{cm}^2}$$

6

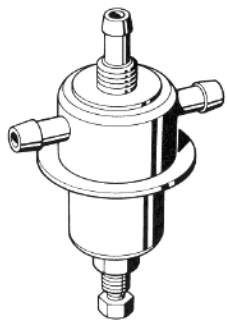


Fig. 6
Fuel-pressure regulator (EFI-D)

7

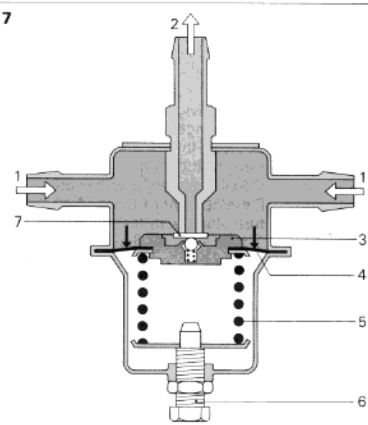


Fig. 7
Cross-sectional drawing of the fuel-pressure regulator

1 Fuel connection
2 Return flow to fuel tank
3 Valve support
4 Diaphragm
5 Pressure spring
6 Adjustment screw
7 Valve

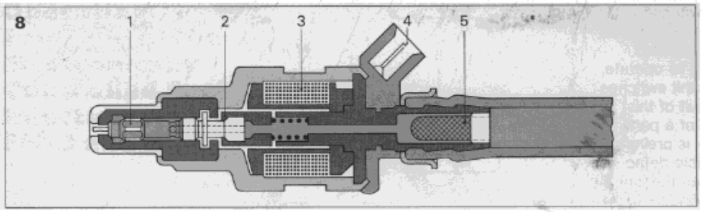


Fig. 8
Cross-sectional drawing of the injection valve

1 Nozzle valve
2 Solenoid armature
3 Solenoid winding
4 Elec. connection
5 Filter

Solenoid-operated Injection Valve

A solenoid-operated injection valve is associated with each cylinder. The injection valve is installed in the intake manifold and sprays fuel in front of the intake valve.

This design of the injection system offers the advantages not only of being able to operate at low injection pressure, but also of making injection of fuel possible to groups of valves at the same time, thus considerably reducing equipment costs.

When the EFI-D is used in 4-cylinder engines, two groups of 2 injection valves each are formed. The valves in a given group are connected electrically in parallel and open simultaneously. The same principle applies for 6- and 8-cylinder engines (2 groups of 3 valves and 4 groups of 2 valves respectively).

When the EFI-L is used, all injection valves are combined into a single group.

This means an additional important simplification in the injection system. In order to attain sufficient uniformity in the distribution of the fuel mixture despite this grouping, half of the amount of fuel required for one operating cycle is injected twice during each rotation of the camshaft.

The solenoid-operated injection valve consists essentially of a valve body and a nozzle valve with the superimposed solenoid armature. The movable armature is attached rigidly to the nozzle valve which is pressed against the nozzle body sealing seat by a helical spring. At the back of the valve body is the solenoid winding and in the front section is the guide for the nozzle valve.

The electric pulses received from the control unit generate a magnetic field in the solenoid winding. As a result, the armature is drawn back and lifts the nozzle valve from its seat. This opens the channel for the fuel, which is under pressure. The stroke of the armature is about 0.15 mm. The duration of the period during which the valve remains open is determined by the electronic control unit and depends on the particular operating condition of the engine.

Fig. 9
Fuel injection valve

Intake System

The air required for combustion of the fuel is led from the air filter through the throttle valve into the common intake manifold. From here individual intake manifolds of equal length branch off to each cylinder. In this way exactly uniform distribution of air to the individual cylinders is achieved. Development of the air-fuel mixture starts with the injection of the fuel into the air drawn into the engine as a result of the movement of the pistons.

Matching the Fuel Quantity during Cold Starting and the Warm-up Period

In addition to the exact metering of the fuel under all load conditions of the warm engine, a number of compensation factors are required for proper operation of the engine under exceptional conditions:

- enrichment of the mixture during cold starting,
- enrichment of the mixture during the warm-up period.

Compensation for these conditions is carried out in the same way in the EFI-D and EFI-L.

On the other hand, compensation is carried out in different ways in these two systems for the following operating conditions:

- enrichment of the mixture during acceleration,
- full-load enrichment,
- matching the mixture during overrun,
- compensation for the intake air temperature, and
- compensation for the effect of altitude.

Cold Starting

In a cold engine fuel condenses in the intake manifold and on the walls of the cylinders. As a result, less fuel mixes with the intake air than in a warm engine. This means that an ignitable mixture is not developed. The function of the start valve near the air throttle valve is to enrich the air in the intake manifold with finely atomized fuel. This valve only sprays fuel, however, when the starting motor is turned on and when, at the same time, a thermo-switch or thermo-time switch located in the coolant circuit is closed.

Start Valve

In this valve a helical spring presses the movable armature of the solenoid together with the seal against the valve seat and blocks the flow of fuel.

When the armature is drawn back, however, the valve seat is opened. The fuel then flows along the sides of the armature to the swirl nozzle. In this nozzle a swirling motion is imparted to the fuel and the fuel leaves the nozzle in finely atomized form.

Thermo-switch and Thermo-time switch

The thermo-switch closes or opens the electric circuit leading to the start valve depending on engine temperature. This means that the start valve is activated only at engine temperatures below a certain level; depending on engine type, this level is generally between 0° C and +15° C.

The thermo-time switch performs the same function as the thermo-switch but in addition is designed to limit the time during which the start valve is switched on.

This is necessary in engines which tend to wet the spark plugs with a rich starting mixture. The thermo-time switch is so designed that, depending on engine type, the maximum length of time the start valve is switched on during the starting process ranges between 5 and 20 seconds at a coolant temperature of −20° C; at higher coolant temperatures this time is shortened and at temperatures between +20° C and +40° C it reaches zero.

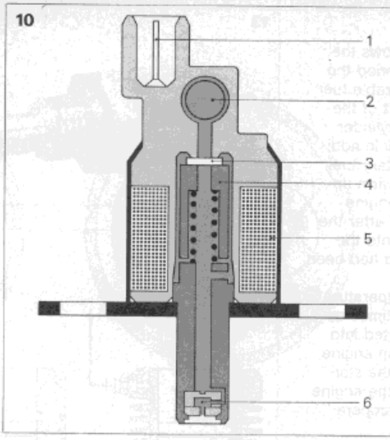


Fig. 10
Start valve

1 Elec. connection
2 Fuel inlet
3 Seal
4 Solenoid armature
5 Solenoid winding
6 Swirl nozzle

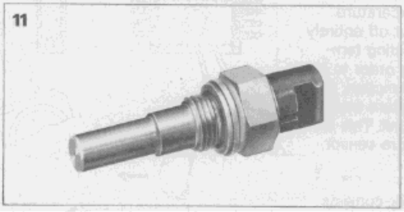


Fig. 11
Thermo-time switch

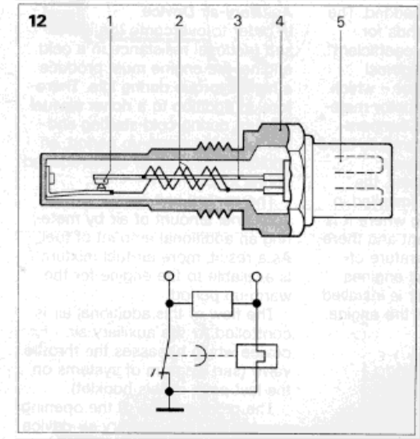


Fig. 12
Cross-sectional drawing of the thermo-time switch

1 Contact
2 Heating windings
3 Bimetallic strip
4 Housing
5 Elec. connection

This limitation in the duration of the period the start valve is switched on is accomplished in the thermo-time switch by an electrically-heated bimetallic strip which interrupts the electric circuit powering the start valve as a function of engine temperature after a certain heating time.

Warm-up

The warm-up period follows the cold start. During this period the engine requires considerable fuel enrichment because part of the fuel condenses on the cylinder walls which are still cold. In addition, without supplementary fuel enrichment during the warm-up period a major drop in engine speed would be noticed after the additional fuel sprayed into the engine by the start valve had been cut off.

For example, at a temperature of −20° C, two to three times as much fuel must be injected into the engine, depending on engine type, immediately after the starting operation as when the engine is at normal operating temperature.

This enrichment must be reduced as the engine temperature rises, and must be shut off entirely when the normal operating temperature is reached. In order to be able to carry out this function, data on the engine temperature must be fed to the control unit. This is done by the temperature sensor.

Temperature Sensor
The temperature sensor consists of a hollow threaded pin in which an NTC resistor is embedded. The abbreviation "NTC" stands for "negative temperature coefficient" and means that the electrical resistance of this resistor – which is made of a semiconductor material – decreases as the temperature increases. This change is used for measurement purposes.

In water-cooled engines, the temperature sensor is installed in the thermostat housing where it is immersed in the coolant and therefore senses the temperature of this water. In air-cooled engines the temperature sensor is installed in the cylinder head of the engine.

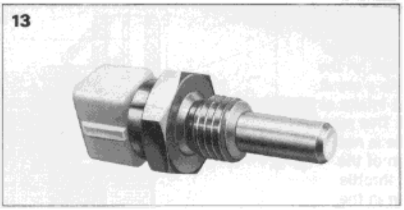


Fig. 13
Temperature sensor

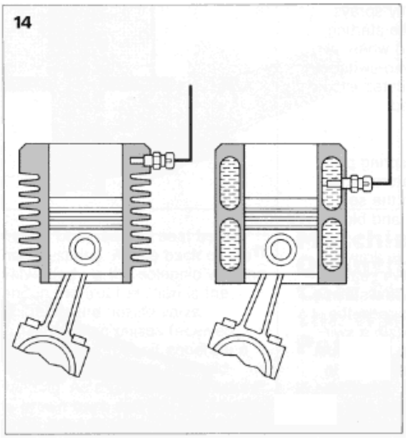


Fig. 14
Temperature sensors installed in an air-cooled and in a water-cooled engine.

Auxiliary-air Device
In order to overcome the increased frictional resistance in a cold engine, the engine must produce a higher torque during idle. Therefore, in addition to a richer air-fuel mixture during cold starting and the following warm-up period, an additional amount of air is required during idle.

The control unit reacts to this additional amount of air by metering an additional amount of fuel. As a result, more air-fuel mixture is available to the engine for the warm-up period.

The flow of this additional air is controlled by the auxiliary-air device which bypasses the throttle valve (see diagram of systems on the last page of this booklet).

The cross-section of the opening provided by the auxiliary-air device is adjusted as a function of temperature so that at every engine temperature the necessary idle speed is maintained. As the engine temperature rises, the opening through which the air can flow is steadily reduced, and at a coolant temperature of +60° C to +70° C it is completely closed.

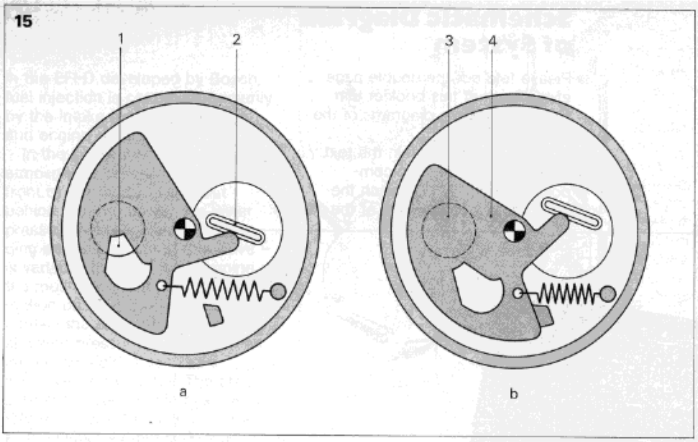


Fig. 15
Diagrams showing operation of the auxiliary-air device with external heating

1 Opening for auxiliary air
2 Bimetallic strip with heating winding
3 Cross-section of bypass channel partly open in drawing "a", closed in drawing "b"
4 Blocking plate
a Bypass channel partly open
b Bypass channel closed (engine at normal operating temperature)

Various types of auxiliary-air device are in use.

In the design employing a blocking plate, the plate is moved by a bimetallic strip which is heated electrically. When the engine is started, heating of this strip is switched on. As a result, the strip bends and turns the blocking plate against the restoring force of a spring. As it moves, therefore, the blocking plate changes the cross-section of the channel open to the auxiliary air.

In the design employing a rotary slider, the slider is controlled by an electrically-heated bimetallic spiral. In air-cooled engines this spiral is in contact with the engine oil in the crankcase. Another design of the auxiliary-air device is controlled by an expansion element. This type of auxiliary-air device consists of a metal cylinder filled with a wax-like substance that expands under the influence of heat. When it is heated, therefore, this substance expands and displaces a cylindrical pin against the restoring force of a spring. This pin in turn acts against a piston which changes the open cross-section of the auxiliary-air channel. This type of auxiliary-air device is installed in or on the engine in such a way that the expansion element is immersed in the coolant.

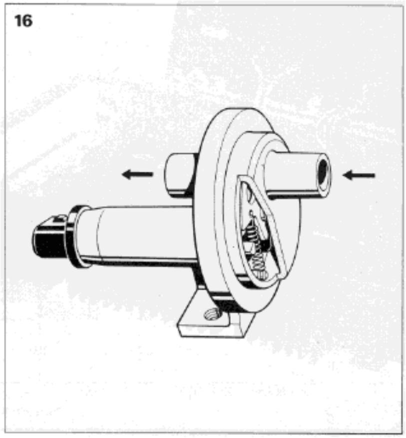


Fig. 16
Auxiliary-air device with external heating

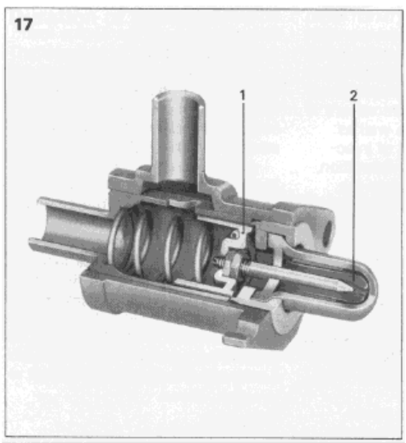


Fig. 17
Auxiliary-air device with expansion element

1 Piston
2 Expansion element

Schematic Diagram of System

Please fold out the double page at the back of this booklet that shows schematic diagrams of the EFI-D and EFI-L.

The numbers given in the text below with the various components in the EFI-D match the numbers on the diagram of the system.

18

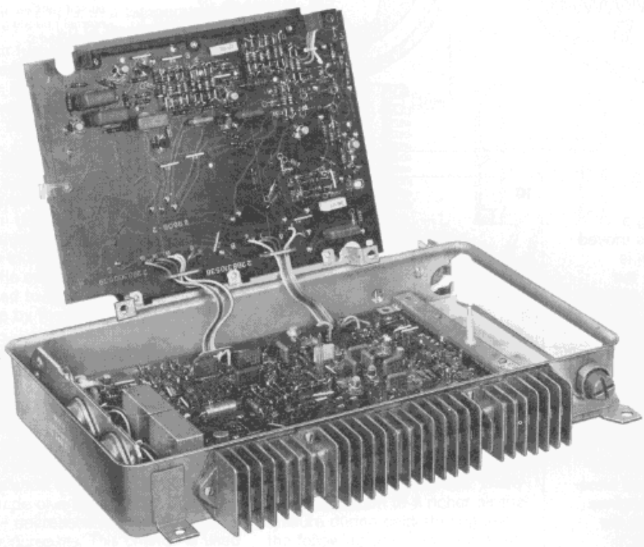


Fig. 18
Control unit in the EFI-D

Electronic control unit (1)
This unit receives data concerning intake manifold pressure, intake air temperature, coolant and cylinder head temperature, position and movement of the throttle valve, the starting process, as well as engine speed and start of injection; it processes this information, transmits electric pulses to the solenoid-operated injection valves, and switches the fuel pump on.
It is connected with the electrical components in the system by means of a multiple-pin plug and wiring harness. It contains about 300 components, about 70 of which are semiconductors, and is constructed using printed circuitry.

Injection valve (2)
sprays the fuel into the intake manifolds of the engine cylinders.

Pressure sensor (3)
transmits data on the engine load to the control unit.

Temperature sensors (4)
report the temperature of the air, coolant or cylinder head to the control unit.

Thermo-switch (5)
or thermo-time switch switches off the start valve.

Start valve (6)
sprays additional fuel into the intake manifold during starting at low temperatures.

Electric fuel pump (7)
continuously delivers fuel to the injection valves.

Fuel filter (8)
is installed in the fuel line to clean the fuel.

Fuel pressure regulator (9)
holds the pressure in the fuel lines constant.

Auxiliary-air device (10)
provides additional air as a function of temperature during warm-up.

Throttle-valve switch (11)
signals idle, acceleration and full-load to the control unit.

Trigger contacts (12)
installed in the ignition distributor, designed to transmit pulses to the control unit for begin of injection and information on the engine speed.

Operating Principle

In the EFI-D developed by Bosch, fuel injection is controlled primarily by the intake manifold pressure and engine speed.

In the intake manifold, atmospheric pressure prevails in front of the throttle valve but behind the throttle valve a lower pressure prevails which – depending on the position of this valve – is variable. In order to determine the most important item of information on engine operation, namely the engine load, this lower absolute pressure in the common intake manifold is used as a measurement quantity. The pressure in the common intake manifold is a measure for the volume of the intake air and is thus a measure of the engine load. Information on the pressure in the common intake manifold is provided by the pressure sensor. This is the reason why this system is designated "manifold pressure sensitive" or "EFI-D" for short because the German word for "pressure" begins with the letter "D".

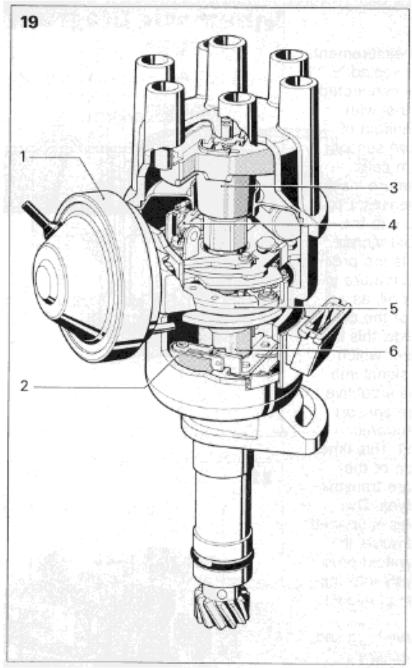


Fig. 19
Ignition distributor with trigger contacts (6-cylinder engine)

1 Vacuum unit
2 Trigger contacts
3 Distributor rotor
4 Distributor contact points
5 Mechanical ignition timing adjustment mechanism
6 Cam

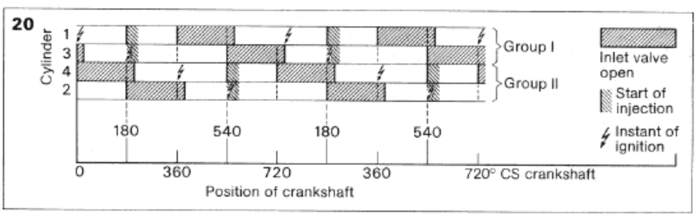


Fig. 20
Fuel injection timing diagram (EFI-D)

Start of Injection

The start of the pulse which opens the injection valves – depending on the position of the camshaft – is determined by special contacts in the ignition distributor. These contacts are installed under the mechanical (centrifugal force) timing adjustment mechanism in the ignition distributor and are activated by a cam on the distributor shaft. In addition, the control unit receives information on the engine speed in the form of the interval in time between the trigger pulses and this information, together with other data, is used to calculate the duration of fuel injection.

Duration of Injection

The duration of injection is determined mainly by two factors: the condition of load of the engine and the engine speed. Pressure sensors and trigger contacts provide the necessary signals for the control unit. The control unit calculates the required duration of injection and then by means of electrical pulses controls the injection valves so that they inject more or less fuel. In this way the so-called "basic quantity of fuel" is determined.

In principle, the following must be noted: the start of injection is determined by the trigger contacts in the ignition distributor. On the other hand, the duration of injection – and thus the quantity of fuel injected – is determined by the pressure sensor operating through the electronic time switch in the control unit.

Pressure Sensor

The pressure-sensor measurement system is installed in a sealed metal housing which is connected through a special channel with the common intake manifold of the engine. The pressure sensor contains two diaphragm cells which displace an armature inside a coil. As the load increases, i. e., as the absolute pressure in the common intake manifold increases, the diaphragm cells are pressed together and the armature is drawn farther into the coil; as a result, the inductance of the coil increases. In other words, this is a measurement transducer which converts a pneumatic signal into an electrical signal. The inductive pick-up (in the pressure sensor) is connected to an electronic timer in the control unit. This timer determines the duration of the electric pulses which are transmitted to the injection valves. The group of injection valves is opened for the duration of the pulse. In this way the intake manifold pressure is converted directly into the corresponding duration of injection.

When the throttle valve is closed, the intake manifold pressure is low. As a result, the diaphragm cells are pressed less firmly together and they slide the armature out of the coil. The inductance of the coil is thus lowered, the pulse becomes shorter, and the valves inject less fuel.

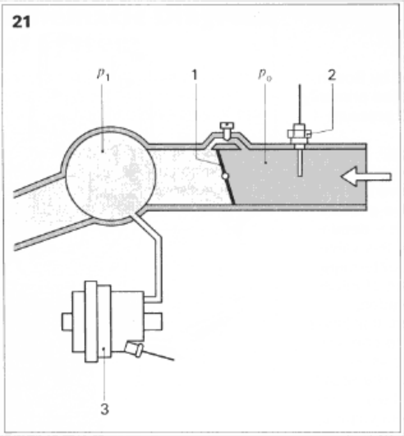


Fig. 21
Pressure conditions in the intake manifold

- p_0 Atmospheric pressure
- p_1 Pressure in common intake manifold
- 1 Throttle valve
- 2 Temperature sensor
- 3 Pressure sensor

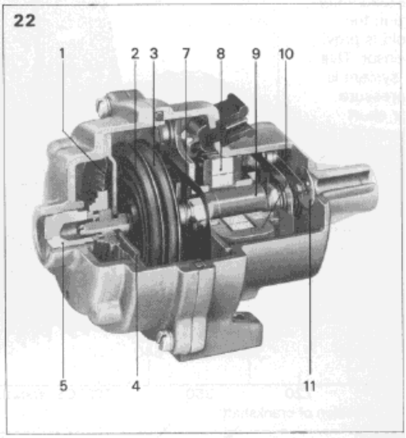


Fig. 22
Pressure sensor with additional diaphragm for the full-load enrichment

1 Diaphragm
2 Diaphragm cell
3 Diaphragm cell
4 Part-load stop
5 Full-load stop
7 Flat spring
8 Coil
9 Armature
10 Core
11 Valve

Matching to Operating Conditions

Full-load

During part-load operation of the engine, the fuel is metered so that the fuel consumption and the proportion of unburned components in the exhaust gas are as low as possible.

At full-load, however, the amount of fuel required is determined on the basis of maximum power, i. e., at full-load additional fuel must be injected into the engine.

Information on this full-load enrichment (pressure conditions in the intake manifold) is provided by the pressure sensor. Controlled by the diaphragm part, the inductance of the coil is changed. In the part-load range (Fig. 24) the atmospheric pressure, p_0, is greater than the pressure in the intake manifold, p_1. As a result, the diaphragm is pressed against its part-load stop. Only diaphragms 1 and 2 act on the armature.

In the case of full-load (Fig. 25), the intake manifold pressure is about equal to the atmospheric pressure. The spring is then able to press the diaphragm against its full-load stop.

This additional movement counteracts the movement of the armature caused by diaphragm cells 1 and 2, and signals the full-load condition to the control unit.

In systems which are subject to more demanding exhaust gas conditions, full-load enrichment is controlled by an additional contact in the throttle valve switch. As a result, the diaphragm section of the pressure sensor is eliminated for full-load enrichment.

23

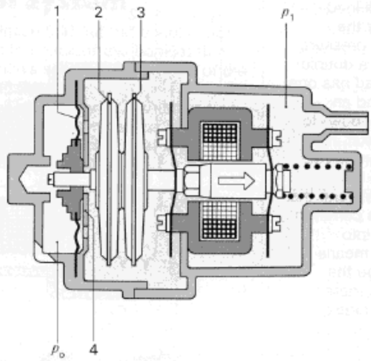


Fig. 23
Pressure sensor during idle, $p_1 \ll p_0$
Basic operation: diaphragm cells (2/3) expanded.
Auxiliary operation: diaphragm (1) pressed against part-load stop (4)

1 Diaphragm
2 Diaphragm cell
3 Diaphragm cell
4 Part-load stop
p_0 Atmospheric pressure
p_1 Intake manifold pressure

24

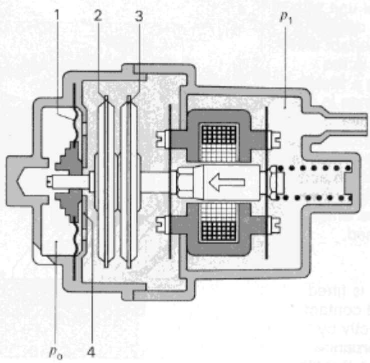


Fig. 24
Pressure sensor at part load, $p_1 < p_0$
Basic operation: diaphragm cells (2/3) pressed lightly together
Auxiliary operation: diaphragm (1) pressed against part-load stop (4)

1 Diaphragm
2 Diaphragm cell
3 Diaphragm cell
4 Part-load stop
p_0 Atmospheric pressure
p_1 Intake manifold pressure

25

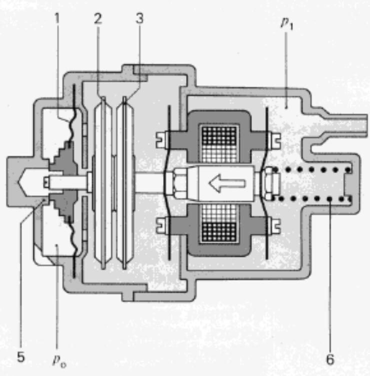


Fig. 25
Pressure sensor at full-load, $p_1 \approx p_0$
Basic operation: diaphragm cells (2/3) pressed together
Auxiliary operation: diaphragm (1) pressed against full-load stop (5)

1 Diaphragm
2 Diaphragm cell
3 Diaphragm cell
5 Full-load stop
6 Spring
p_0 Atmospheric pressure
p_1 Intake manifold pressure

Altitude Compensation

In systems employing full-load enrichment controlled by the throttle valve switch, the pressure sensor does not contain a double-diaphragm cell but instead has one closed diaphragm cell and an additional diaphragm cell open to the atmosphere. As a result, not only the absolute pressure in the intake manifold, but also the difference in pressure between the free atmosphere and the common intake manifold is taken into account. In practice this means that in the part-load range the engine is matched much more accurately to varying altitudes.

Acceleration

When the throttle valve opens – i. e., during acceleration – the pressure sensor reports the rise in pressure to the control unit with a slight delay. This slight delay in response results from the fact that the increase in pressure in the pressure sensor requires a slightly longer time than the change in the position of the throttle valve. In order to bridge this slight delay in response, a throttle valve switch is included in the system which acts through the control unit to provide additional injection pulses when the throttle valve is opened.

Throttle Valve Switch

The throttle valve switch is fitted with sliding contacts and contact paths. It is activated directly by the throttle shaft in accordance with the movement of the throttle valve. During acceleration, the sliding contact moves across the comb-shaped contact paths and as a result produces not only extended injection time but also additional injection pulses for acceleration enrichment.

Overrun

Combustion is continued during overrun because the emission of noxious components in exhaust gases is lower than if an engine is restarted after its combustion chamber has cooled down as a result of combustion having been stopped. Since there is a poorer mixing of air and fuel in a cooled combustion chamber, if combustion is interrupted, renewed ignition would result in the emission of an unacceptably large amount of incompletely burned and thus noxious components in the exhaust gas. In addition, in engines fitted with exhaust gas catalyzers, the danger would arise that these catalyzers would burn through.

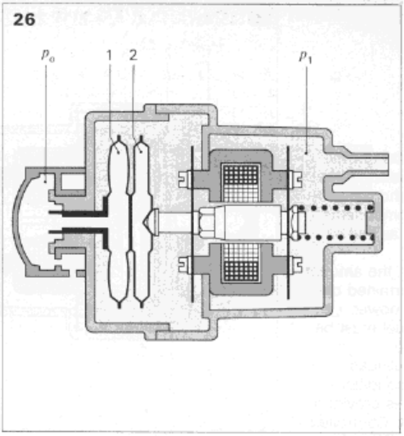


Fig. 26
Pressure sensor without diaphragm for the full-load enrichment, with altitude compensation

p_0 Atmospheric pressure
1 Diaphragm cell 1, open
2 Diaphragm cell 2, closed
p_1 Intake manifold pressure

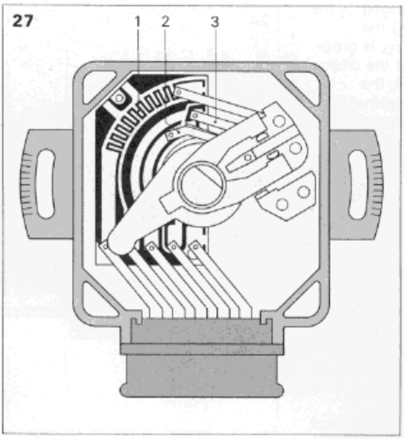


Fig. 27
Throttle valve switch

1 Contact path for acceleration enrichment
2 Full-load contact
3 Idle contact

Intake Air Temperature

Temperature Sensor

The quantity of fuel injected into the engine is controlled mainly by the intake manifold pressure. This control, however, applies exactly only for a constant temperature because at a low ambient temperature the density and thus the weight of the air drawn into the engine is higher, so the air-fuel mixture would become leaner if the control system did not consider the air temperature. Primarily at temperatures between 0° C and −20° C this can result in misfiring. In order to avoid this problem, a temperature sensor is installed in the system (Fig. 21). As the air temperature decreases (higher air density), this temperature sensor, operating through the control unit, causes the amount of fuel injected to be increased in accordance with the air density.

The temperature sensor consists of a temperature-dependent resistor installed in a metal housing (Fig. 13).

Schematic Diagram of System

Please fold out the double page at the back of this booklet that shows schematic diagrams of the EFI-D and EFI-L.

The numbers given in the text below with the various components in the EFI-L match the numbers on the diagram of the system.

28

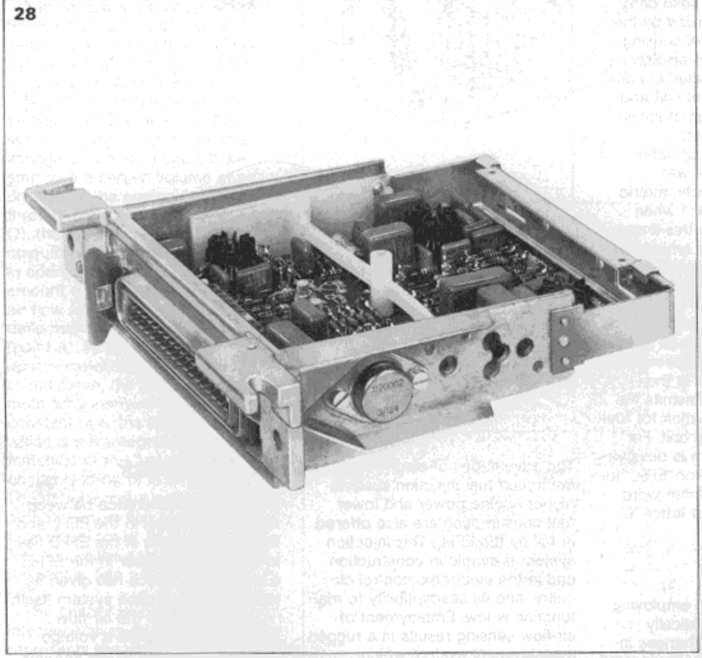


Fig. 28
Control unit in the EFI-L

Electronic control unit (1)
This unit receives information on the quantity of air drawn into the engine, coolant and cylinder head temperature, position of the throttle valve, the starting process, as well as engine speed and start of injection; it processes this information and transmits electric pulses to the solenoid-operated injection valves. It is connected with the electrical components in the system by means of a multiple-pin plug and wiring harness. It contains about 80 components, including 3 integrated circuits, and is constructed on the basis of printed circuitry.

Injection valve (2)
sprays the fuel into the intake manifolds of the engine cylinders.

Air-flow sensor (3)
transmits information on the amount of air drawn into the engine to the control unit and switches the fuel pump on.

Temperature sensors (4)
report the temperature of the coolant or cylinder head to the control unit.

Thermo-time switch (5)
automatically switches off the start valve.

Start valve (6)
sprays additional fuel into the intake manifold during starting at low temperatures.

Electric fuel pump (7)
continuously delivers fuel to the injection valves.

Fuel filter (8)
is installed in the fuel line to clean the fuel.

Fuel pressure regulator (9)
holds the pressure in the fuel lines constant.

Auxiliary-air device (10)
provides additional air as a function of temperature during warm-up.

Throttle valve switch (11)
signals idle and full-load to the control unit.

Relay set (12)
switches the control unit and the fuel pump on.

Operating Principle

In the EFI-L developed by Bosch, fuel injection is controlled by the amount of air drawn into the engine. Reduction of the noxious components in the exhaust gas and simplified construction of the injection system were the primary objectives pursued in the development of this system. These different objectives are fulfilled by the new principle of air-flow sensing. In addition, advantages also result from the use of integrated circuits in the electronic control unit and by the simplified design of individual system components.

In the section "Air-fuel Ratio" earlier in this booklet it was explained that the stoichiometric ratio of air to fuel is 14 : 1 when gasoline is used. From this it can be recognized that the amount of air drawn into the engine is a very exact measure for the amount of fuel required.

The amount of air drawn into the engine is measured with an air-flow sensor developed specially to meet the requirements in the vehicle. This sensor transmits the most important information for fuel metering to the control unit. For this reason, this system is designated "air-flow sensitive" or "EFI-L" for short because the German word for "air" begins with the letter "L".

Advantages of Air-flow Sensing

- The injection system employing air-flow sensing automatically takes into account all changes in the engine which can occur during the service life of the vehicle (abrasion, deposits in the combustion chamber, change in valve adjustment, etc.). Uniform good quality of exhaust gas is therefore assured.
- In the EFI-L, part of the exhaust gas can be recirculated to lower the temperature in the combustion chamber. The air-flow sensor measures only the fresh air drawn into the engine, and the control unit meters the quantity of fuel required for only the amount of fresh air.
- A supplementary mechanism for mixture enrichment during acceleration is not required because the signal transmitted by the air-flow sensor precedes charging of the cylinders. In addition, idle stability is improved.

29

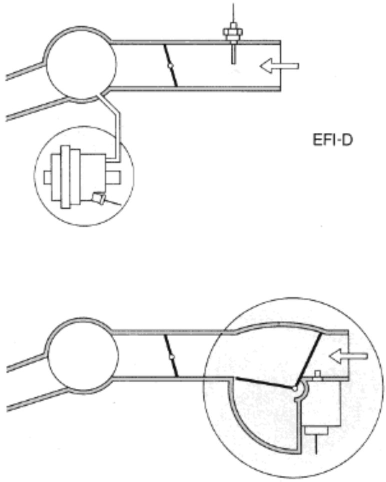


Fig. 29
Comparison of the measurement systems
Above: EFI-D (pressure sensor),
below: EFI-L (air-flow sensor)

The advantages of electronically-controlled fuel injection such as higher engine power and lower fuel consumption are also offered in full by the EFI-L. This injection system is simple in construction and in the electronic control circuitry, and its susceptibility to malfunction is low. Employment of air-flow sensing results in a rugged measurement system which directly takes into account many variables affecting engine operation. The use of integrated circuits in the control unit has also resulted in low susceptibility to malfunction. Moreover, the control unit can be designed at low cost to monitor and control future exhaust gas regulation equipment. The EFI-L thus represents a more highly developed system and an even more effective system to meet exhaust gas regulations which are certain to become more stringent in the future.

Air-flow Sensor

The principal difference between the intake system in the EFI-L and the intake system in the EFI-D lies in the air-flow sensor in the EFI-L, a component which has given its name to the injection system itself.

The function of the air-flow sensor is to generate a voltage signal proportional to the amount of air drawn into the engine. This signal and the information on the engine speed are the main inputs used by the control unit to determine the duration of injection. In the air-flow sensor the air drawn in by the engine exerts a force on a movable air-flow sensor flap. Depending on the air-flow and the effective opposing restoring force of a spring, the air-flow sensor flap is held in a certain angular position which is sensed by a potentiometer.

A compensation flap attached to the air-flow sensor flap compensates for possible back-pressure oscillations because it has the same effective surface area as the sensor flap, so these oscillations have no effect on the air-flow sensing function. At the same time the compensation flap, together with a damping chamber, reduces oscillations in the measurement system.

The air-flow sensor flap is also fitted with a non-return valve designed to protect the air-flow sensor against damage in event of back-pressure surges.

Fig. 32 shows the relationships between volume of air, air-flow sensor flap angle, potentiometer voltage, and fuel injected. If we start with a certain volume of air drawn into the engine and flowing through the air-flow sensor (point Q), the theoretically required amount of fuel is found (point D). In addition, depending on the amount of air flowing through the air-flow sensor, the sensor flap is deflected to a certain flap angle (point A). As a result of the approximately logarithmic shape of the curve, the relative measurement error remains very nearly constant over the entire range, which is advantageous for exact matching of the fuel when the engine is idling or is at part-load. The potentiometer activated by the air-flow sensor flap sends a voltage signal (point B) – which is a function of the angular position of the sensor flap – to the control unit.

The control unit controls the injection valves. In Fig. 32 point C represents the amount of fuel injected into the engine as a function of the potentiometer voltage, and point D represents the amount of fuel injected as a function of the amount of air drawn into the engine. It can be seen that the theoretically required amount of fuel and the amount of fuel actually injected are the same (line C–D).

30

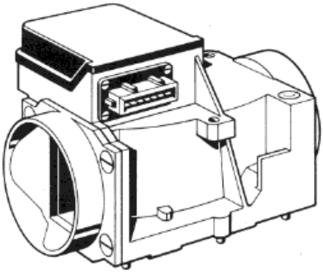


Fig. 30
Air-flow sensor

31

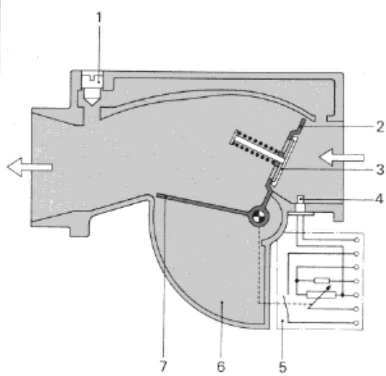


Fig. 31
Cross-sectional drawing of the air-flow sensor

1 Mixture adjustment screw for the idle range
2 Air-flow sensor flap
3 Non-return valve
4 Air-temperature sensor
5 Elec. connections
6 Damping chamber
7 Compensation flap

32

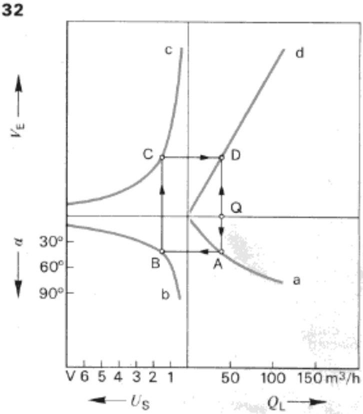


Fig. 32
Relationships between volume of air, sensor flap angle, potentiometer voltage, and amount of fuel injected

a Angle of air-flow sensor flap,
b Potentiometer voltage, U_S
c Amount of fuel metered by control unit, V_e
d Amount of fuel theoretically required by engine, determined from the amount of air, Q_L, drawn into the engine

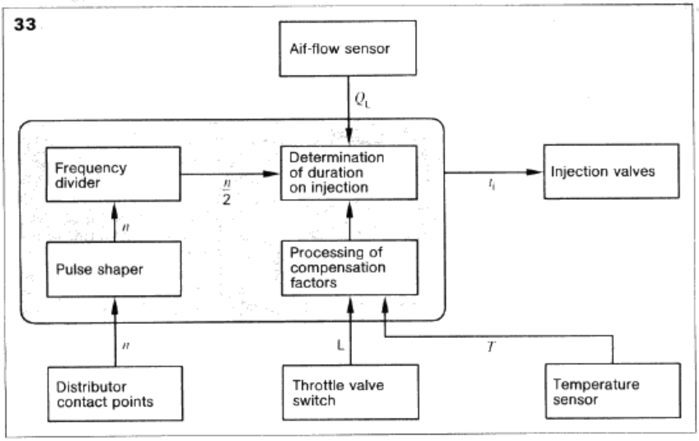


Fig. 33
Block operating diagram of the EFI-L

Signals for:
n Rotational speed
Q_L Amount of air
T Temperature
t_i Duration of injection
L Idle, full-load

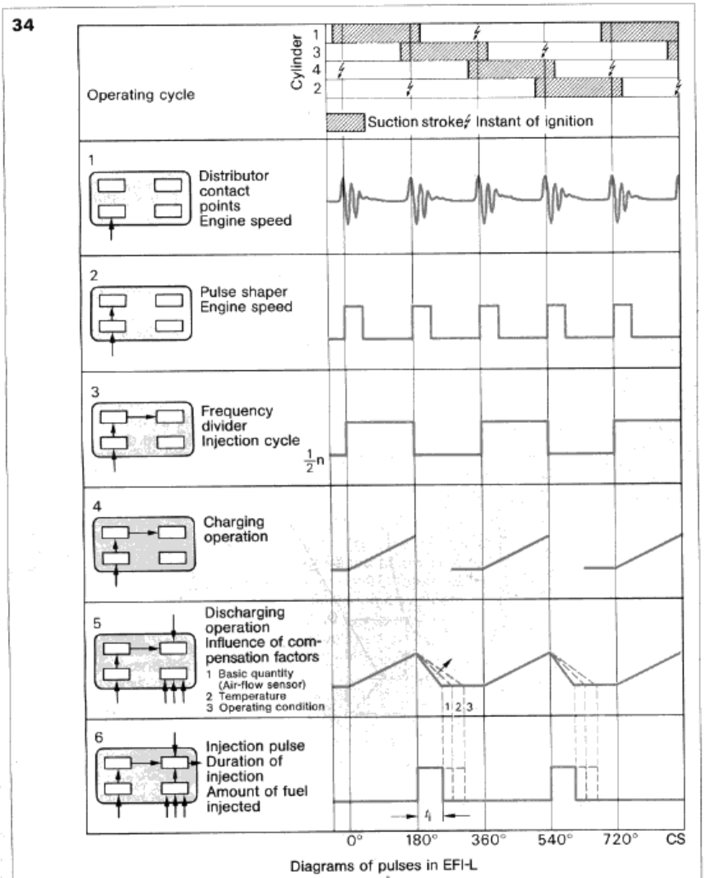


Fig. 34
Diagram of pulses in EFI-L

Start of Injection

All injection valves are connected electrically in parallel and simultaneously inject half of the required amount of fuel twice during each rotation of the camshaft. This simplifies the electronic circuitry in the control unit, and in addition a fixed relationship between the camshaft angle and the start of ignition is no longer necessary. As a result, the trigger contacts in the ignition distributor can be eliminated. The injection pulses are controlled from the distributor contact points.

In a 4-cylinder engine, the distributor contact points open four times during each operating cycle of the engine. However, since fuel is injected only twice per engine operating cycle, the frequency must be divided in half in the control unit. In 6-cylinder engines the frequency is divided similarly by a factor of 3.

Duration of Injection

Fig. 34 shows the pulses generated in the basic operation of the control unit, as explained below.

The pulses received from the contact points in the ignition distributor (1) are converted to rectangular pulses in the pulse shaper (2).

Since injection occurs only twice per rotation of the camshaft but four pulses are transmitted during each rotation of the camshaft, the frequency must be divided in half in the frequency divider (3).

The rectangular pulses are used to charge a capacitor (4). Each injection pulse, t_i, begins with the discharge of this capacitor; here, the position of the air-flow sensor flap in the air-flow sensor – as a measure of the volume of air, Q_L, drawn into the engine – is the most important factor determining the duration of injection. Various compensation factors (full-load and idle from the throttle valve switch, engine temperature from the temperature sensor), together with the signal from the air-flow sensor and the injection frequency (derived from the engine speed) determine the duration of injection (5) which is fed in the form of pulses to the injection valves (6).

35

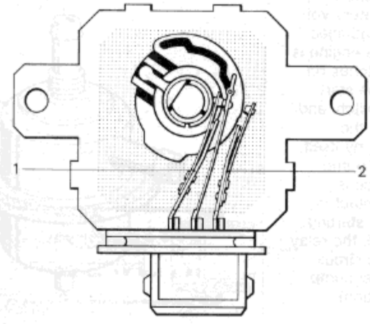


Fig. 35
Throttle valve switch

1 Idle contact
2 Full-load contact

Matching to Operating Conditions

In comparison with the EFI-D, fewer compensation adjustments are required for the duration of injection in the EFI-L. The reason for this is that the principle of air-flow sensing takes direct account of a multitude of factors which influence the fuel requirement of the engine. Matching to cold-start conditions and to the warm-up process takes place in this system similar to the way these processes are carried out in the EFI-D and is described in the general section of this booklet.

Idle and Full-Load

In comparison with the throttle valve switch in the EFI-D, the throttle valve switch in the EFI-L has been greatly simplified. The contact paths for temporary enrichment have been eliminated and the throttle valve switch contains only one contact for idle and one for full-load. The switching contact travels in a specially shaped track and switches on the contacts for idle and full-load (as the case may be) as a function of certain positions of the air throttle valve. The output signals are processed by the control unit when determining the duration of injection.

Starting

Relay Set

When the ignition is switched on, the relay set switches battery voltage to the control unit and injection valves, and when the engine is started, the relay set switches on the electric fuel pump, the start valve, the thermo-time switch, and the auxiliary-air device. If the engine begins to operate by itself, the power supply for the pump and the auxiliary-air device is maintained through a contact in the air-flow sensor. If the starting process is not successful, the relay set interrupts the electric circuit leading to the electric fuel pump (cylinder flooding protection).

Fuel-pressure Regulator

A major difference in the fuel-pressure regulator in the EFI-L compared with the regulator in the EFI-D is that the spring chamber is connected through a line with the intake manifold. As a result, the difference between the intake manifold pressure and the fuel pressure is held constant. The drop in pressure across the injection valves is therefore equal for all load conditions.

Solenoid-operated Injection Valves

The injection valves in the EFI-L differ from the designs used in the EFI-D only by a smaller opening cross-section. This reduction is necessary because the fuel is injected twice per rotation of the camshaft in the EFI-L whereas it is injected only once per camshaft rotation in the EFI-D.

36

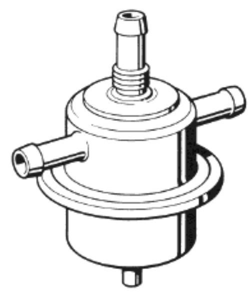


Fig. 36
Fuel-pressure regulator (EFI-L)

37

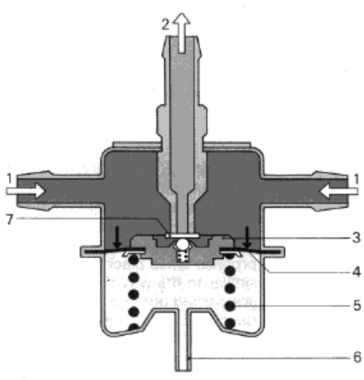


Fig. 37
Cross-sectional drawing of the fuel-pressure regulator

1 Fuel connection
2 Return line to fuel tank
3 Valve support
4 Diaphragm
5 Pressure spring
6 Connection to intake manifold
7 Valve

Lambda Probe

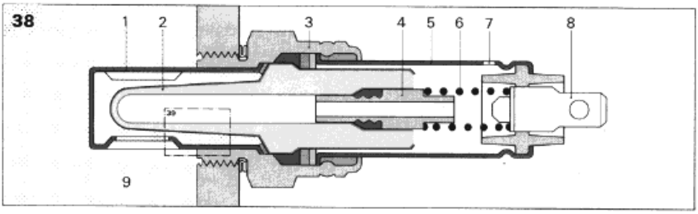
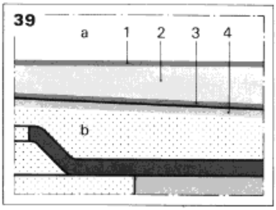


Fig. 38
Cross-sectional drawing of the Lambda probe

1 Protective tube
2 Ceramic body
3 Housing
4 Contact bushing
5 Protective sleeve
6 Contact spring
7 Ventilation opening
8 Elec. connection
9 Exhaust gas



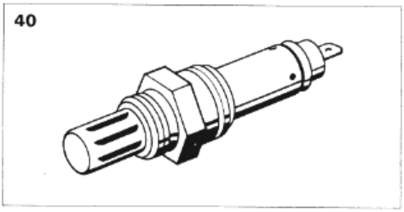


Fig. 39
Section from Fig. 38

a Air side
b Exhaust gas side
1 Elec. conductive layer
2 Ceramic body
3 Elec. conductive layer
4 Porous ceramic layer

Fig. 40
Lambda probe

General

Regulations limiting the concentration of noxious components in the exhaust gases emitted from internal combustion engines are constantly becoming more stringent and this dictates continually more accurate metering of the air-fuel mixture.

Bosch has developed a probe which measures the oxygen concentration in exhaust gases. The output signal from this probe is used to regulate the air-fuel mixture and as a result makes it possible – used together with special exhaust gas catalyzers – to lower the concentration of noxious components in exhaust gases.

Construction

Fig. 38 shows the construction of the Lambda probe. The ceramic body of the probe is fitted in a housing which protects the ceramic body against mechanical influences and serves for installation of the probe. The outer part of the ceramic body is positioned in the stream of exhaust gases, while the inner part is in contact with the ambient air.

The ceramic body consists basically of zirconium dioxide. Each of its surfaces (inside and outside) is coated with an electrode made of a thin layer of platinum permeable to gas. In addition, a porous ceramic layer is applied to the surface exposed to the exhaust gases. This layer protects the surface of the electrode against contamination caused by combustion residues in the exhaust gas stream and assures that the characeristics of the probe do not change.

Principle of Operation

Operation of the Lambda probe is based on the fact that the ceramic material used becomes conductive for oxygen ions at temperatures of about 300° C and higher. If the concentration of oxygen inside the probe differs from that outside the probe, an electrical voltage is developed between the two surfaces because of the special characteristics of the material used. This voltage is a measure for the difference in the oxygen concentration on the two sides of the probe.

The exhaust gases emitted from an internal combustion engine contain residual components of oxygen even when combustion takes place with an excess of fuel. For example, with $\lambda = 0.95$, these oxygen components amount to 0.2...0.3 % by volume. The residual oxygen concentration depends greatly on the composition of the air-fuel mixture which is fed into the engine for combustion purposes.

This dependence makes it possible to use the oxygen concentration in the exhaust gas as a measure for the air-fuel ratio and thus for the air factor, λ.

As a result of suitable selection of probe materials, we have succeeded in setting the highest sensitivity of the probe in the range of $\lambda = 1$.

Operation in Vehicle

The special sensitivity of the λ probe in the range of $\lambda = 1$ makes it possible to feed the output signal from the probe as an actual value to the control unit in the EFI-D or EFI-L. As a result, it is possible to construct a closed loop. This means that the system itself can monitor whether the specified air-fuel mixture actually results in combustion that emits exhaust gas low in noxious components. If the mixture deviates from the specified value, this is sensed by the λ probe on the basis of the residual oxygen concentration in the exhaust gas, and this condition is communicated to the control unit in the form of an electrical signal. The control unit processes this signal to change the duration of injection, and thus corrects the air-fuel mixture practically inertia-free.

Using the λ closed loop and the EFI-D or EFI-L, it is possible to achieve the degree of accuracy in regulating the composition of the air-fuel mixture which is required for effective operation of exhaust gas catalyzers for detoxication of exhaust gases. (See Bosch Technical Instruction "Fuel Injection, Continuous Injection System", Order No. VDT-UBP 741/1 B.)

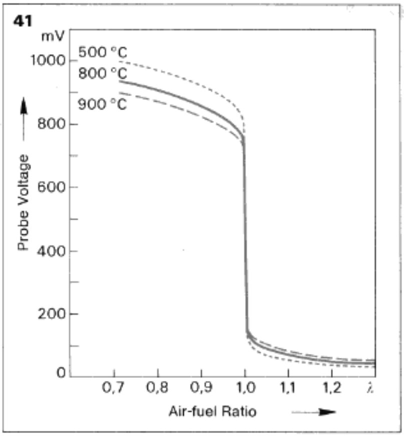


Fig. 41
Operating characteristic of the Lambda probe

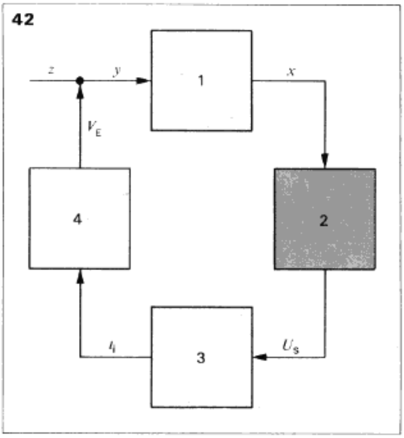


Fig. 42
Simplified schematic block diagram of the λ closed loop for regulation of the air-fuel mixture.

1 Controlled system (engine)
2 Sensing element (λ probe)
3 Regulator (control unit)
4 Regulating element (injection valves)
x Regulated condition (oxygen concentration in exhaust gas)
U_s Probe voltage (function of x)
t_i Regulating pulses for injection valves
V_E Amount of fuel injected
Z Disturbance factor (for example changed operating conditions)
y Air-fuel mixture

Bibliography

G. Baumann:
Eine elektronisch gesteuerte Benzineinspritzung für Otto-Motoren. Bosch Technical Report 2 (1967) Issue 3, page 107; MTZ 28 (1967), page 475.

H. Scholl:
Elektronische Benzineinspritzung. ATZ 70 (1968) page 115. Elektronisch gesteuerte Benzineinspritzung. Weiterentwicklung der Jetronic. Bosch Technical Report 3 (1969) Issue 1, page 3.

N. Rittmannsberger:
Eine elektronisch gesteuerte Benzineinspritzung. ETZ-B (1970) Vol. 22, Issue 2, page 23.

H. Scholl and W. Söll:
Die elektronisch gesteuerte Benzineinspritzung, Feinwerktechnik (1970) Issue 5, page 210.

O. Glöckler, N. Rittmannsberger and H. Scholl:
Weiterentwicklung der elektronisch gesteuerten Benzineinspritzung "Jetronic". ATZ 73 (1971), 4.

H. Scholl:
Elektronische Benzineinspritzung mit Steuerung durch Luftmenge und Motordrehzahl. MTZ 34 (1973), 4.

O. Glöckler and B. Kraus:
L-Jetronic – Elektronisches Benzineinspritzsystem mit Luftmengenmessung. Bosch Technical Report 5 (1975) Issue 1, page 7.

Glossary

Air factor
A numerical factor found by dividing the actual amount of intake air by the theoretical amount of air required for complete combustion of the fuel provided. Mathematical symbol λ.

Air-flow sensor
A device designed to meter the volume of air drawn into the engine.

Air-flow sensor flap
A flap located in the air-flow sensor, the position of which is a measure for the volume of air drawn into the engine.

Altitude compensation
The density of the air decreases as the altitude increases. If the fuel metering were held constant, this fact would result in the air-fuel mixture becoming too rich at higher altitudes. The amount of fuel fed to the engine is therefore changed and this process is designated altitude compensation.

Auxiliary-air device
A special cut-off device installed in the air line bypassing the throttle valve. Inside this device a sliding plate with a hole through it holds a channel for additional air open when the engine is cold. As it warms up, however, a bimetallic strip is heated and shifts the plate, gradually cutting off the bypass line so that it is completely closed when the engine reaches normal operating temperature.

Back-pressure oscillations
Sudden surges in pressure in the intake manifold caused by misfiring.

Basic quantity of fuel
This is the quantity of fuel injected into the engine minus the additional quantities of fuel injected as a result of all other compensation factors.

Bimetal (Bimetallic strip)
Two metals with different coefficients of thermal expansion mechanically joined to each other. The bending of the bimetal when subjected to heat is used for measurement and control purposes.

Catalyzer
A material which by virtue of its presence promotes chemical reactions but which itself is not changed by these reactions.

Cold starting
Starting with a cold engine.

Common intake manifold
Part of the intake system in spark-ignition engines which feeds air to the engine. Individual intake manifolds lead from the common intake manifold to the individual cylinders. The throttle valve is located in the common intake manifold.

Condensation loss
In cold engines, particles of the fuel condense out of the air-fuel mixture on the cold walls in the intake manifold and combustion chamber. As a result, the mixture becomes leaner.

Cylinder-flooding protection
A protective circuit in the EFI-D and EFI-L which prevents the cylinders from being flooded with fuel.

Damping chamber
The chamber in the air-flow sensor in which the damping (compensation) flap moves (operating like a shock absorber).

Duration of injection
The period of time during which the injection valves are open.

EFI-D
Electronically-controlled fuel injection system, the operation of which is based on manifold-pressure sensing.

EFI-L
Electronically-controlled fuel injection system, the operation of which is based on air-flow sensing.

Electric fuel pump
An electrically-driven fuel pump.

Electrode
A conductive part which is designed to conduct electric current to a particular medium.

Exhaust gas recirculation
A process in which a part of the exhaust gas is fed back to the engine. Recirculation takes place in the manifold.

Fuel injection
Adding the fuel to the air drawn into the engine by means of an injection system.

Fuel pressure regulator
A regulator device which holds the difference between the fuel pressure and the intake manifold pressure constant (EFI-L).

Ignitable mixture
An air-fuel mixture is ignitable in the range of $\lambda = 0.7 \ldots 1.3$.

(Individual) intake manifold
The cylinders are supplied with air through the individual intake manifolds which are connected to the common intake manifold.

Integrated circuit
An electronic circuit consisting of inseparable semiconductor elements on a single, usually very small, mounting plate. Abbreviation: IC.

Intermittent
Operating with interruptions. Intermittent injection means that the fuel is not injected continuously but instead periodically, i. e., at set intervals.

Ions
Atoms, molecules, or molecular groups with an electric charge.

λ probe (Lambda probe)
A probe designed to measure the oxygen concentration in exhaust gases.

Lean mixture
A mixture in which an excess of air exists, $\lambda > 1$, i. e., the volume of air is greater than the theoretical requirement.

Measurement transducers (measurement sensors)
Instruments which convert physical quantities into other quantities. For example: conversion of heat, pressure, etc. into electrical signals.

NTC resistor
A temperature-dependent semiconductor resistor, the resistance of which decreases as the temperature increases (thermistor). "NTC" stands for "negative temperature coefficient".

Operating cycle (of the internal combustion engine)
One operating cycle includes all processes in the cylinder, starting from a certain condition until the next repetition of the same condition. In the 4-stroke engine one operating cycle includes 2 rotations of the crankshaft, representing 4 strokes of the pistons.

Overrun
Vehicle operation during which the engine is driven by the vehicle, for example when driving downhill.

Part-load
The load range between idle and full-load.

Potentiometer
An electrical resistor, the resistance of which can be changed mechanically.

Pressure sensor
A mechanism which reports the pressure to be measured to the control unit in the form of electrical signals.

Relay set
A circuit consisting of two relays. By means of the relay set, the control unit is switched on and the starting operations for the fuel pump and the start valve are initiated.

Rich mixture
A mixture in which a deficiency of air exists, $\lambda < 1$, i. e., the volume of air is less than the theoretical requirement.

Roller-cell fuel pump
A fuel pump with a rotor disc operating eccentrically with respect to the pump housing. In recesses in the edge of this rotor disc are metal rollers which are pushed against the pump housing by centrifugal force and act as seals. The fuel is carried in the gaps between the rollers and is then forced into the fuel injection tubing at the outlet from the pump.

Solenoid-operated injection valve
An injection valve which is operated electromagnetically, i. e., by a solenoid.

Spark-ignition engine (otto engine)
An internal combustion engine in which combustion of the compressed air-fuel mixture is induced by external ignition at certain controlled times.

Start of injection
The instant in time when the injection valves open.

Start valve
A solenoid-operated injection nozzle which sprays additional fuel in finely atomized form into the engine common intake manifold during a starting process when the engine is cold.

Stoichiometric air-fuel ratio
The ratio of the amount of air theoretically required for complete combustion of a certain amount of fuel. For gasoline, the average stoichiometric air-fuel ratio is 14:1, i. e., 14 kg of air are required for complete combustion of 1 kg of fuel.

Swirl nozzle
An injection nozzle in which a swirling motion is imparted to the fuel by tangential intake ports so that the fuel leaves the nozzle in finely atomized form.

Temperature sensor
An instrument which measures temperatures and reports them in the form of electrical signals to the control unit.

Thermo-switch
A switch which operates as a function of temperature.

Thermo-time switch
A switch which operates as a function of temperature (similar to the thermo-switch) but which remains switched on for only a certain limited length of time.

Throttle valve switch
A switch which is activated by the throttle valve. The throttle valve switch signals the operating conditions of idle and full-load to the control unit.

Trigger contacts
Contacts in the ignition distributor in the EFI-D which transmit the pulses for start of ignition to the control unit and also provide information on engine speed.

Warm-up
Transition period of the engine from cold to normal operating temperature.

Warm-up enrichment
In order to compensate for the air-fuel mixture becoming leaner as a result of condensation losses, an additional amount of fuel is fed to the engine during warm-up.

Test Page

This test page gives you the opportunity to check your knowledge of the material discussed in this technical instruction booklet.

The correct answers are given at the end of these questions so that you may check your answers.

1. How much air is required for complete combustion of 1 kg of fuel (gasoline)?
   - ☐ a) 1 kg
   - ☐ b) 14 kg
   - ☐ c) 28 kg

2. What is the term given to the ratio of air and fuel for complete combustion?
   - ☐ a) mixture ratio
   - ☐ b) stoichiometric ratio
   - ☐ c) charging ratio

3. With the throttle valve closed and with the engine operating, the pressure in the common intake manifold is:
   - ☐ a) lower than
   - ☐ b) the same as
   - ☐ c) higher than

   the air pressure in front of the throttle valve.

4. The start valve sprays additional fuel:
   - ☐ a) directly into the cylinder
   - ☐ b) into the common intake manifold
   - ☐ c) in front of the throttle valve

5. How are the injection valves operated?
   - ☐ a) mechanically
   - ☐ b) by solenoids
   - ☐ c) hydraulically

6. The engine requires additional air:
   - ☐ a) when idling after a cold start
   - ☐ b) at the normal operating temperature
   - ☐ c) during acceleration

7. The additional air is fed to the engine through:
   - ☐ a) the auxiliary-air device
   - ☐ b) the auxiliary-air funnel
   - ☐ c) the start valve

8. The EFI-D is controlled mainly by:
   - ☐ a) the air-flow sensor
   - ☐ b) the throttle valve
   - ☐ c) the pressure sensor

9. What component in the EFI-D has the greatest influence on the duration of injection?
   - ☐ a) the pressure sensor
   - ☐ b) the throttle valve switch
   - ☐ c) the pressure regulator

10. What component in the EFI-D determines the start of injection?
    - ☐ a) the breaker contacts in the ignition distributor
    - ☐ b) the trigger contacts in the ignition distributor
    - ☐ c) the pressure sensor

11. The measurement unit "1 bar" in technical usage corresponds to:
    - ☐ a) 1 atm
    - ☐ b) approximately 1 $\frac{kgf}{cm^2}$

12. The EFI-L is controlled mainly by:
    - ☐ a) the air pressure
    - ☐ b) the pressure sensor
    - ☐ c) the air-flow sensor

13. An adjustment of the EFI-L is required:
    - ☐ a) as the engine becomes older
    - ☐ b) is not required
    - ☐ c) when the valve adjustment changes

14. The air-flow sensor flap in the air-flow sensor:
    - ☐ a) sends a voltage signal to the control unit proportional to the volume of intake air by means of a potentiometer
    - ☐ b) controls the volume of intake air
    - ☐ c) assumes the function of the throttle valve

15. Start of injection in the EFI-L is triggered by:
    - ☐ a) the air-flow sensor
    - ☐ b) the trigger contacts in the ignition distributor
    - ☐ c) the breaker contacts in the ignition distributor

16. Air-flow sensing requires:
    - ☐ a) more compensation factors
    - ☐ b) fewer compensation factors
    - ☐ c) an expensive control unit

17. What additional operation is performed by the thermo-time switch in comparison with the thermo-switch?
    - ☐ a) It switches off as the coolant temperature increases.
    - ☐ b) It limits the duration of time during which the start valve is switched on.
    - ☐ c) It operates the auxiliary-air device.

18. We understand the term "air factor", λ (Lambda), to represent:
    - ☐ a) the specific weight of air
    - ☐ b) the volume of air drawn into the engine
    - ☐ c) the ratio of the volume of air drawn into the engine to the theoretical requirement of air for complete combustion in the engine

19. The λ probe measures:
    - ☐ a) the quantity of exhaust gas
    - ☐ b) the residual oxygen present in the exhaust gas
    - ☐ c) the exhaust gas temperature

Correct answers:

1 b, 2 b, 3 a, 4 b, 5 b, 6 a, 7 a, 8 c, 9 a,
10 b, 11 b, 12 c, 13 b, 14 a, 15 c, 16 b,
17 b, 18 c, 19 b.

Illustration of Components in Schematic System Diagrams

EFI-D

1 Electronic control unit
2 Injection valve
3 Pressure sensor
4 Temperature sensor
5 Thermo-switch or thermo-time switch
6 Start valve
7 Electric fuel pump
8 Fuel filter
9 Fuel-pressure regulator
10 Auxiliary-air device
11 Throttle valve switch
12 Trigger contacts

EFI-L

1 Electronic control unit
2 Injection valve
3 Air-flow sensor
4 Temperature sensor
5 Thermo-time switch
6 Start valve
7 Electric fuel pump
8 Fuel filter
9 Fuel-pressure regulator
10 Auxiliary-air device
11 Throttle valve switch
12 Relay set

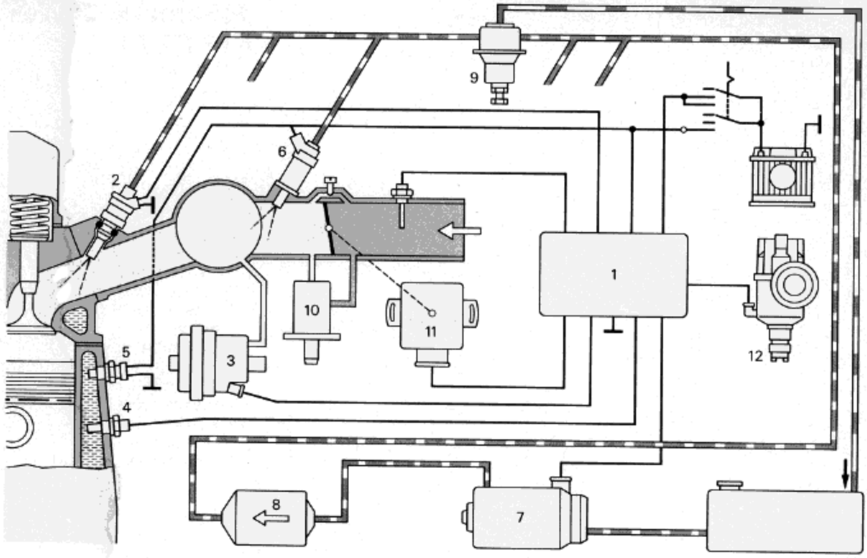
Atmospheric pressure (p_0)

Pressure in intake manifold (p_1)

Fuel

Coolant

EFI-D



EFI-L