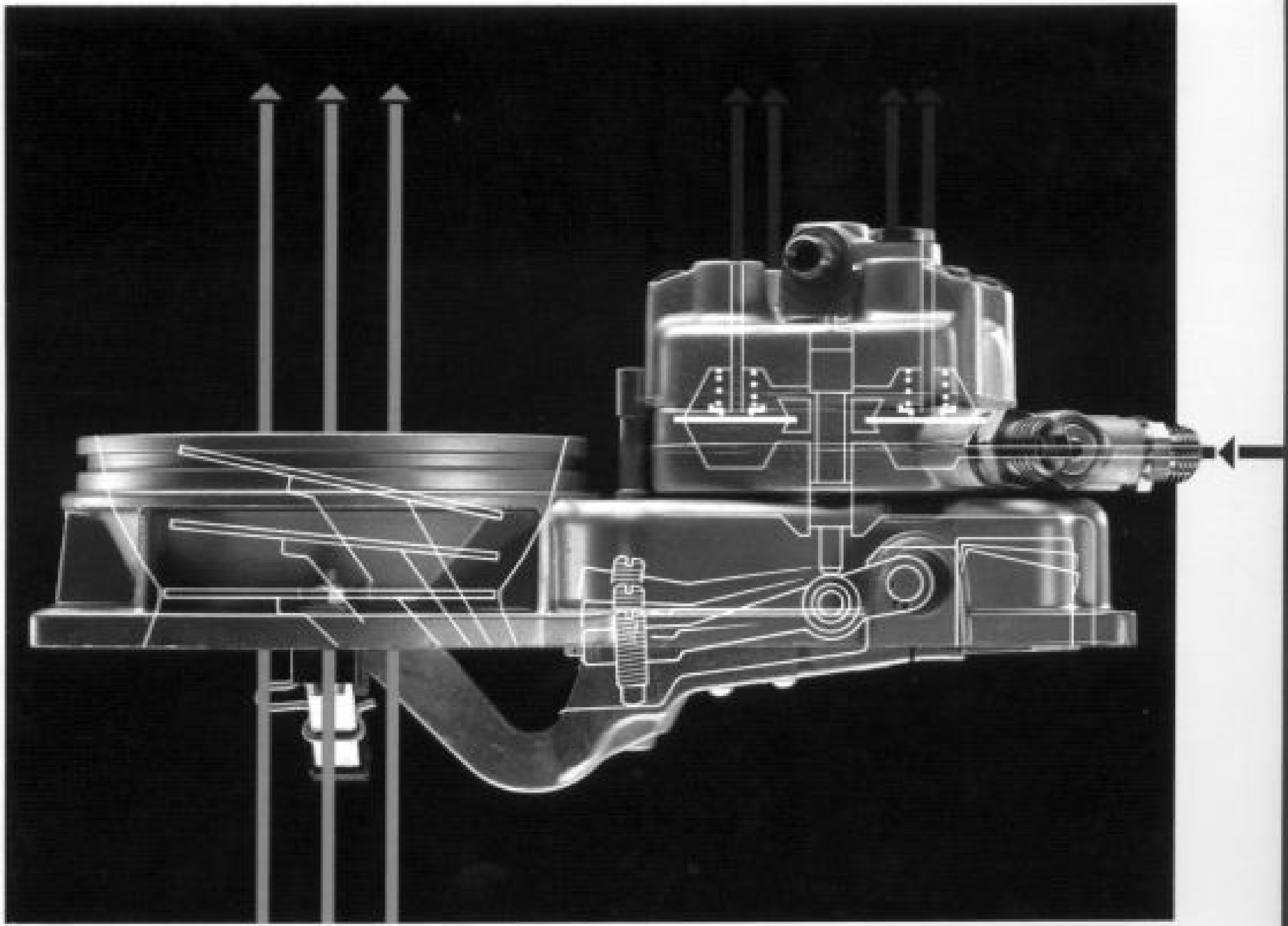
For catalytic-converter operation

BOSCH

Mechanical Gasoline Fuel-Injection System with Lambda Closed-Loop Control

K-Jetronic



Technical Instruction

K-Jetronic

Since their introduction, the Jetronic fuel-injection systems have proved themselves millions of times over under the harsh conditions of everyday driving. This success is a result of the advantages which fuel injection can offer when considering today's demands for economy, performance, and cleaner exhausts. The K-Jetronic is a mechanical system in which the fuel is continuously metered in accordance with the amount of air drawn in by the engine. Using the Lambda sensor together with additional equipment for the Lambda closed-loop control facility, the K-Jetronic can already comply today with the exhaust-gas regulations of tomorrow. The construction and principle of operation of the K-Jetronic is dealt with in this Technical Instruction manual.

The engine's fuel requirements 2
Air-fuel ratio
Excess-air factor

Fuel-management systems 3
Electronically controlled systems
Mechanical systems

K-Jetronic 4

Fuel supply 5
Outline of system
Electric fuel pump
Fuel accumulator
Fuel filter
Primary-pressure regulator
Fuel-injection valve

Fuel management 8
Mixture-control unit
Air-flow sensor
Fuel distributor
Control pressure
Differential-pressure valves
Mixture formation

Mixture adaptation 12
Cold start
Warm-up
Load conditions
Acceleration response
Influencing the air-fuel mixture

Electrical circuitry 19
Function

Exhaust-gas techniques 20
Exhaust-gas composition
Catalytic aftertreatment
Lambda closed-loop control

Installation schematic 24

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The Engine's Fuel Requirements

A spark-ignition engine needs a particular air-fuel ratio in order to operate. The ideal air-fuel ratio is 14.7:1. Certain operating conditions make it necessary to correct the mixture accordingly.

The air-fuel ratio

Essentially, the power, the fuel consumption and the exhaust-gas composition of a spark-ignition engine depend upon the air-fuel ratio. Perfect ignition and perfect cumbustion only take place within particular air-fuel ratios. In the case of gasoline (petrol), the ideal air-fuel ratio is about 15:1. In other words, 15 kg of air are required for complete combustion of 1 kg of gasoline (stoichiometric ratio). Deviations from this ratio affect engine operation.

The amount of fuel to be injected depends upon load, engine speed and the particular exhaust-gas regulations in force at the time. Depending upon the mode of operation, i.e. idle, part load or full load, a different air-fuel ratio is optimal in each case. Of decisive importance is the strict adherence to the particular most favorable air-fuel ratio at any one time.

The excess-air factor

The excess-air factor is identified by the symbol λ (Lambda).

$$\lambda = \frac{\text{amount of air supplied}}{\text{theoretical air requirement}}$$

$\lambda = 1$
This means that the amount of air supplied to the engine corresponds to the theoretical amount of air required (stoichiometric air-fuel ratio).

$\lambda < 1$
This means air deficiency, or a rich mixture, and increased power.

$\lambda > 1$
This means air excess, or lean mixture, lower fuel consumption, less power.

$\lambda > 1.3$
This means that the mixture will no longer ignite, the lean misfire limit (LML) has been exceeded.

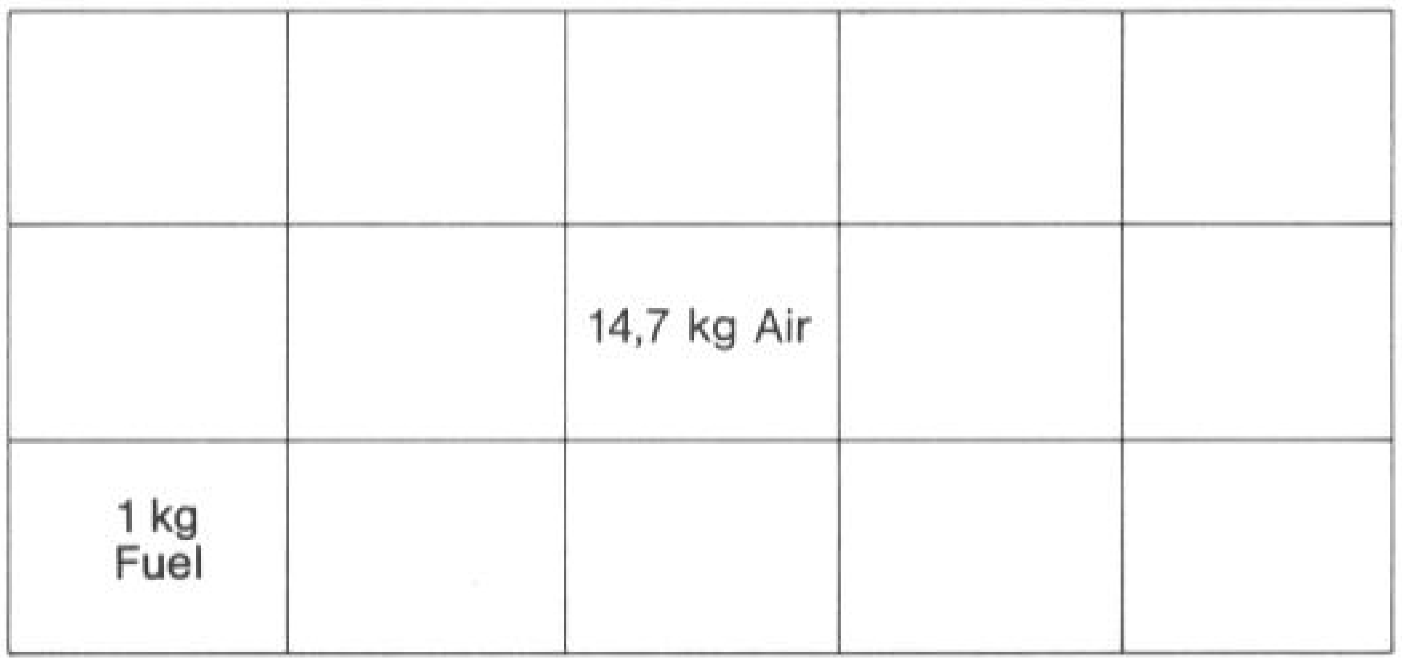


Fig. 1
Theoretical air-fuel ratio for complete combustion.

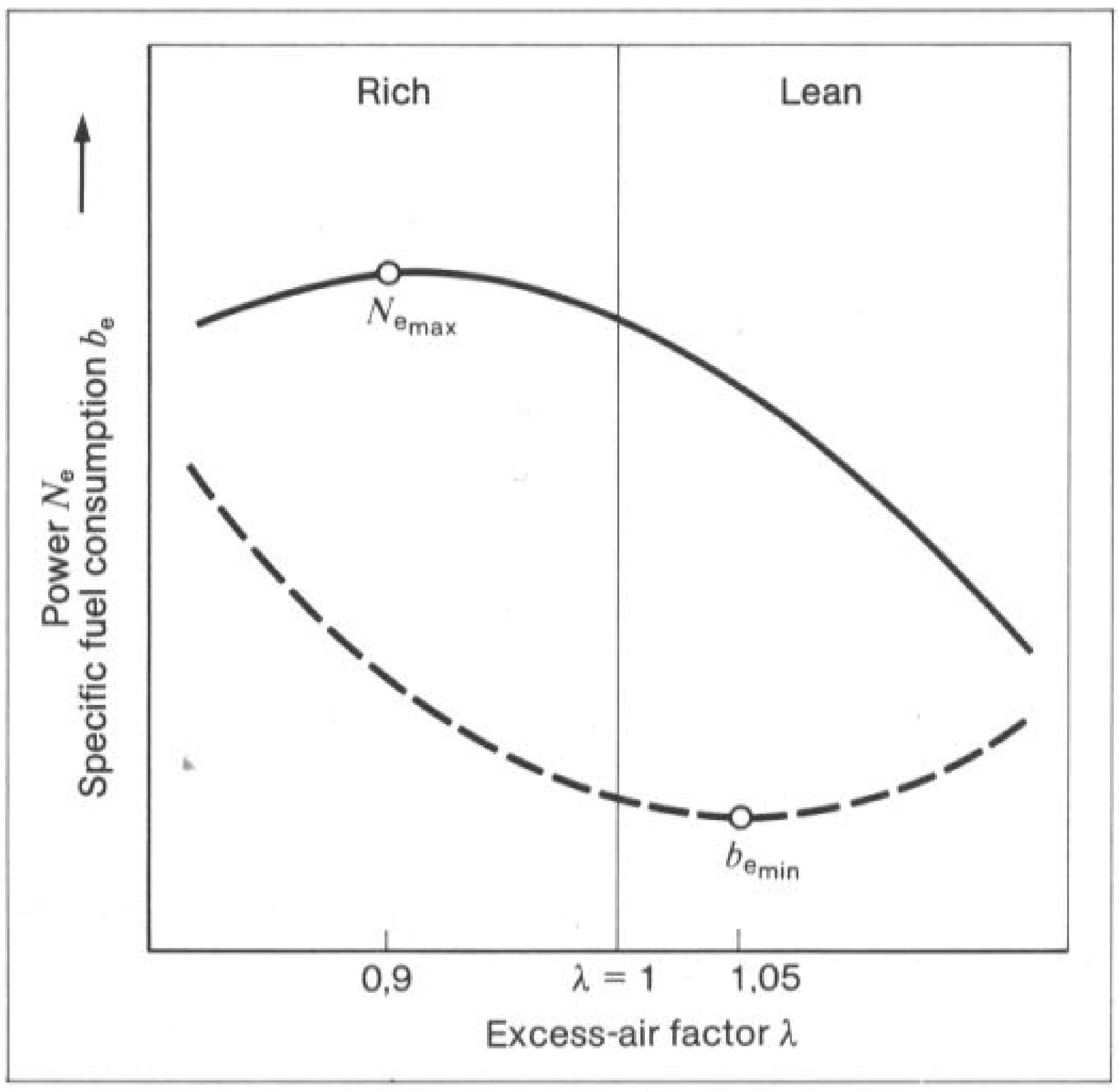


Fig. 2
Influence of the excess-air ratio λ on the power and the specific fuel consumption.

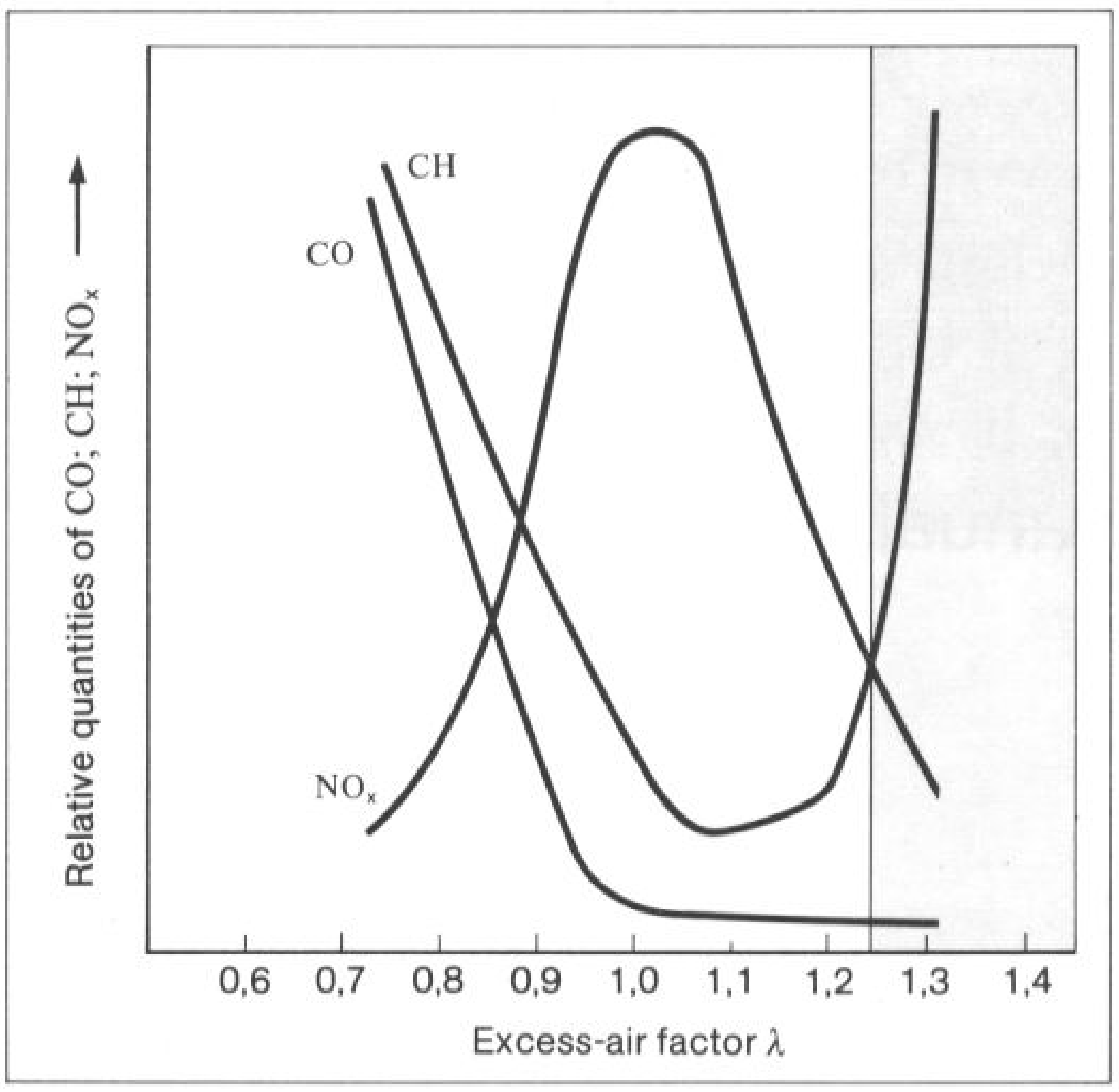


Fig. 3
Influence of the excess-air factor λ on the composition of the exhaust gases from a spark-ignition engine.

CH:
Hydrocarbons

CO:
Carbon monoxide

NO$_x$:
Nitrogen monoxide

The illustrations demonstrate the manner in which power, specific fuel-consumption and exhaust-gas composition are all affected by the excess-air factor. It can be seen that there is no single ideal excess-air factor at which all these factors are at an optimum value. In practice, excess-air factors of λ = 0.9 ... 1.1 have proved to be the most appropriate. If, however, the excess-air factor is to be maintained within strict limits, the amount of air sucked in by the engine must be precisely measured and a finely-dosed amount of fuel precisely metered to the engine.

Fuel-management systems

Fuel-management systems, whether of the carburetor or injection types, have the task of preparing an optimum air-fuel mixture. Fuel management by means of manifold injection permits the optimum adaptation of the air-fuel mixture to every operating phase of the engine. It also ensures a lower level of pollutants in the exhaust gas.

In spark-ignition systems, fuel management is by means of either a carburetor or a fuel-injection system. Although, up to now, the carburetor has been the most commonly used method, there has been a distinct trend in the last couple of years towards manifold fuel injection.

This trend came about due to the advantages offered by fuel injection as regards the demands for fuel economy, high performance and, last but not least, a lower level of pollutants in the exhaust gas.

These advantages are based on the fact that manifold fuel injection permits extremely precise metering of the fuel depending upon the operating conditions of the engine and its load, and taking environmental effects into account. With manifold fuel injection, the correct air-fuel ratio is maintained so precisely that the pollutant level in the exhaust gas is considerably lower. Since with this system, the carburetor is no longer required, the intake paths can be optimally designed and laid out. This results in better cylinder charge which in turn leads to a more favorable torque characteristic.

What types of mixture formation are available using fuel injection?

There are both mechanically and electronically controlled systems available. The K-Jetronic is a mechanical fuel-injection system which injects continuously and which needs no form of drive whatsoever.

Electronically controlled systems

The fuel is supplied by an electrically driven fuel pump which develops the pressure necessary for injection. The fuel is injected by solenoid-operated fuel-injection valves into the cylinder intake ports. The injection valves are controlled by an electronic control unit (ECU) and the amount of fuel injected depends upon the length of time that they stay open. By means of sensors, the ECU is provided with information about the operating conditions of the engine and about the ambient conditions around the vehicle. The basis for assessing the amount of fuel to be injected is the amount of air drawn in by the engine. The L-Jetronic is an electronically controlled fuel-injection system. In the case of the L-Jetronic, the amount of air drawn in by the engine is directly measured by an air-flow sensor. Electronically controlled fuel-injection systems are dealt with in detail in the Publication "Electronically Controlled Fuel Injection" in the Bosch Technical Instruction series.

Mechanical systems

With mechanical fuel-injection systems, one differentiates between those which require a drive from the engine and those which do not.

The engine-driven systems comprise a fuel-injection pump with an integrated governor. Their principle of operation is the same as that of the fuel-injection systems for Diesel engines.

The other variation of the mechanical system is one which needs no drive and which injects continuosly. This system, the K-Jetronic, is described in the following.

The K-Jetronic

The K-Jetronic is a mechanical fuel-injection system from Bosch.

It is divided into three main functional areas:

- ● Air-flow measurement
- ● Fuel supply
- ● Fuel induction

Air-flow measurement

The amount of air sucked in by the engine is controlled by a throttle valve and measured by an air-flow sensor.

Fuel supply

An electrically driven fuel pump delivers the fuel to the fuel distributor via a fuel accumulator and a filter. The fuel distributor allocates this fuel to the injection valves in the cylinder intake tubes.

Fuel induction

The amount of air, corresponding to the position of the throttle plate, sucked in by the engine serves as the criterium for the metering of the fuel to the individual cylinders. The amount of air sucked in by the engine is measured by the air-flow sensor which, in turn, controls the fuel distributor.

The air-flow sensor and the fuel distributor are assemblies which form part of the mixture control unit. Injection takes place continuously, that is, without regard to the position of the intake valve. During the intake-valve closed phase, the fuel is "stored" in the intake tubes.

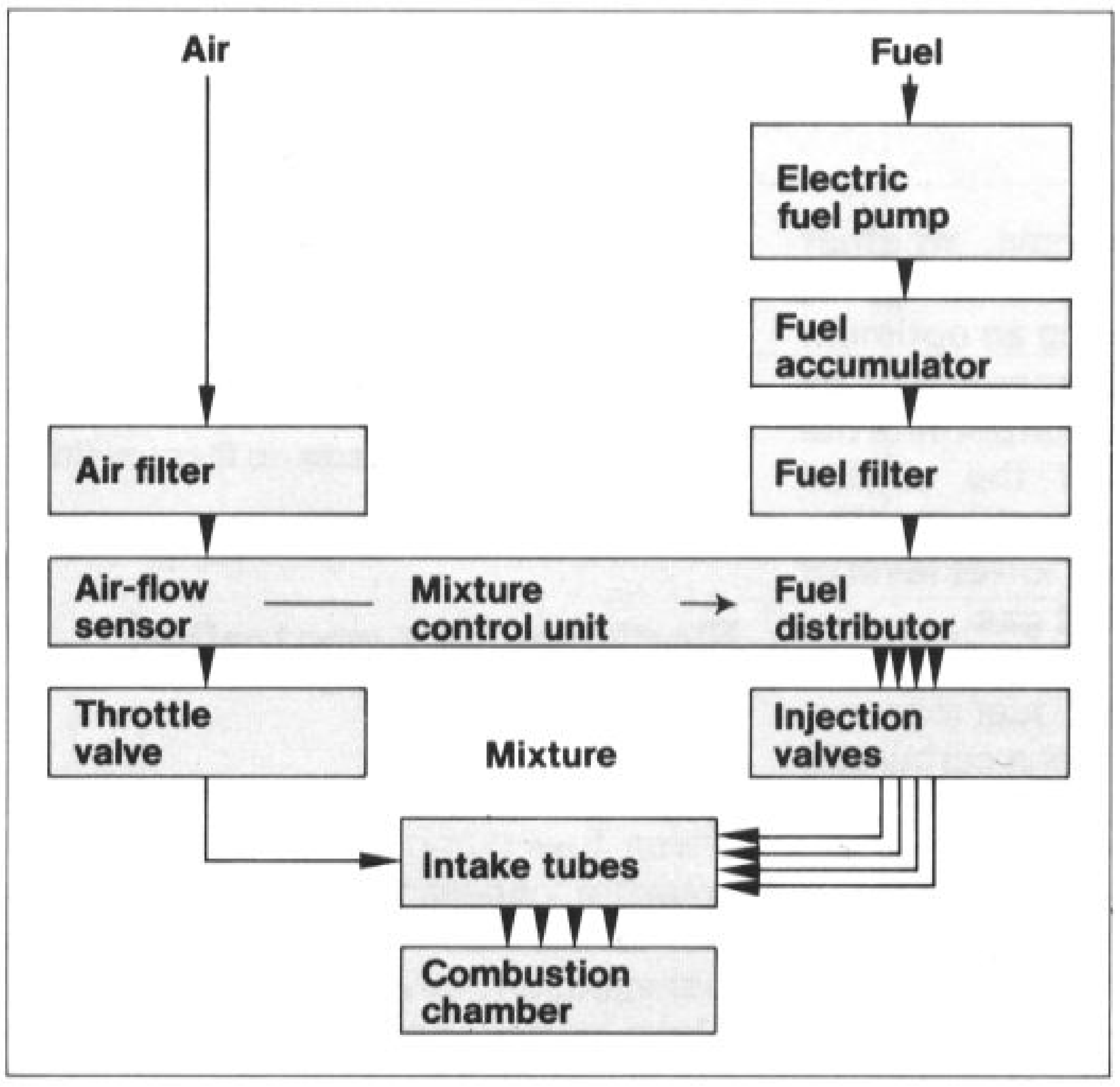


Fig. 4
Basic schematic of the K-Jetronic.
Functional areas:
Air flow measurement
Fuel supply
Fuel induction

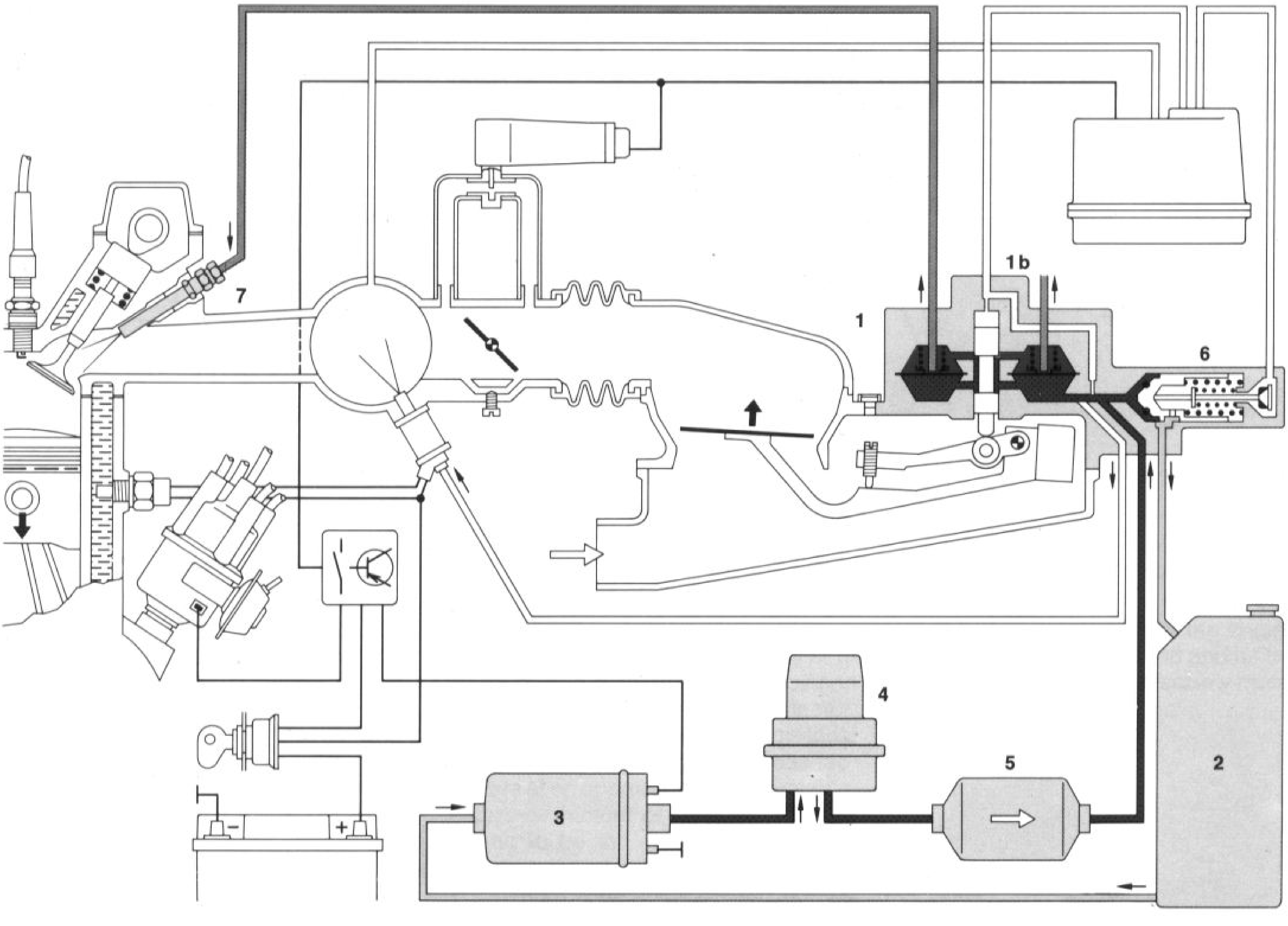


Fig. 5
Schematic diagram of the K-Jetronic.
Functional area:
Fuel supply
1 Mixture control unit
1b Fuel distributor
2 Fuel tank
3 Electric fuel pump
4 Fuel accumulator
5 Fuel filter
6 Pressure regulator
7 Fuel-injection valve

Fuel supply

Outline of system

The fuel is drawn out of the fuel thank by an electrically driven fuel pump. It is then forced, under pressure, through a pressure accumulator and a fine filter to the fuel distributor which is located in the mixture control unit. The pressure is held constant by a pressure regulator in the mixture control unit from where it flows to the fuel-injection valves.

The injection valves inject fuel continuously into the intake ports of the engine cylinders. The designation K-Jetronic stems from his fact ("K" stands for the German word for "continuous"). When the intake valves open, the air-fuel mixture is drawn into the cylinders.

The individual subassemblies of the fuel-supply system are described in the following.

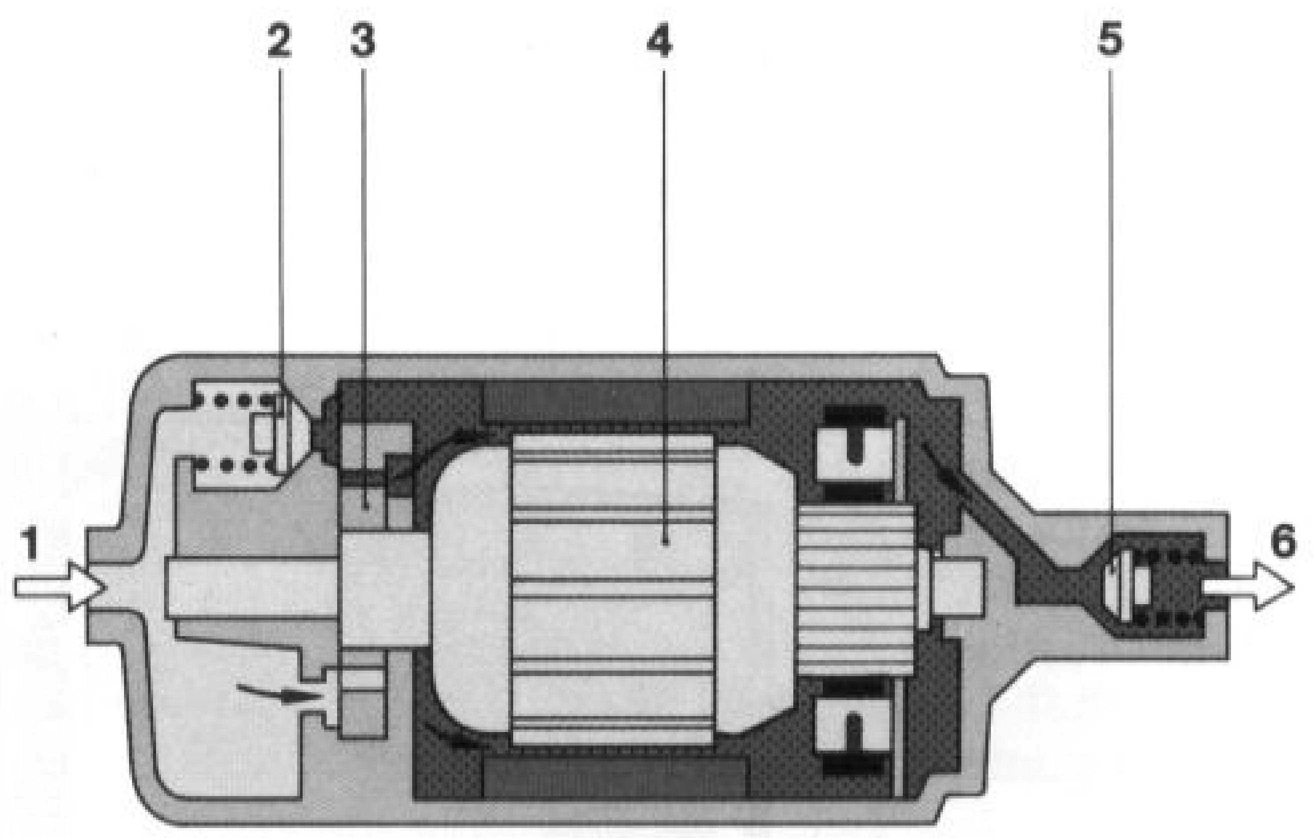


Fig. 6
Electric fuel pump
1 Intake side
2 Excess-pressure valve
3 Roller-cell pump
4 Electric-motor armature
5 Non-return valve
6 Pressure side

Electric fuel pump

The electric fuel pump is a roller-cell pump the electric motor of which is permanently surrounded by fuel.

The fuel pump is driven by a permanent-magnet electric motor.

The rotor disc which is eccentrically mounted in the pump housing is fitted with metal rollers in notches around its circumference which are pressed against the thrust ring of the pump housing by centrifugal force and act as seals. The fuel is carried in the cavities which form between the rollers. The fuel flows directly around the electric motor. There is no danger of explosion, however, because there is never an ignitable mixture in the pump housing. The pump delivers more fuel than the maximum requirement of the engine so that the pressure in the fuel system can be maintained under all operating conditions.

During starting, the pump runs as long as the ignition key is operated. The pump continues to run when the engine has started. A safety circuit is incorporated to stop the pump running and fuel being delivered if the ignition is switched on but the engine has stopped turning (for instance in the case of an accident).

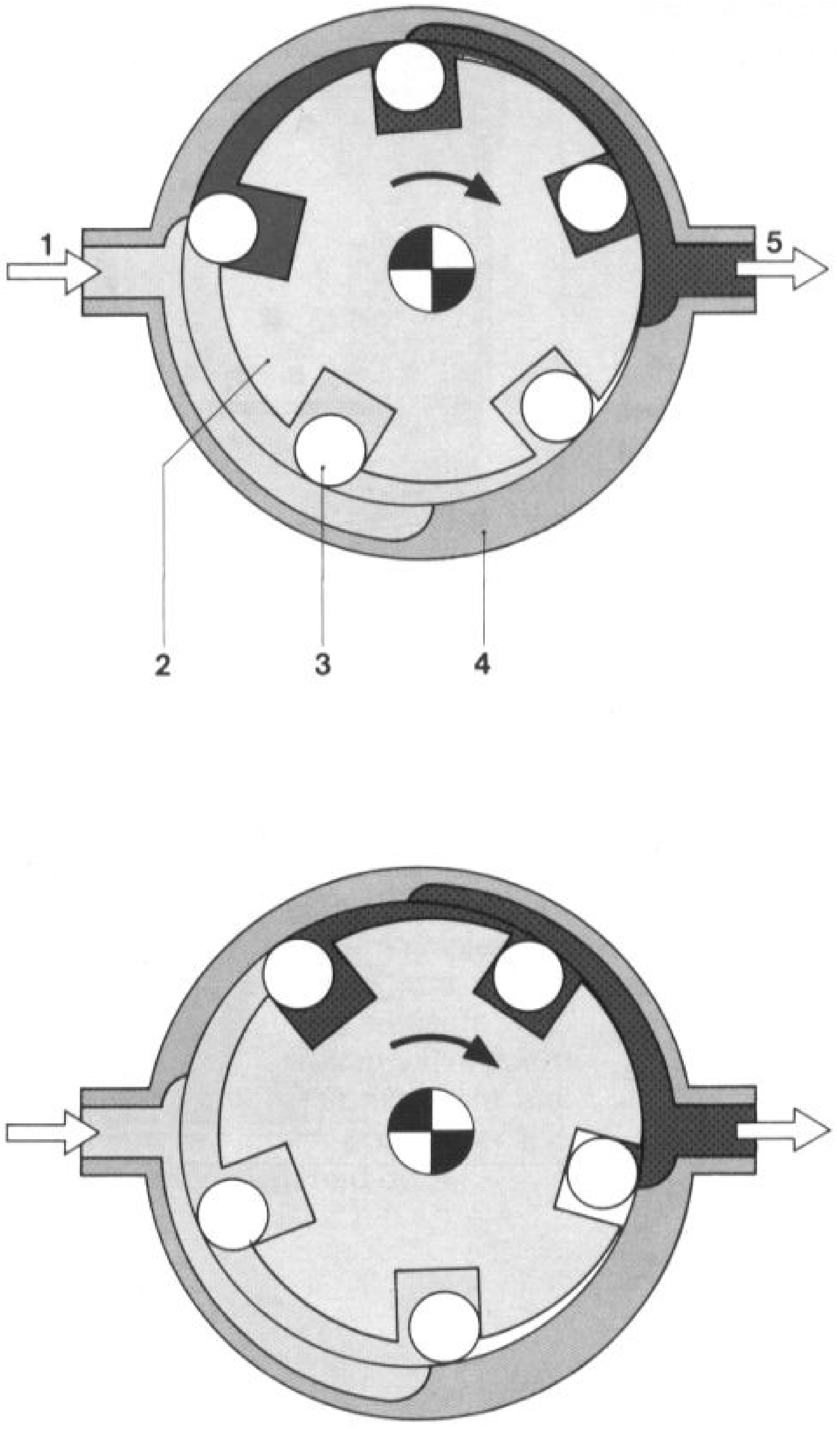


Fig. 7
Roller-cell pump
Pumping process
1 Intake side
2 Rotor disc
3 Roller
4 Pump housing
5 Pressure side

□ Fuel, pressureless
■ Fuel, being conveyed
▩ Fuel, pressurized

Fuel accumulator

The fuel accumulator maintains the pressure in the fuel system for a certain time after the engine has been switched off. When the engine is running it serves to deaden the noise of the electric fuel pump.

After the engine has been switched off, the fuel accumulator maintains the pressure in the fuel system in order to facilitate re-starting, particularly when the engine is hot. The design of the accumulator housing is such that it deadens the noise from the fuel pump when the engine is running.

The interior of the fuel accumulator is divided into two chambers by means of a diaphragm. One chamber serves as the accumulator volume for the fuel, the other chamber contains a spring.

During operation the accumulator chamber is filled with fuel. This causes the diaphragm to bend back against the force of the spring until it is halted by the stops in the spring chamber. The diaphragm remains in this position, which corresponds to the maximum accumulator volume, as long as the engine is running.

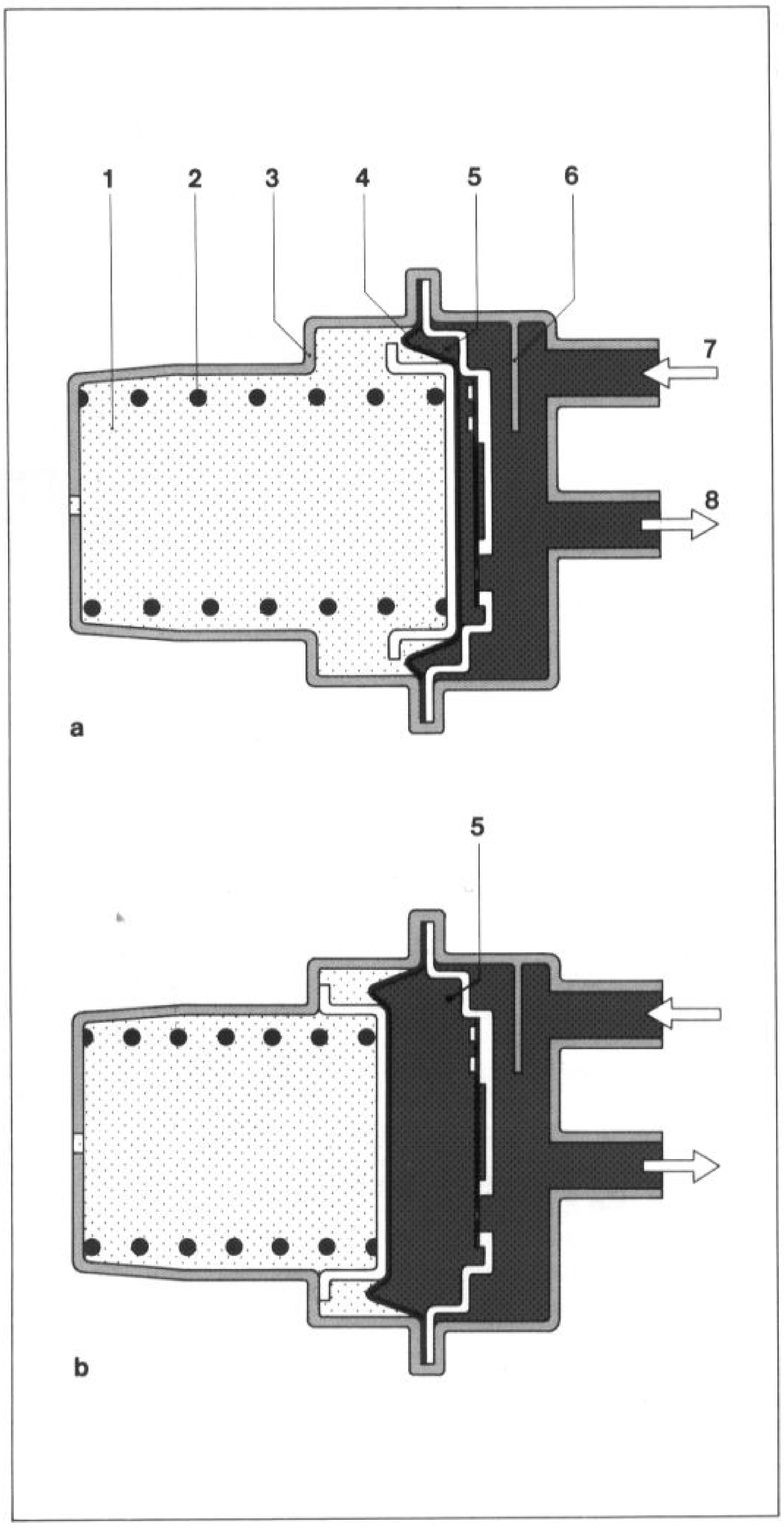


Fig. 8
Fuel accumulator
a empty
b full
1 Spring chamber
2 Spring
3 Stop
4 Diaphragm
5 Accumulator volume
6 Baffle plate
7 Fuel entry
8 Fuel exit

Fuel filter

Due to the extremely close tolerances of various components in the system, it is necessary to fit a special fine filter for the fuel in order to guarantee faultless performance of the K-Jetronic.

The fuel filter retains particles of dirt which are present in the fuel and which would otherwise adversely affect the functioning of the injection system.

The fuel filter contains a paper filter element which is backed up by a strainer. This combination results in a high degree of cleaning being achieved. A supporting plate is used to hold the filtering elements in place in the filter housing. It is of utmost importance that the direction of flow indicated on the housing is complied with. The filter is fitted in the fuel line downstream of the fuel accumulator.

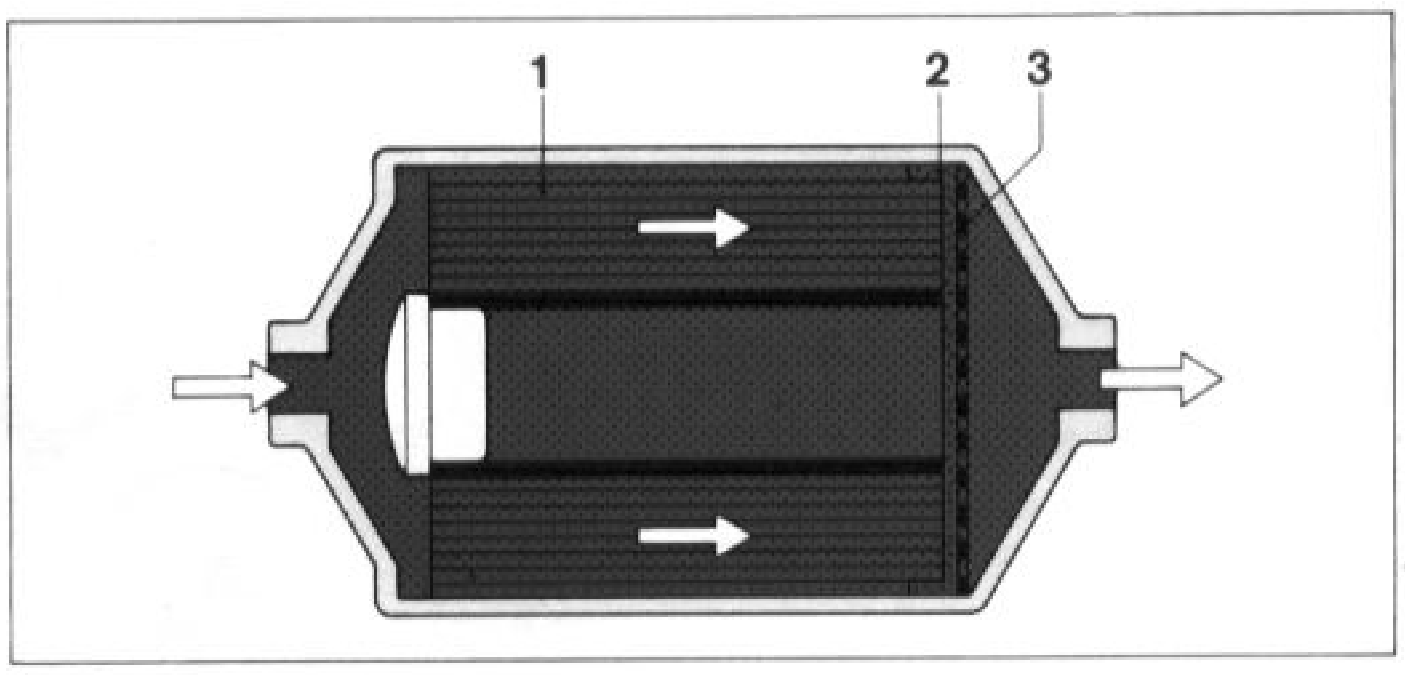


Fig. 9
Fuel filter
1 Paper element
2 Strainer
3 Supporting plate

Primary-pressure regulator

The primary-pressure regulator maintains the pressure in the fuel system constant.

The pressure regulator incorporated in the fuel-distributor housing maintains the delivery pressure (= primary pressure) at about 5 bar. Due to the fact that the fuel pump delivers more fuel than the engine needs, a plunger shifts in the pressure regulator and opens a port through which excess fuel can return to the fuel tank.

The pressure in the fuel system and the force exerted by the spring on the plunger in the pressure regulator balance each other out. If for instance, the fuel pump delivers slightly less fuel, the plunger is shifted by the spring into the corresponding new position and in doing so reduces the open section of the port through which excess fuel flows back to the tank. This means that less fuel leaves the system at this point, and as a result the primary pressure in the system increases to the specified value.

When the engine is switched off, the fuel pump also stops running. The primary pressure drops to below the injection-valve opening pressure. The pressure regulator closes the return-flow port and prevents further pressure reduction in the fuel system.

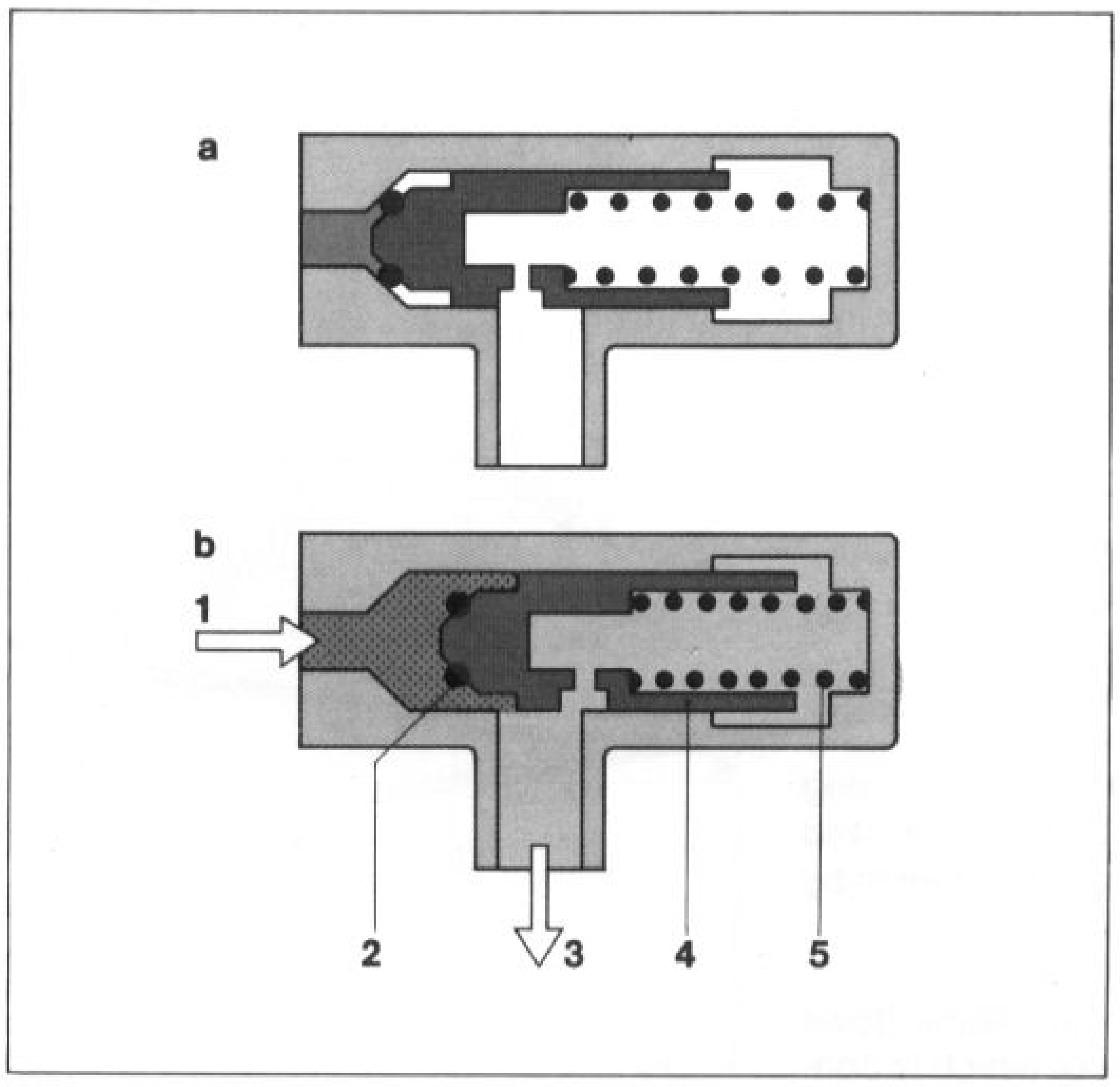


Fig. 10
Primary-pressure regulator in the fuel distributor
a Inoperative
b During operation
1 Primary-pressure input
2 Seal
3 Return to fuel tank
4 Plunger
5 Regulator spring

Fuel-injection valve

The fuel-injection valves open at a certain pressure and inject fuel into the intake tubes. The fuel is atomized by the oscillation of the valve needle.

The injection valves inject the fuel allocated by the fuel distributor into the intake ports directly in front of the intake valves of the cylinders.

The injection valves are secured in a special holder in order to insulate them from engine heat. The insulation prevents vapor bubbles forming in the fuel-injection lines which would lead to poor starting behaviour when the engine is hot.

The injection valves have no metering function. They open of their own accord when the opening pressure of 3.3 bar is exceeded. They are fitted with a valve needle which vibrates ("chatters") audibly at high frequency when fuel is injected. This means that excellent fuel atomization is achieved, even with the smallest of injected quantities. When the engine is switched off, the injection valve closes tightly and forms a seal when the fuel-system pressure has dropped below the injection-valve opening pressure. As a result, no more fuel can drip into the intake ports after the engine has been switched off.

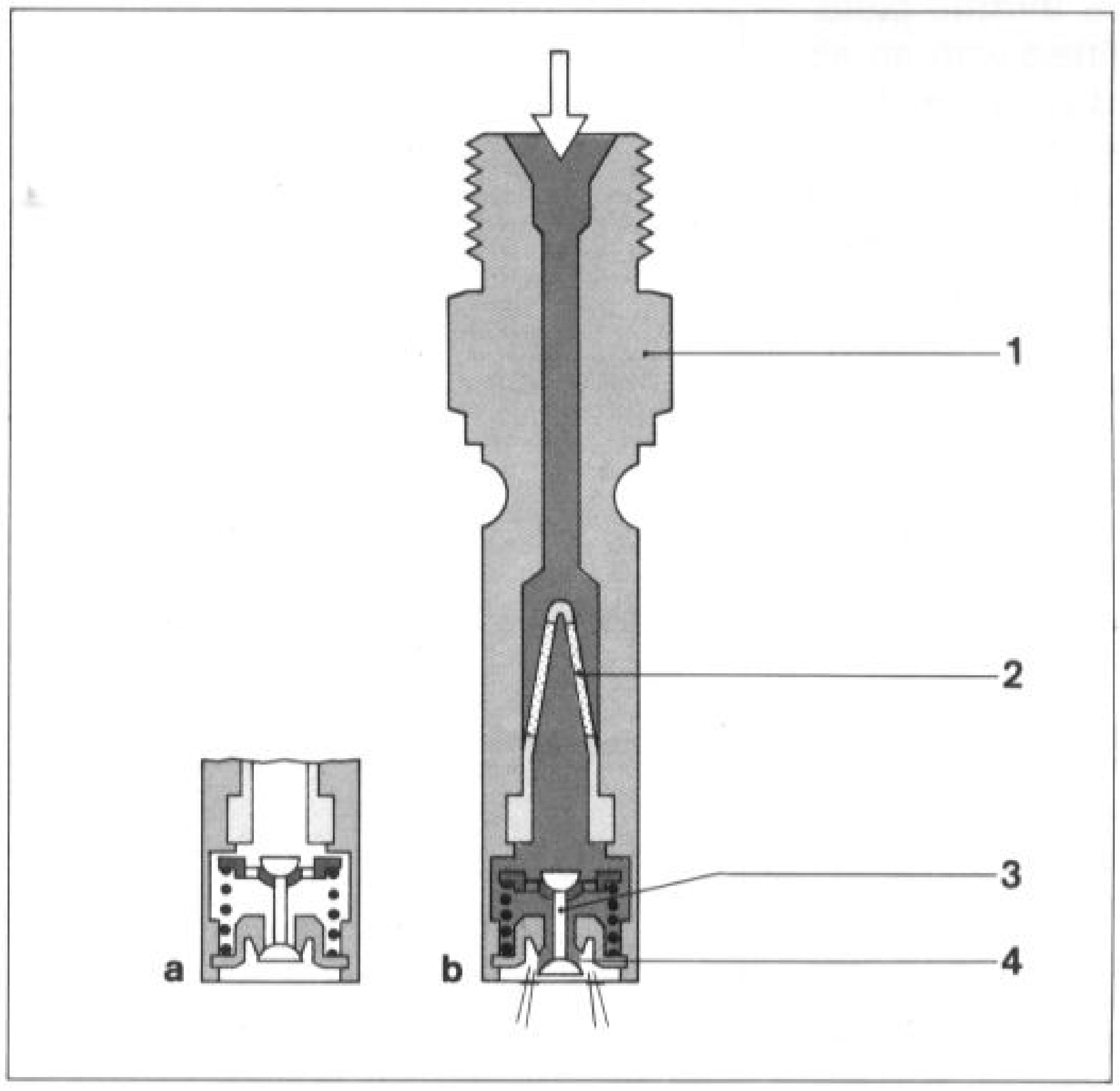


Fig. 11
Fuel-injection valve
a Inoperative
b During injection
1 Valve housing
2 Filter
3 Valve needle
4 Valve seat

Fuel Management

Mixture control unit

The task of fuel management is to meter, or allocate, the correct quantity of fuel which corresponds to the amount of air drawn in by the engine. Fuel management carried out by the mixture control unit. This comprises the air-flow sensor and the fuel distributor.

Air-flow sensor

The air-flow sensor operates according to the suspended-body principle and measures the amount of air drawn in by the engine.

All the air drawn in by the engine flows through an air-flow sensor which is connected upstream of the throttle plate. The air-flow sensor is fitted with an air funnel in which is located a movable sensor plate (the suspended body).

The air drawn in through the air funnel shifts the sensor plate by a certain amount out of its zero position. The movement of the sensor plate is transmitted to a control plunger by a lever system. This plunger determines the quantity of fuel required.

Considerable pressure shocks can occur in the intake system if backfiring takes place in the intake manifold. For this reason, the airflow sensor is so designed that the sensor plate can swing back in the opposite direction, past its zero position, and thus open a relief cross-section in the funnel. A rubber buffer limits the swing-back in the downward direction (in the case of the updraft air-flow sensor, the swing-back in the upwards direction is also limited by a rubber buffer). A leaf spring ensures that the sensor plate assumes the correct zero position when the engine is stationary. The sensor-plate movements are transmitted to the control plunger in the fuel distributor by means of a lever system. The weight of the sensor plate and the lever system are balanced by a counterweight.

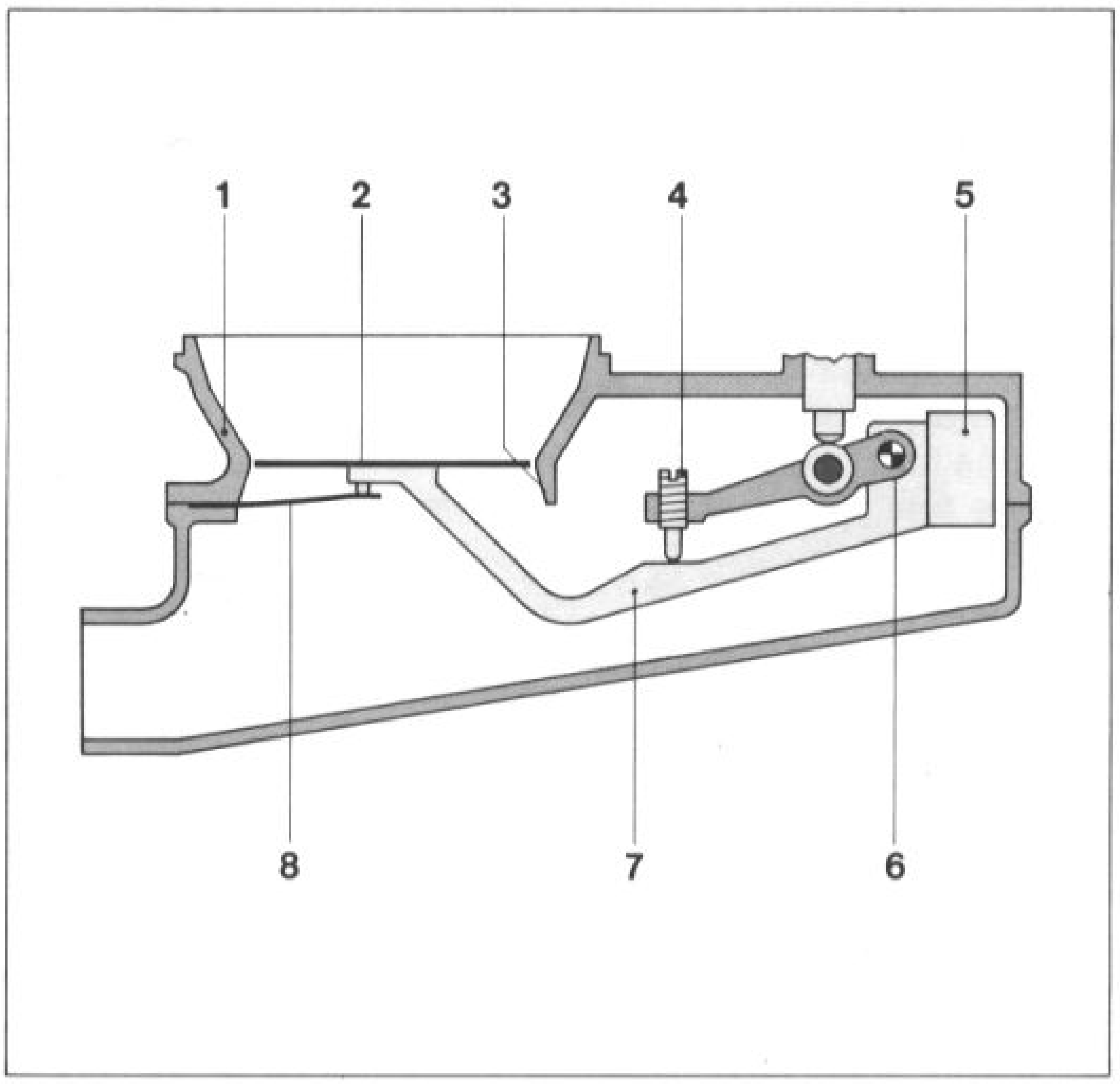


Fig. 12
Updraft air-flow sensor in zero position
1 Air funnel
2 Sensor plate
3 Relief cross-section
4 Idle mixture adjusting screw
5 Counterweight
6 Fulcrum
7 Main lever
8 Leaf spring

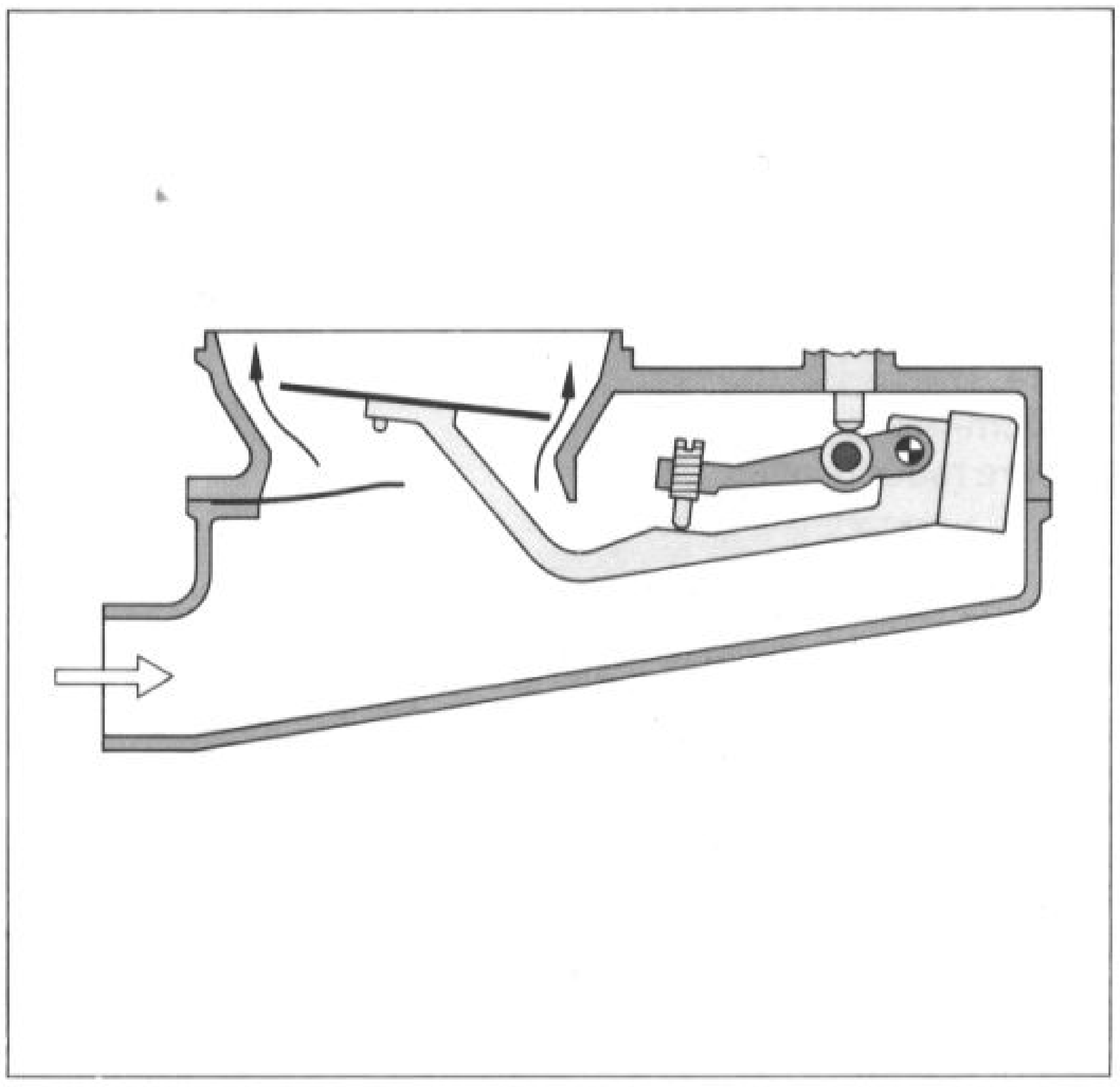


Fig. 13
Updraft air-flow sensor in operation, simplified representation.

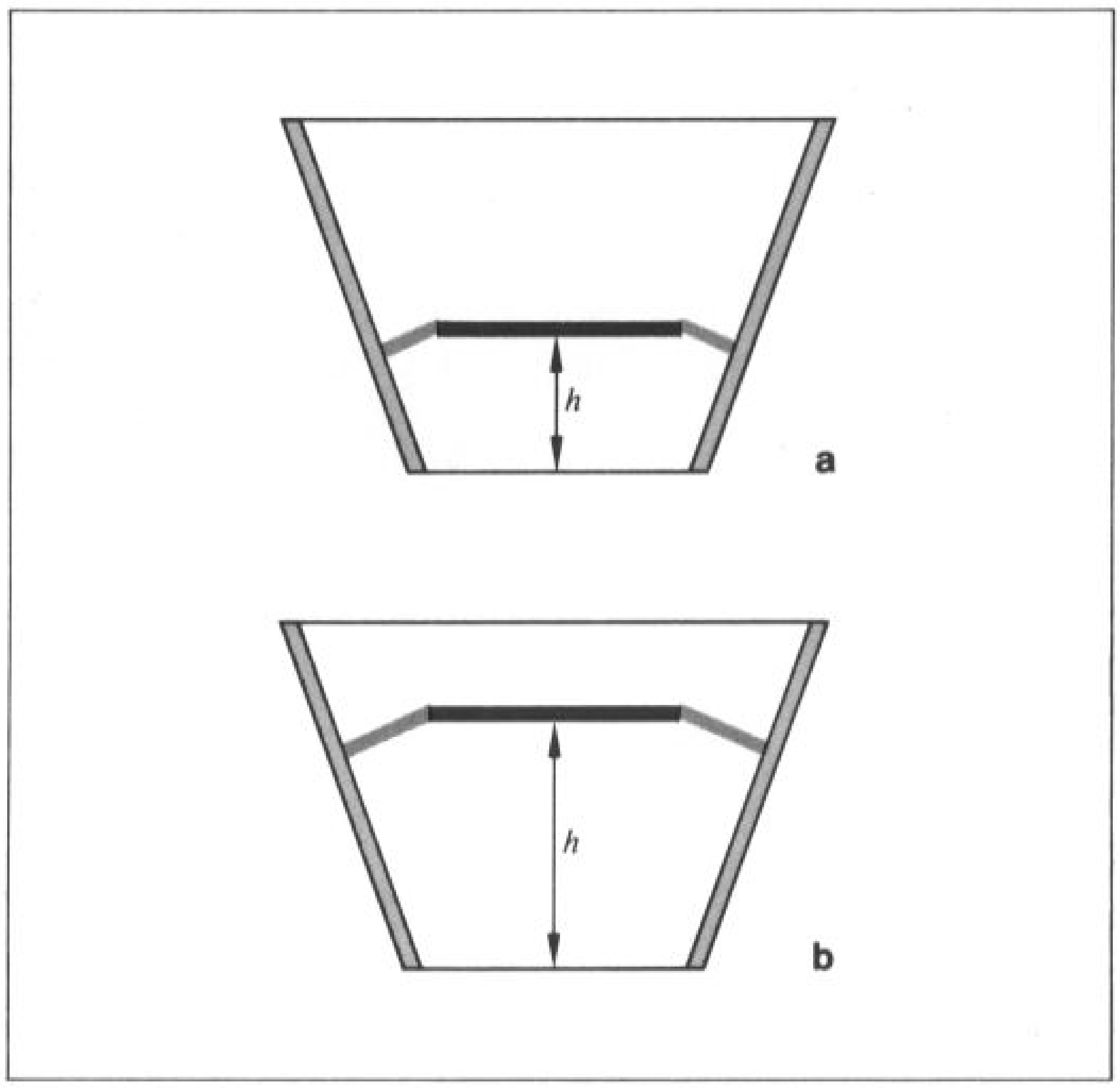


Fig. 14
Principle of the air-flow sensor
a Small amount of air drawn in: sensor plate is only lifted slightly
b Larger amount of air drawn in: sensor plate is lifted much further

Fuel distributor

The fuel distributor meters (allocates) the correct amount of fuel to the individual cylinders in accordance with the position of the air-flow sensor plate.

As already mentioned, the position of the sensor plate is a measure of the amount of air drawn in by the engine. The position of the plate is transmitted to the control plunger by a lever. The control plunger controls the amount of fuel which is to be injected.

Depending upon its position in the barrel with metering slits, the control plunger opens or closes the slits to a greater or lesser degree. The fuel flows through the open section of these slits to the differential pressure valves and then to the fuel-injection valves.

If sensor-plate travel is only small, then the control plunger is only lifted slightly and as a result only a small section of the slot is opened for the passage of fuel. With larger plunger travel, the plunger opens a larger section of the slits and more fuel can flow.

There is, therefore, a linear relationship between sensor-plate travel and the slit section in the barrel which is opened for fuel flow.

The force applied to the control plunger by the sensor plate travel is opposed by another force which comes from the so-called control pressure. One of the functions of this control pressure is to ensure that the control plunger follows the movements of the sensor plate immediately and does not, for instance, stay in the (upper) end position when the sensor plate moves back down again. Further important functions of the control pressure are discussed in the chapters dealing with warm-up and full-load enrichment.

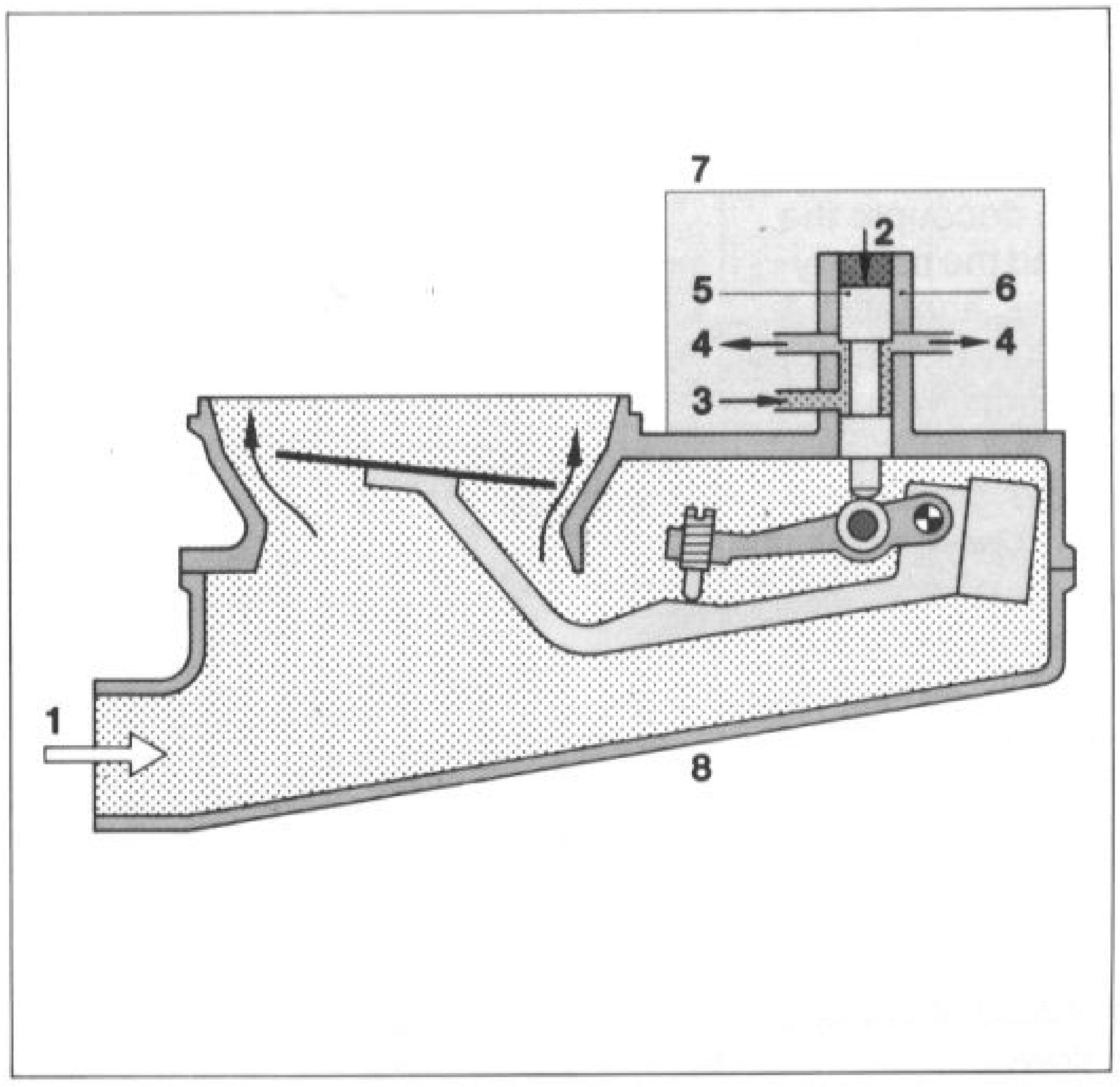


Fig. 15
Barrel with metering slits.
1 Intake air
2 Control pressure
3 Fuel intake
4 Fuel metered to cylinders
5 Control plunger
6 Barrel with metering slits
7 Fuel distributor
8 Air-flow sensor

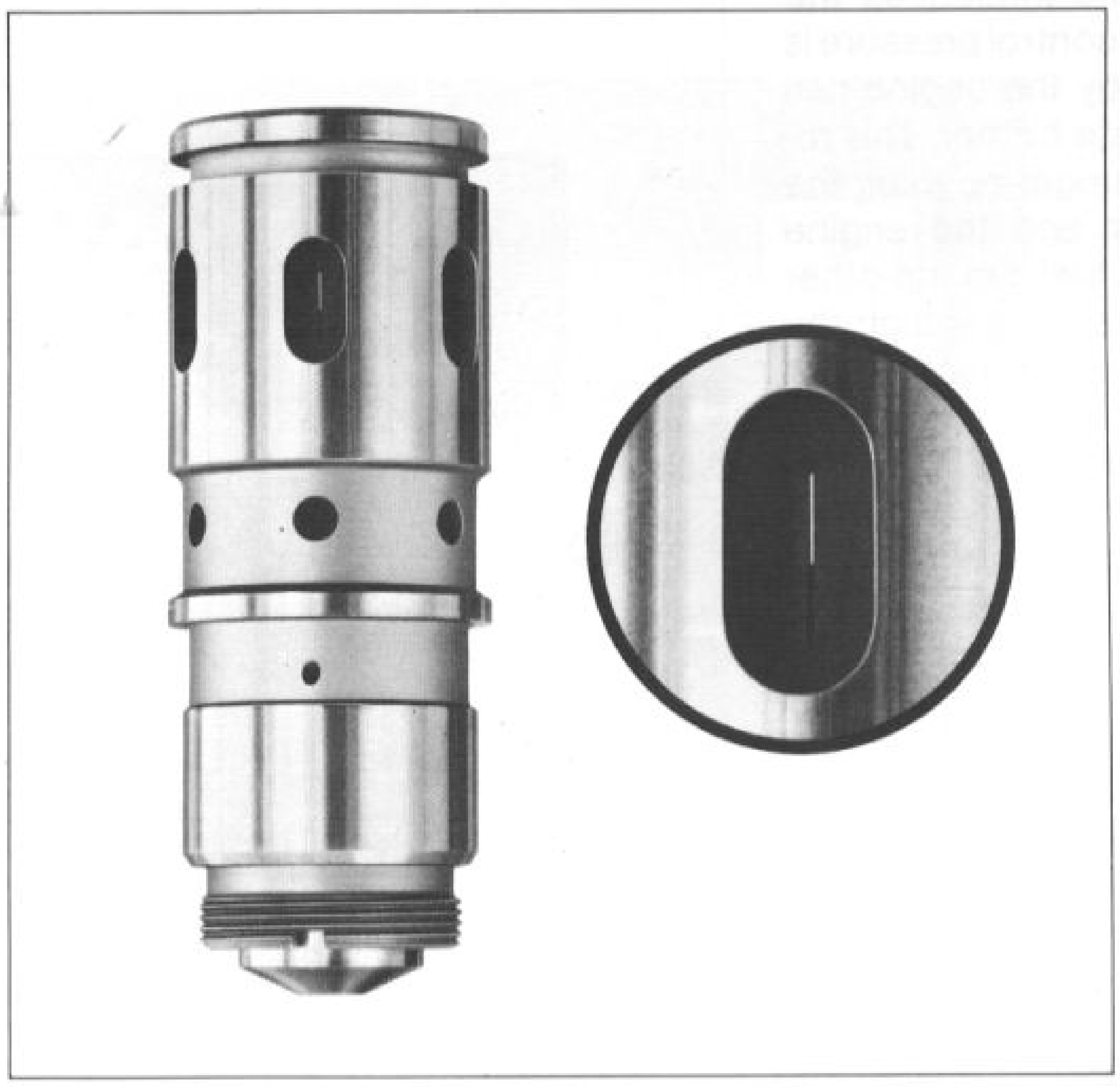


Fig. 16
Barrel with metering slits. The slits are shown enlarged.
(The actual slit is about 0.2 mm wide.)

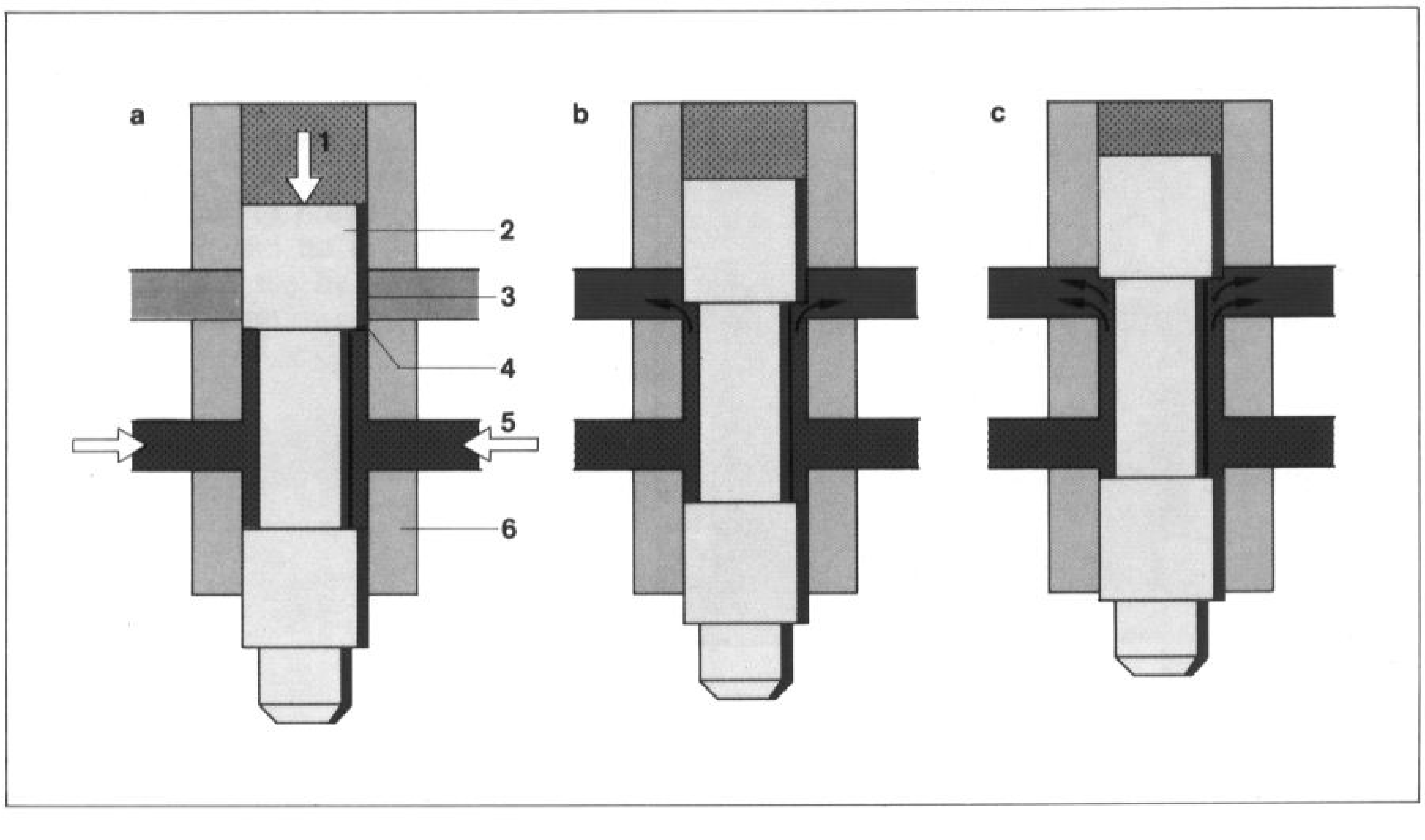


Fig. 17
Barrel with metering slits and control plunger.
a Zero (inoperated) position
b Part load
c Full load
1 Control pressure
2 Control plunger
3 Metering slit in the barrel
4 Control edge
5 Fuel intake
6 Barrel with metering slits

Control pressure

The control pressure is tapped off from the primary pressure through a restriction bore which serves to decouple the control-pressure circuit and the primary-pressure circuit from one another. A connection line joins the fuel distributor and the warm-up regulator (control-pressure regulator).

When starting the cold engine the control pressure is about 0.5 bar. As the engine warms up, the warm-up regulator increases the control pressure to about 3.7 bar.

The control pressure acts through a damping restriction on the control plunger and thereby develops the force which opposes the force of the air in the air-flow sensor. In doing so, the restriction dampens a possible oscillation of the sensor plate which could result due to pulsating air-intake flow.

The control pressure influences the fuel distribution. If the control pressure is low, the air drawn in by the engine can deflect the sensor plate further. This results in the control plunger opening the metering slits further and the engine being allocated more fuel. On the other hand, if the control pressure is high the air drawn in by the engine cannot deflect the sensor plate so far and, as a result, the engine receives less fuel.

In order to fully seal off the control-pressure circuit with absolute certainty when the engine has been switched off, and at the same time to maintain the pressure in the fuel circuit, the return line of the warm-up regulator is fitted with a non-return valve. This (push-up) valve is actually in the primary-pressure regulator and is held open during operation by the pressure-regulator plunger.

When the engine is switched off and the plunger of the primary-pressure regulator returns to its zero position, the non-return valve is closed by a spring.

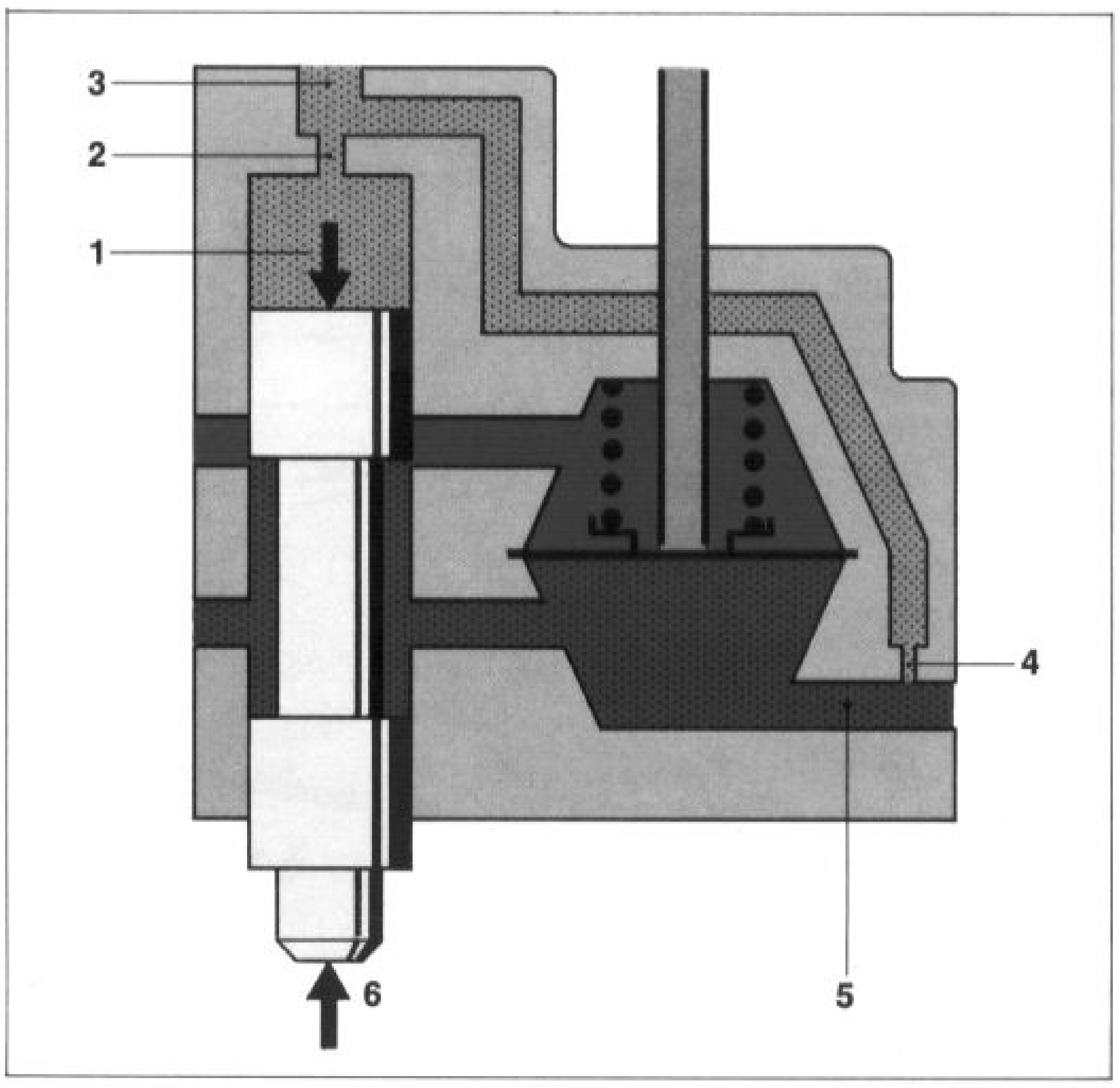


Fig. 18
Primary pressure and control pressure
1 Control-pressure effect (hydraulic force)
2 Damping restriction
3 Line to warm-up regulator
4 Decoupling restriction bore
5 Primary pressure (delivery pressure)
6 Effect of air pressure

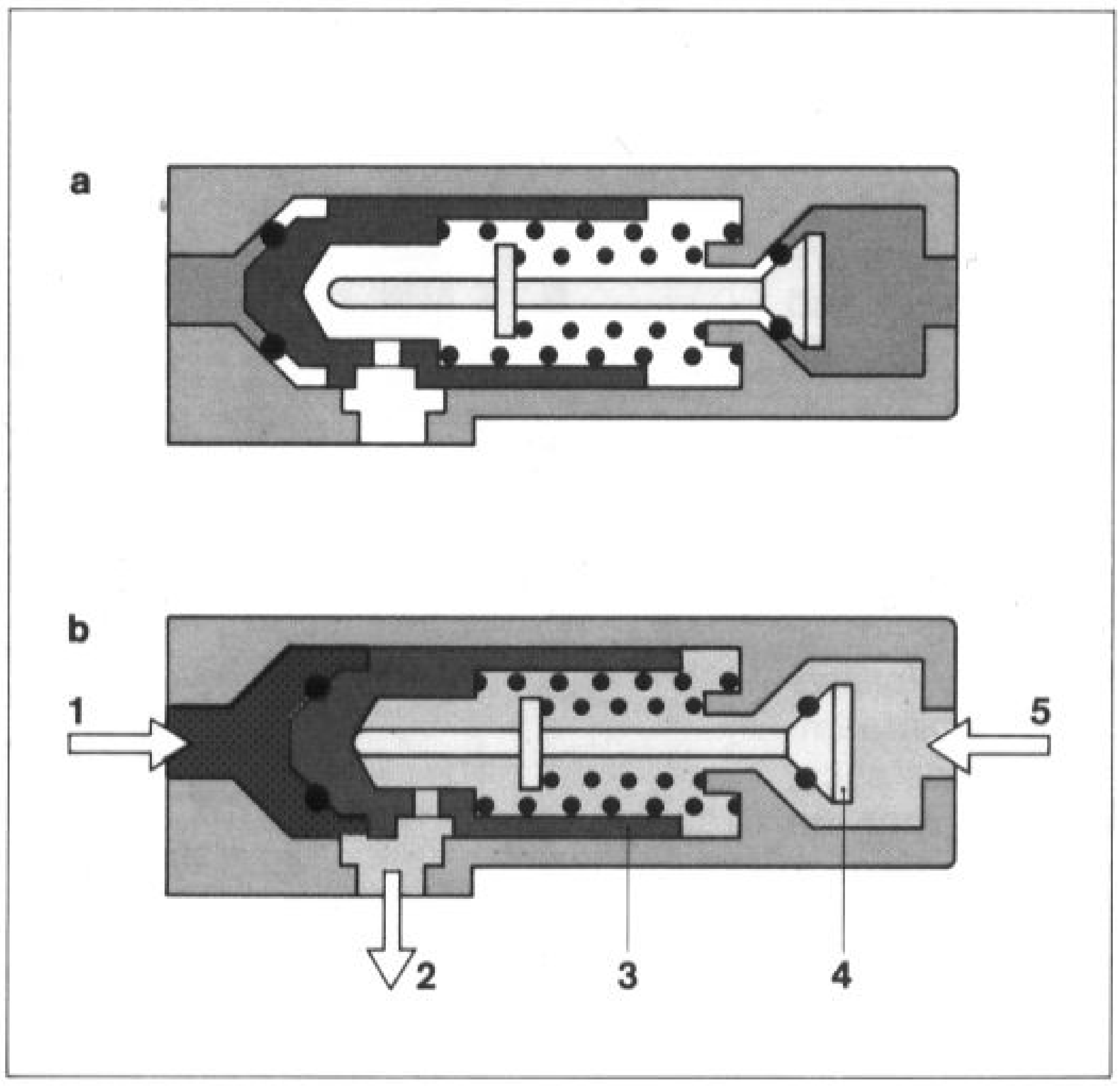


Fig. 19
Primary-pressure regulator with push-up valve in the control-pressure circuit.
a In zero (inoperated) position
b In operating position
1 Primary-pressure intake
2 Return (to fuel tank)
3 Plunger of the primary-pressure regulator
4 Push-up valve
5 Control-pressure intake (from warm-up regulator)

Differential-pressure valves

The differential-pressure valves in the fuel distributor serve to hold the drop in pressure at the metering slits constant.

The air-flow sensor has a linear characteristic. This means that if double the quantity of air is drawn in, the sensor-plate travel is also doubled. If this (linear) travel is to result in a change of delivered fuel in the same relationship, in this case double the travel = double the quantity, then a constant drop in pressure must be guaranteed at the metering slits independent of the amount of fuel flowing through them.

The differential-pressure valves maintain the drop in pressure at the metering slits constant independent of fuel throughflow. The difference in pressure is 0.1 bar, this facilitates a high degree of control accuracy.

The differential-pressure valves are of the flat-seat type. They are fitted in the fuel distributor and one such valve is allocated to each metering slit. The upper and lower chambers of the valve are separated by a diaphragm. The lower chambers of all the valves are connected with one another by a ring main and are subjected to the primary pressure (delivery pressure from fuel-supply pump). The valve seat is located in the upper chamber. Each upper chamber is connected to a metering slit and its corresponding fuel-injection line. The upper chambers are completely sealed off from each other. The diaphragms are spring-loaded and it is this helical spring that produces the pressure differential.

If more fuel flows into the upper chamber through the metering slit, the diaphragm is bent downwards and enlarges the valve cross-section at the outlet line leading to the injection valve until the differential pressure of 0.1 bar set by the spring again prevails. If less fuel flows, the diaphragm bends back towards its original position and decreases the valve cross-section at the outlet line until the differential pressure of 0.1 bar is again present. This causes an equilibrium of forces to prevail at the diaphragm which can be maintained for every quantity of fuel by controlling the valve cross-section.

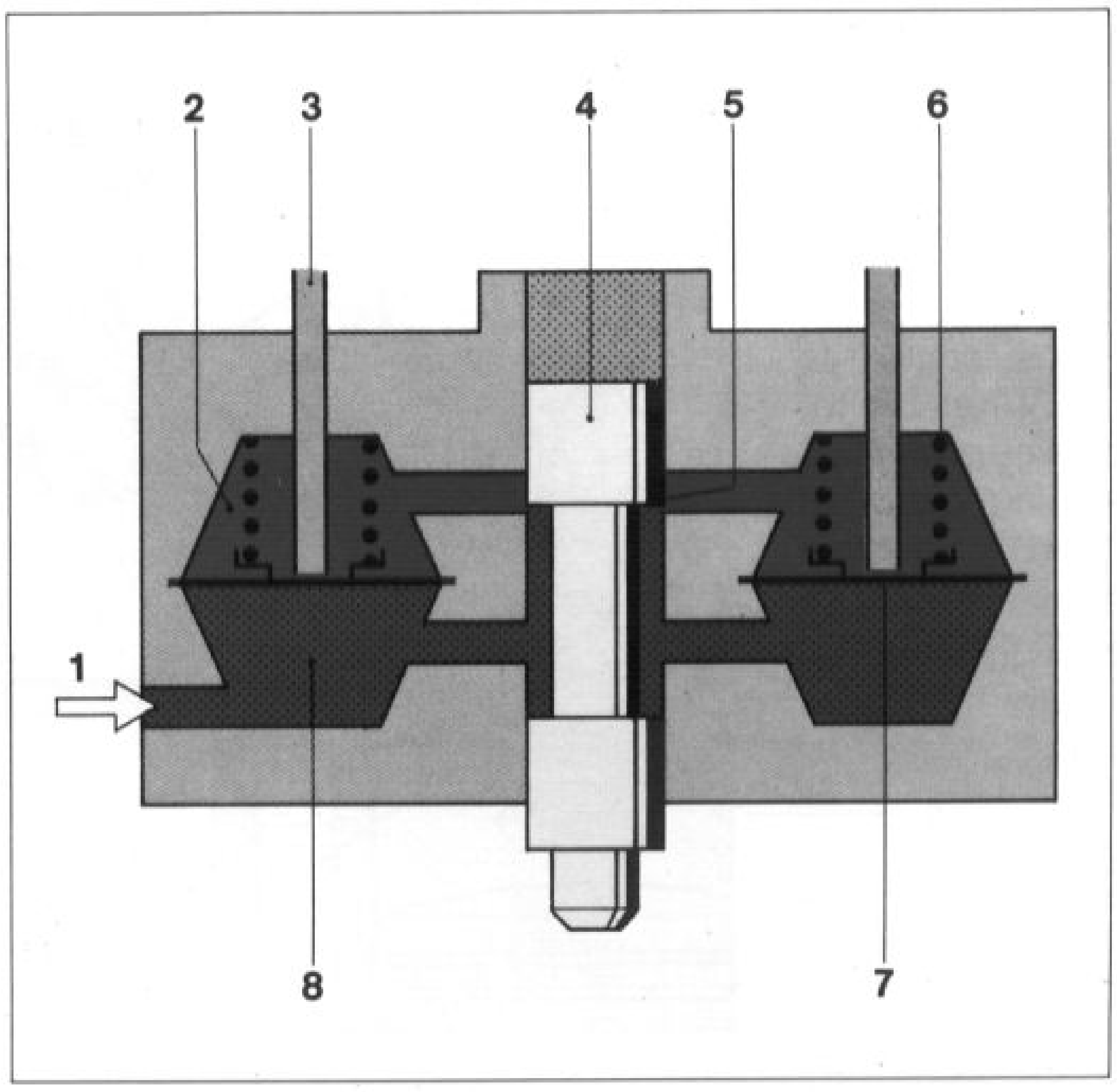


Fig. 20
Fuel distributor with differential pressure valves.
1 Fuel intake (primary pressure)
2 Upper chamber of the differential-pressure valve
3 Line to the fuel-injection valve (injection pressure)
4 Control plunger
5 Control edge and metering slit
6 Valve spring
7 Valve diaphragm
8 Lower chamber of the differential pressure valve

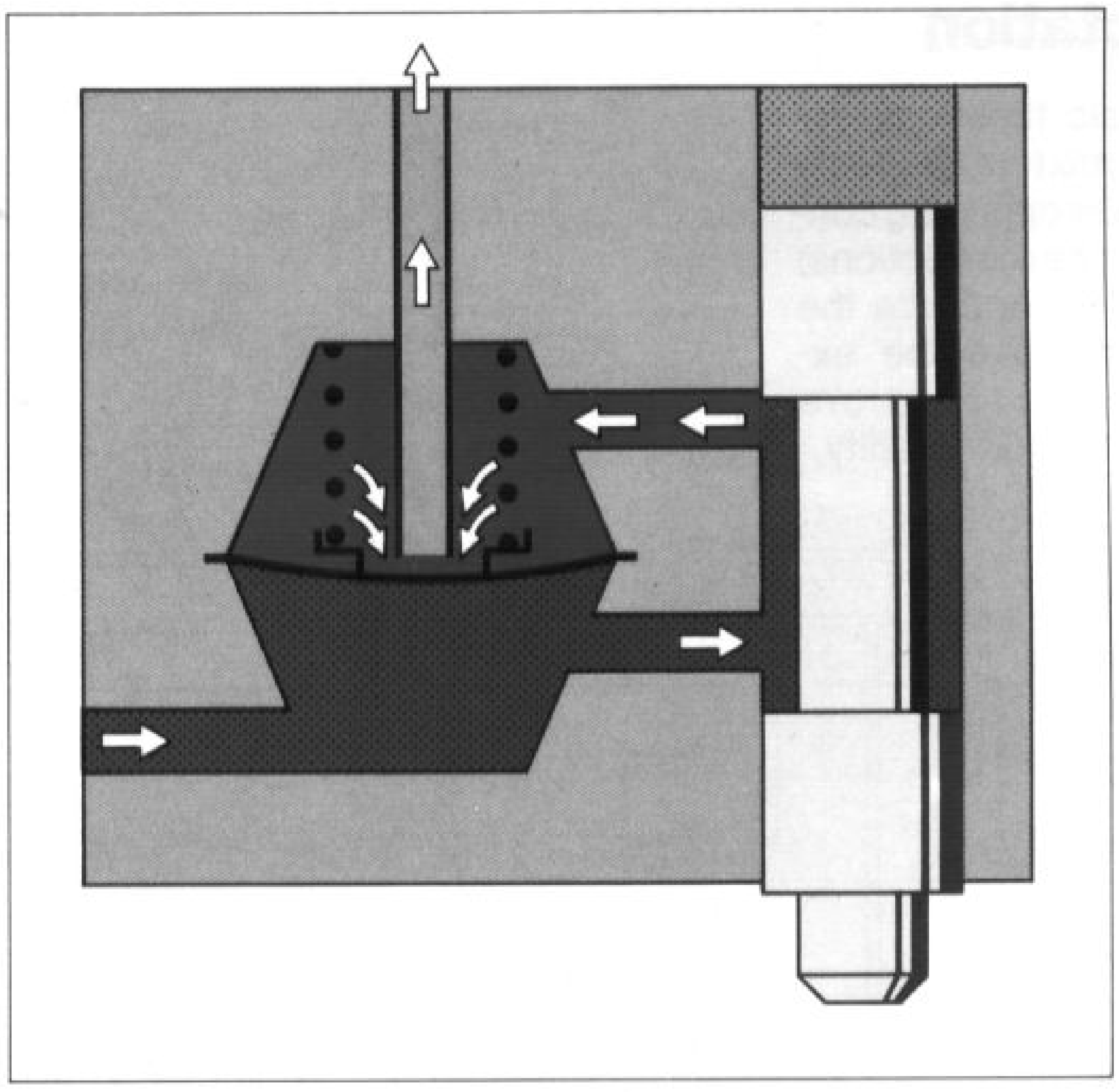


Fig. 21
Differential-pressure valve, diaphragm position with a large injected fuel quantity.

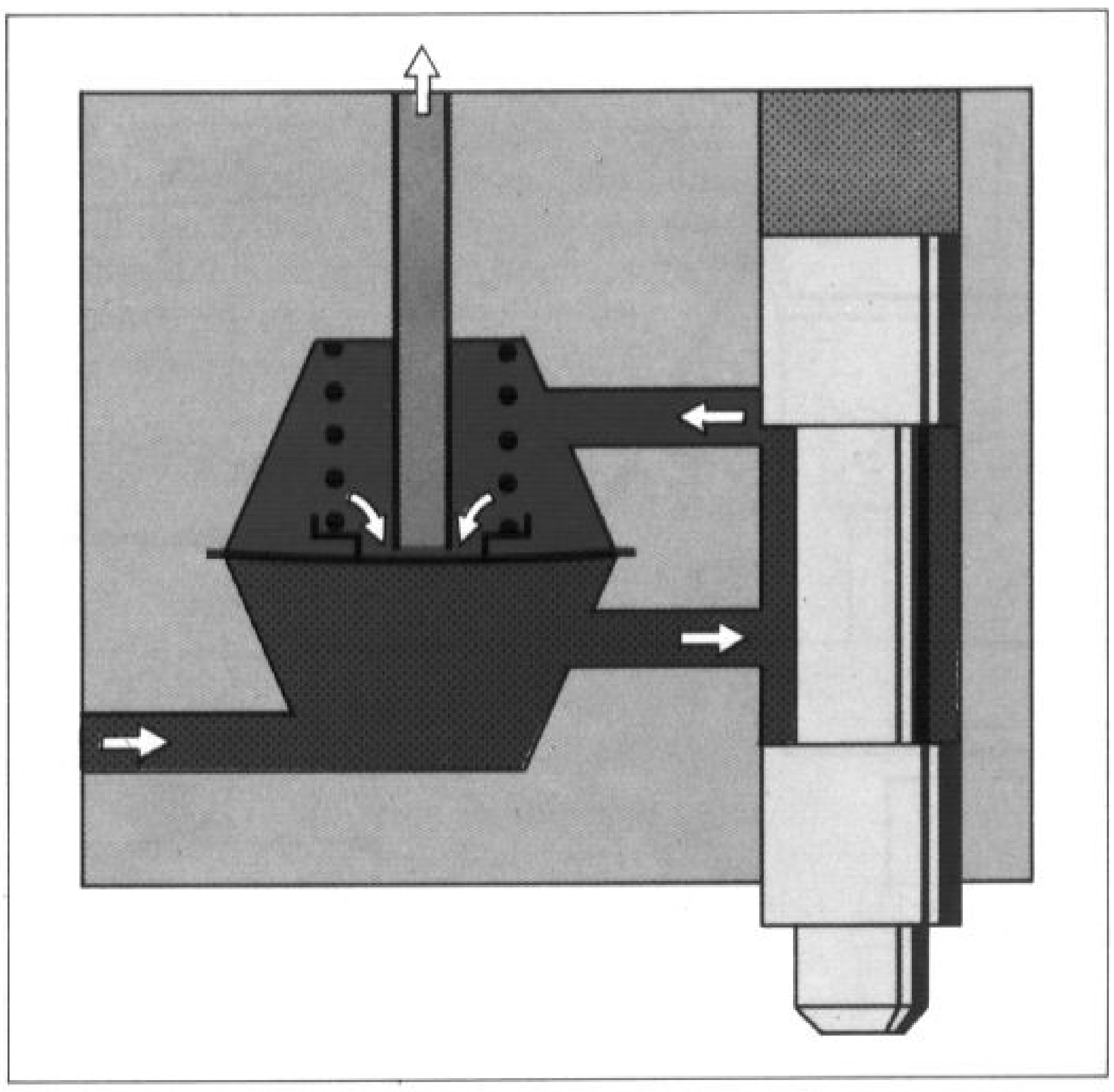


Fig. 22
Differential-pressure valve, diaphragm position with a low injected fuel quantity.

Mixture formation

The formation of the air-fuel mixture takes place in the intake manifold (tubes) and cylinders of the engine.

The continually injected fuel coming from the injection valves is "stored" in front of the intake valves. When the intake valve is opened, the air drawn in by the engine carries the waiting "cloud" of fuel with it into the cylinder. An ignitable air-fuel mixture is formed during the induction stroke due to the swirl effect.

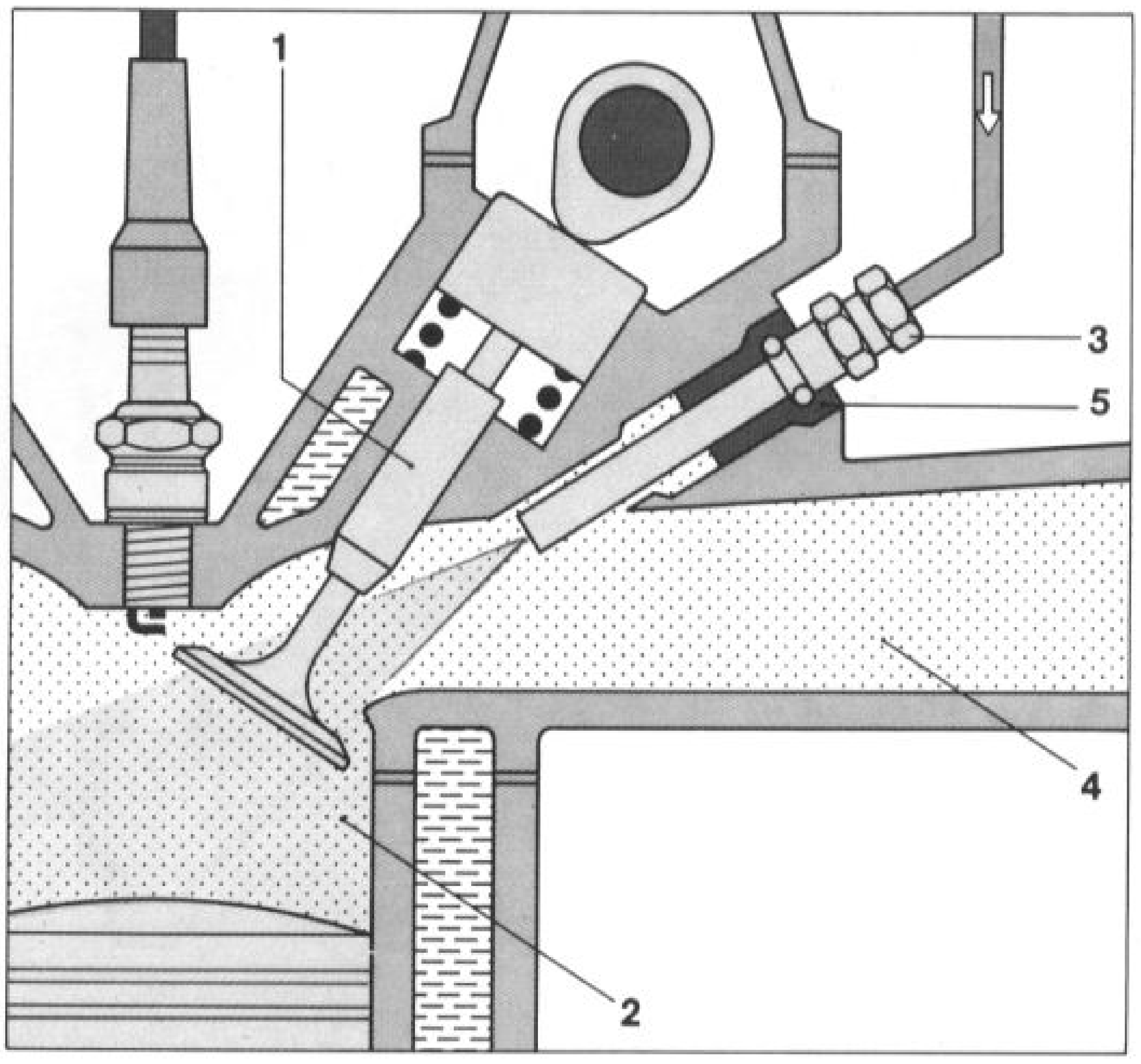
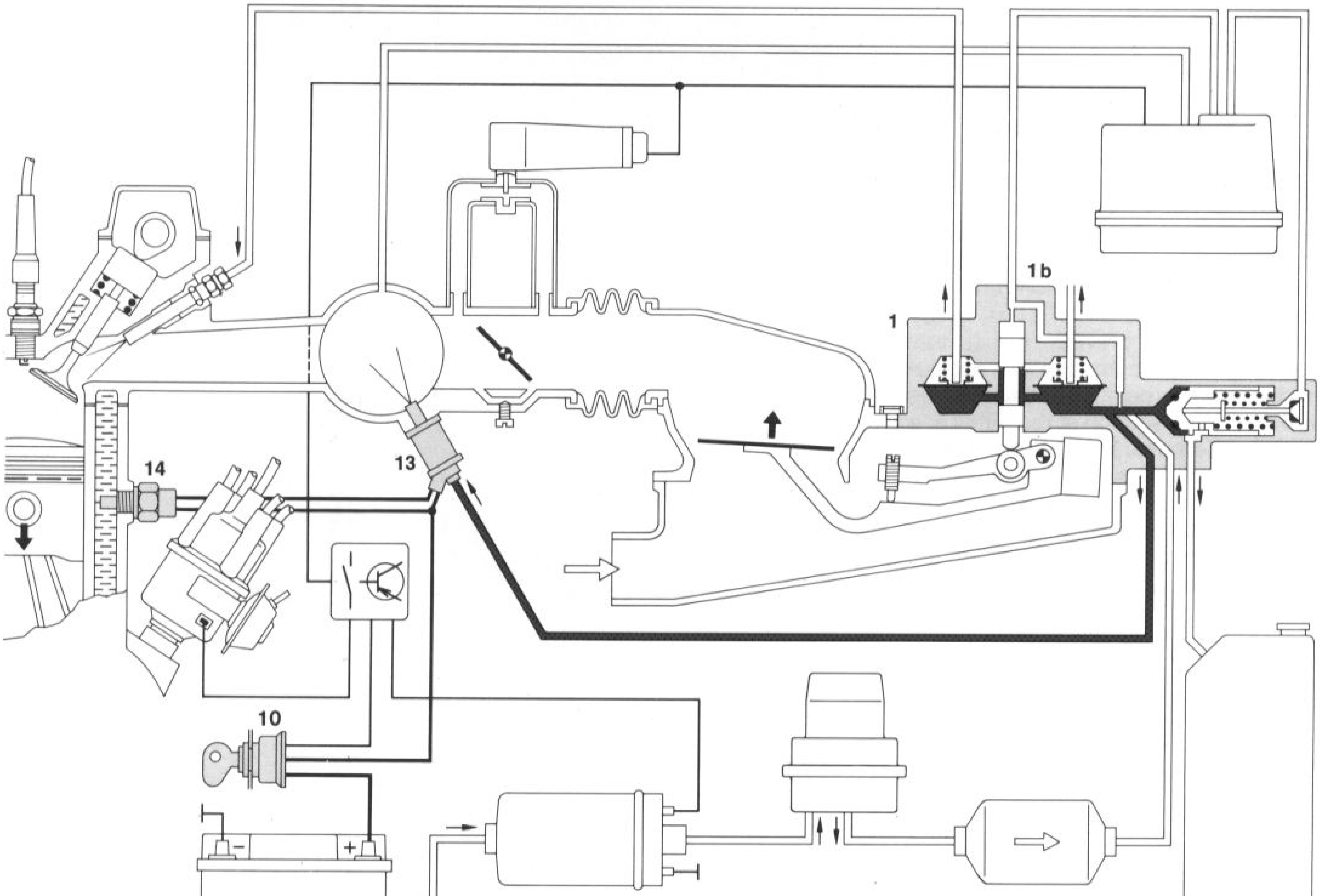


Fig. 23
Mixture formation
1 Intake valve
2 Combustion chamber
3 Fuel-injection valve
4 Intake manifold (tube)
5 Heat-isolating mount

Mixture Adaptation

In addition to the basic functions described up to now, the mixture has to be adapted during particular operating conditions. These adaptations (corrections) are necessary in order to optimize the power delivered, to improve the exhaust-gas composition and to improve the starting behaviour and driveability.

Fig. 24
Cold-start enrichment
1 Mixture-control unit
1b Fuel distributor
10 Ignition/starting switch
13 Start valve
14 Thermo-time switch



Cold start

Depending upon the engine temperature, the start valve injects extra fuel into the intake manifold for a limited period during the starting process.

During cold starting, part of the fuel in the mixture drawn in is lost due to condensation on the cold cylinder walls.

In order to compensate for this loss and to facilitate starting the cold engine, extra fuel must be injected at the instant of start-up.

This extra fuel is injected by the start valve into the intake manifold. The injection period of the start valve is limited by a thermo-time switch depending upon the engine temperature.

This process is known as cold-start enrichment and results in a "richer" air-fuel mixture, i.e. the excess-air factor is temporarily less than 1.

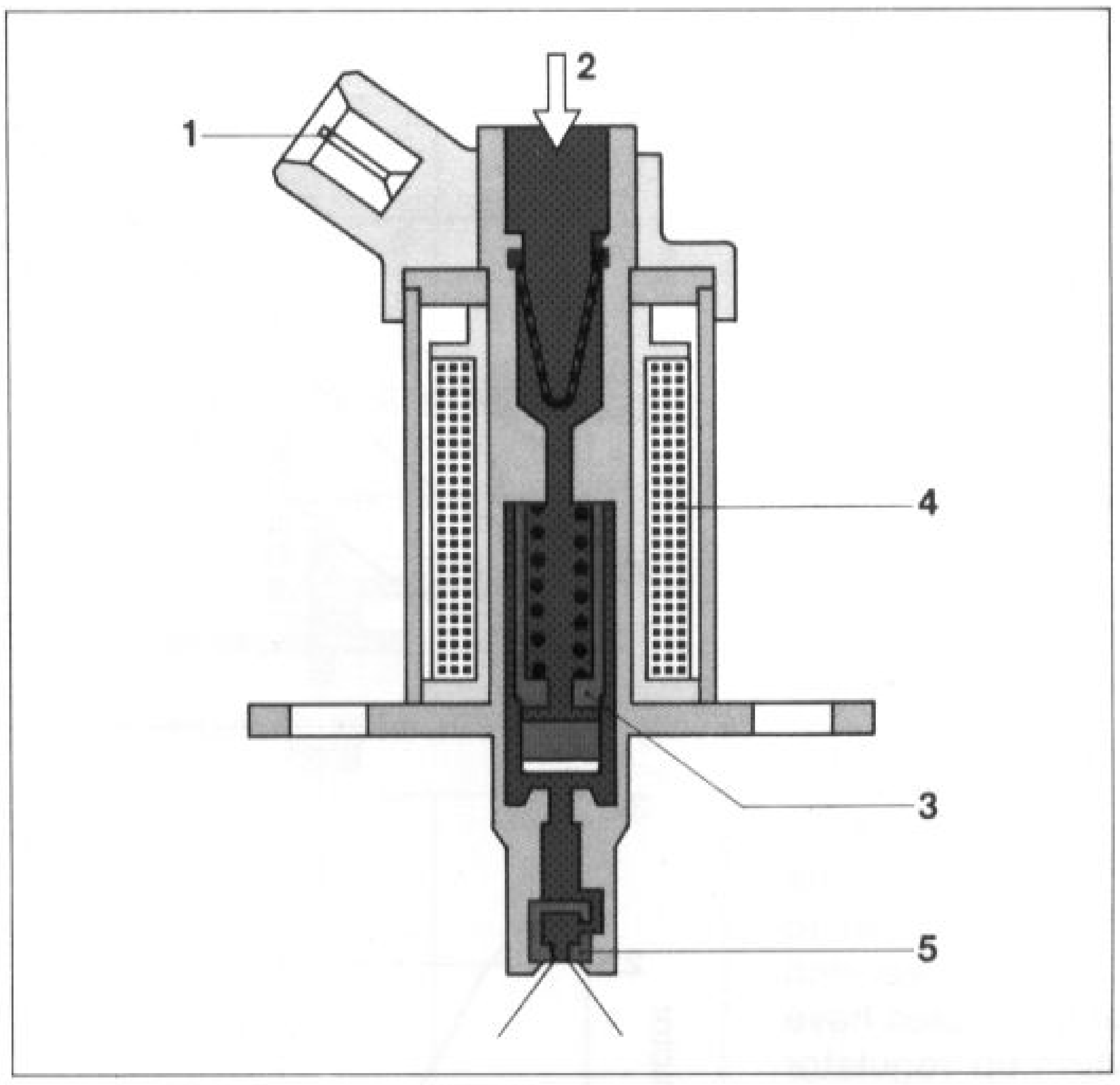


Fig. 25
Start valve in operated state.
1 Electrical connection
2 Fuel supply with strainer
3 Valve (electromagnet armature)
4 Solenoid winding
5 Swirl nozzle

Start valve

The start valve is of the solenoid-operated type. The winding of an electromagnet is fitted inside the valve. In the inoperated state, the movable armature of the electromagnet is forced against a seal by means of a spring and thus closes the valve. When the electromagnet is energized, the armature which as a result has lifted from the valve seat opens the passage for the flow of fuel through the valve. From here, the fuel enters a special nozzle at a tangent and is caused to rotate. The fuel is particularly well atomized by this specially shaped nozzle – the so-called "swirl nozzle" – and enriches the air in the intake manifold, downstream of the throttle valve, with fuel.

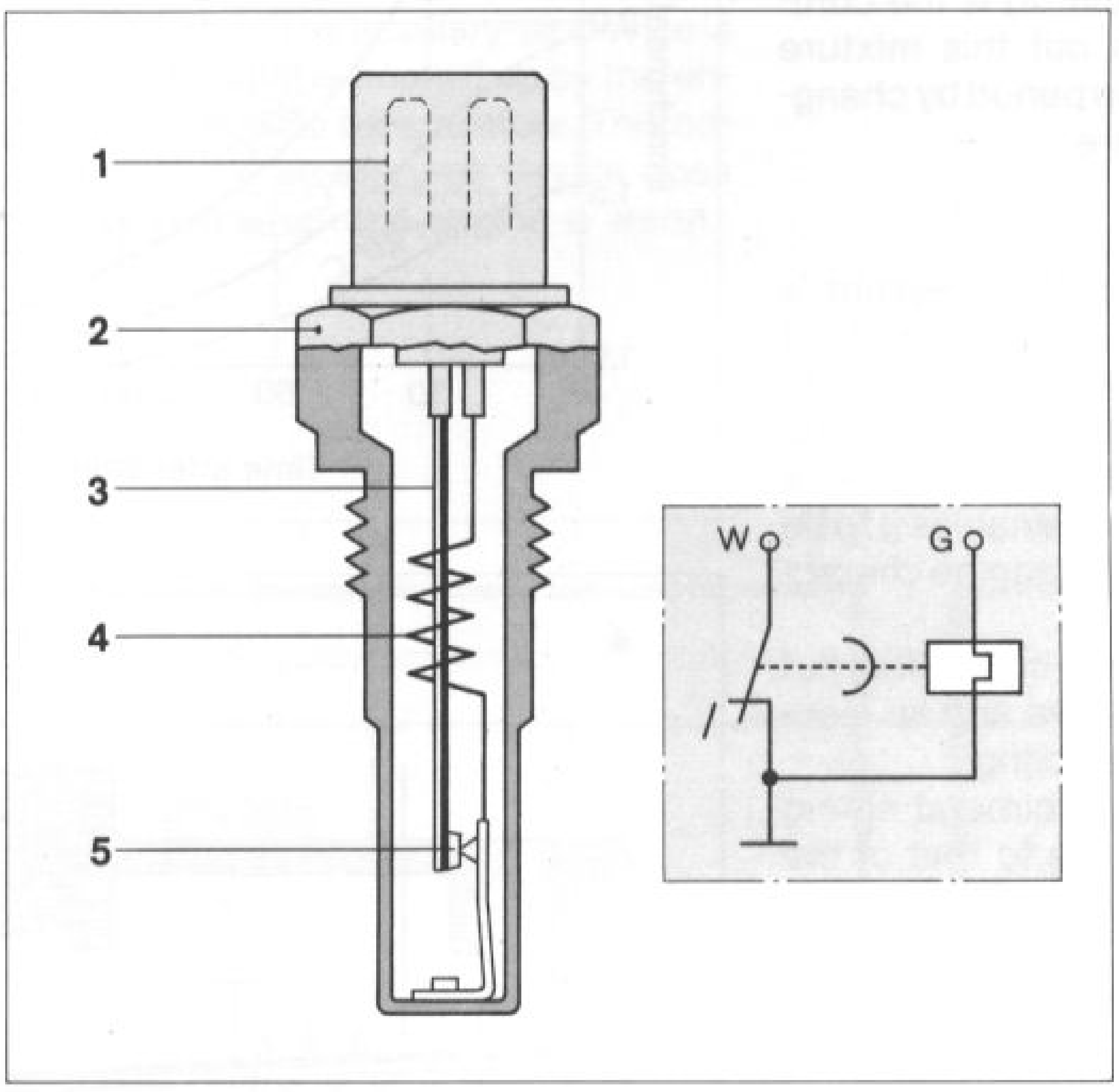


Fig. 26
Thermo-time switch
1 Electrical connection
2 Threaded pin
3 Bimetal
4 Heating filament
5 Switching contact

Thermo-time switch

The thermo-time switch limits the injection period of the start valve dependent upon engine temperature.

It is comprised of an electrically heated bimetal strip which depending upon its temperature either opens or closes an electric contact. The complete device is fitted into a hollow threaded pin which in turn is located at a position where typical engine temperature prevails.

The thermo-time switch determines the injection period of the start valve. In doing so, the warming-up of the switch due both to the engine heat and to the surrounding temperature, as well as its inbuilt electrical heating filament are the determining factors. The inbuilt heating facility is necessary in order to limit the maximum start-valve injection period. The mixture would otherwise become too rich and the engine would not start due to "flooding". During cold start the injection period depends mainly upon the electrical heating facility. (Switch off at −20 °C after approx. 8 seconds). On the other hand, when the engine is already warmed-up the heat from the engine has heated the thermo-time switch to such a degree that it remains permanently open. As a result, an engine which is already at operating temperature is not provided with extra fuel for starting.

Warm-up

Warm-up enrichment is controlled by the warm-up regulator. When the engine is cold the warm-up regulator reduces the control pressure to a degree dependent upon engine temperature and thus causes the metering slits to open further.

At the beginning of the warm-up period which directly follows the cold start, some of the injected fuel still condenses on the cylinder walls and in the intake ports. This can cause combustion miss to occur. For this reason, the air-fuel mixture must be enriched during the warm-up phase ($\lambda < 1.0$). This enrichment must be continuously reduced along with the rise in engine temperature in order to prevent the mixture being over-rich when higher engine temperatures have been reached. The warm-up regulator (control-pressure regulator) is the component which carries out this mixture control for the warm-up period by changing the control pressure.

Warm-up regulator

The change of the control pressure is effected by the warm-up regulator which is so fitted to the engine that it ultimately adopts the engine temperature. In addition, the warm-up regulator is electrically heated which enables it to be precisely matched to the engine characteristic.

It comprises a spring-controlled flat seat diaphragm-type valve and an electrically heated bimetal spring.

In the cold state the bimetal spring exerts an opposing force to that of the valve spring and, as a result, reduces the effective pressure applied to the underside of the valve diaphragm. This means that the valve outlet cross section is slightly increased at this point and more fuel is diverted out of the control-pressure circuit in order to achieve a low control pressure.

As soon as the engine is cranked the bimetal spring is heated electrically and after starting it is also heated by the engine. The spring bends, and in doing so reduces the force opposing the valve spring which, as a result, pushes up the diaphragm of the flat-seat valve. The valve outlet cross section is reduced and the pressure in the control-pressure circuit rises.

Warm-up enrichment is completed when the bimetal spring has lifted fully from the valve spring. The control pressure is now solely controlled by the valve spring and maintained at its normal level. The control pressure is about 0.5 bar at cold start and about 3.7 bar with the engine at operating temperature.

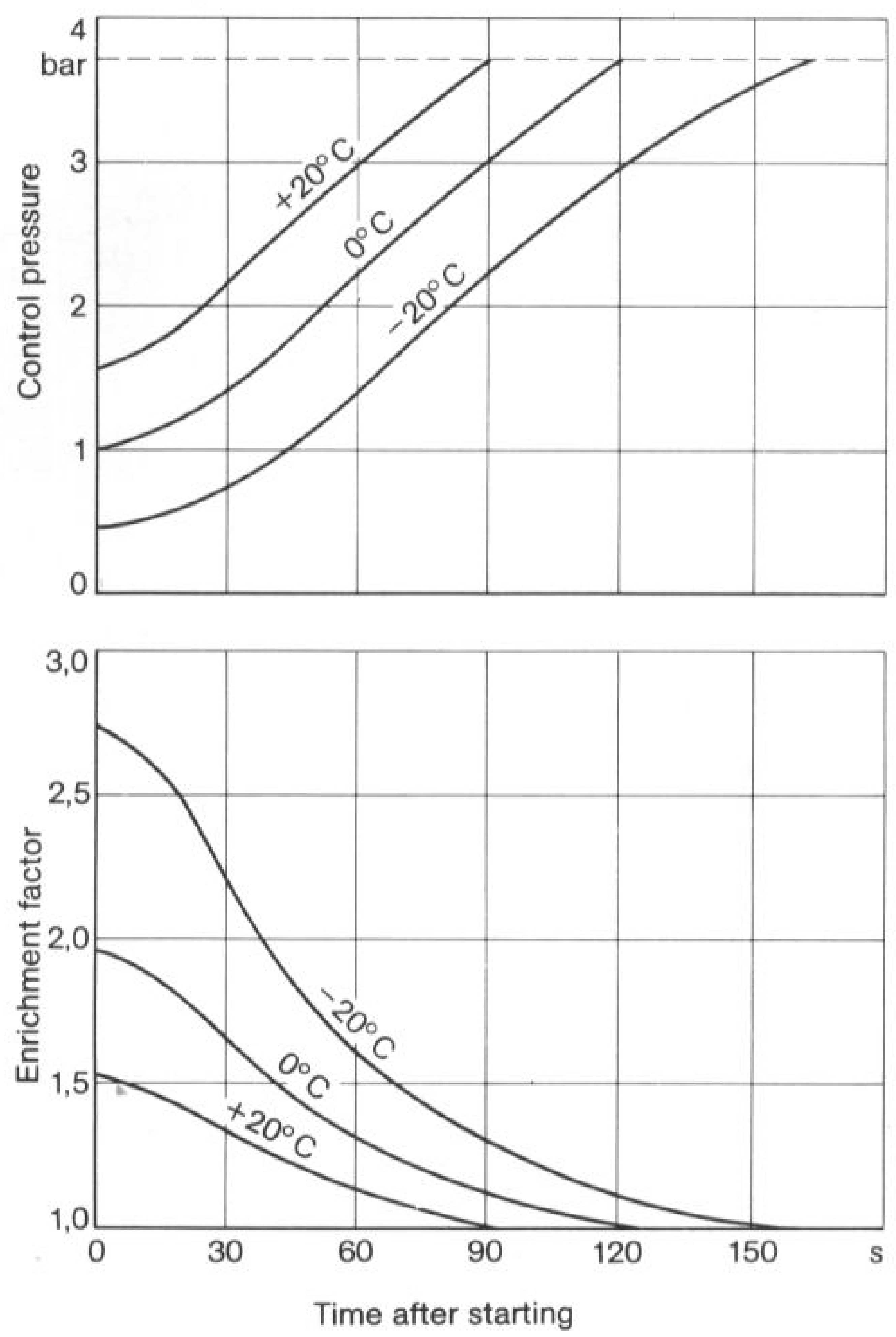


Fig. 27
Warm-up regulator characteristics at various engine temperatures. Enrichment factor 1.0 corresponds to fuel metering with the engine at operating temperature.

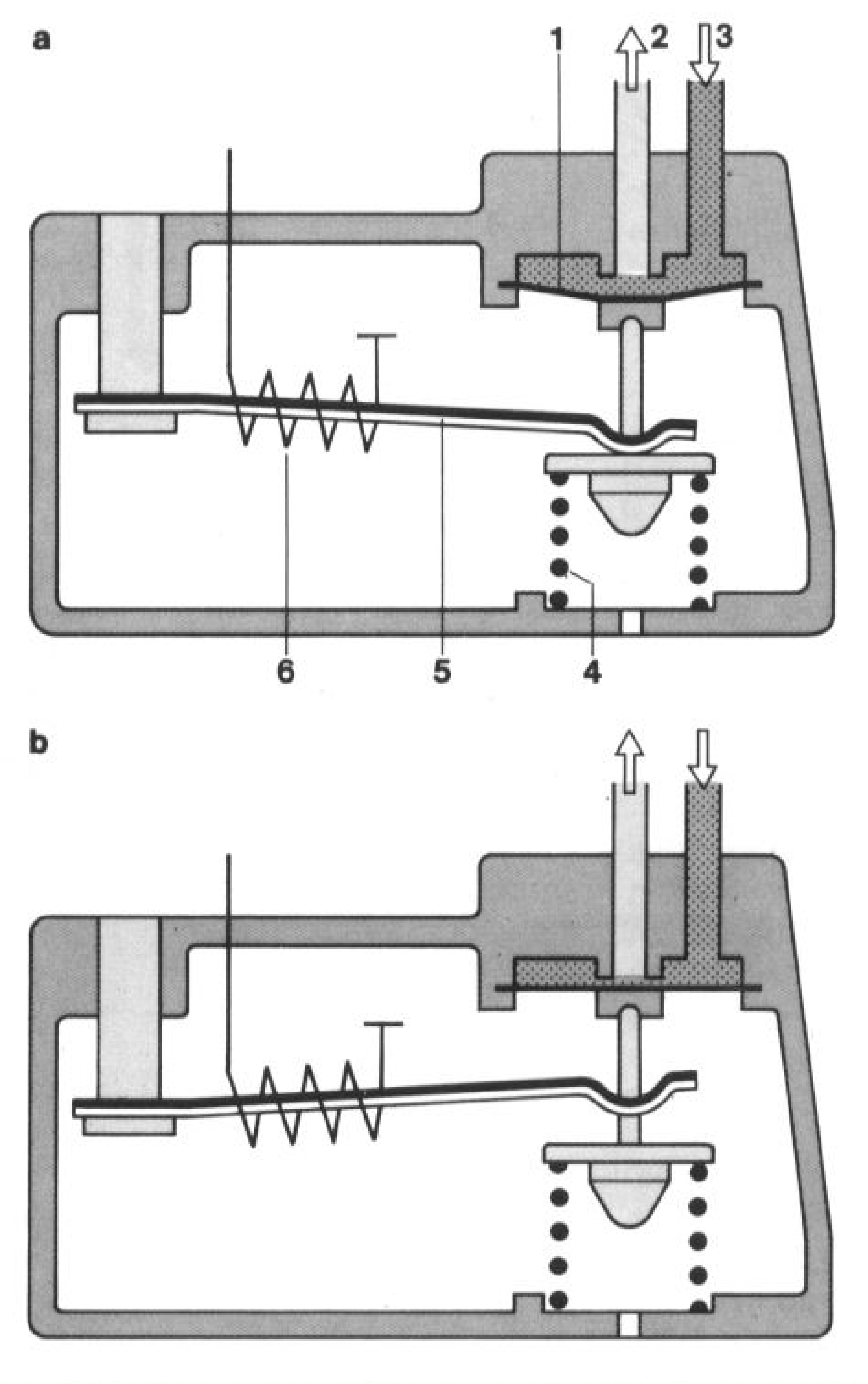


Fig. 28
Warm-up regulator
a with the engine cold
b with the engine at operating temperature
1 Valve diaphragm
2 Return
3 Control pressure (from the mixture-control unit)
4 Valve spring
5 Bimetal spring
6 Electrical heating

Auxiliary-air device

In order to overcome the increased friction in the cold state and to guarantee smooth idling, the engine receives more air-fuel mixture during the warm-up phase due to the action of the auxiliary-air device.

When the engine is cold, the frictional resistances are higher than when it is at operating temperature. These must also be overcome by the engine during idle. For this reason, the engine is allowed to draw in more air by means of the auxiliary-air device which by-passes the throttle valve. Due to the fact that this auxiliary air is measured by the air-flow sensor and taken into account for fuel metering, the engine is provided with more air-fuel mixture. This results in idle stabilization when the engine is cold.

In the auxiliary-air device a perforated plate is pivoted by means of a bimetal spring and changes the open cross section of the bypass line. Dependent upon temperature the plate assumes a given position, so that in the case of a cold engine a correspondingly larger cross section of the bypass line is opened. As the temperature increases the open area is decreased until, finally, it is closed completely. The bimetal is heated electrically. This means that the opening time can be limited according to engine type. The auxiliary-air device is so located that it is heated up by the engine to the engine temperature. This ensures that the auxiliary-air device does not respond when the engine is warm.

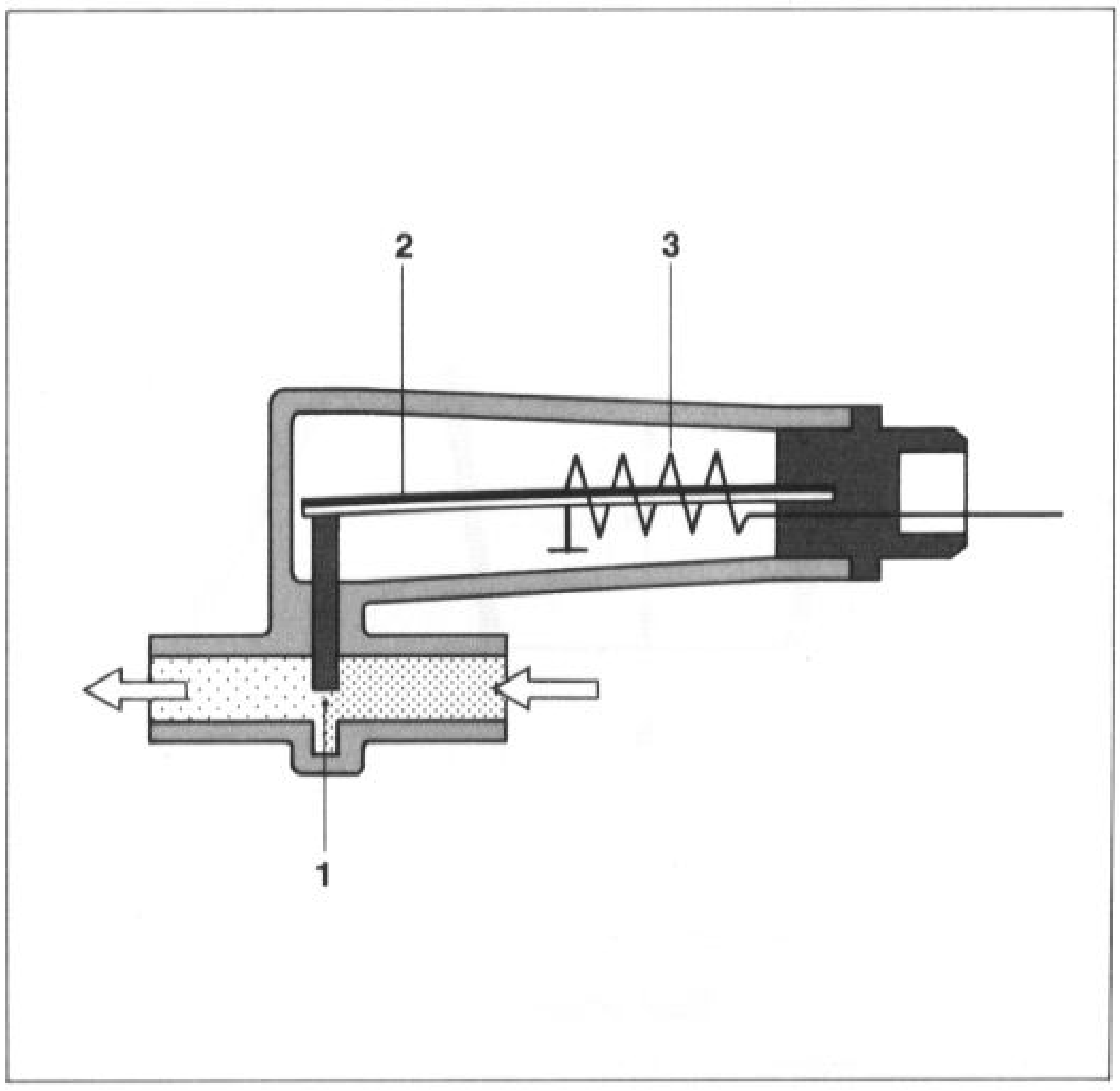


Fig. 29
Auxiliary-air device
1 Bypass line with pivoting plate
2 Bimetal
3 Electrical heating

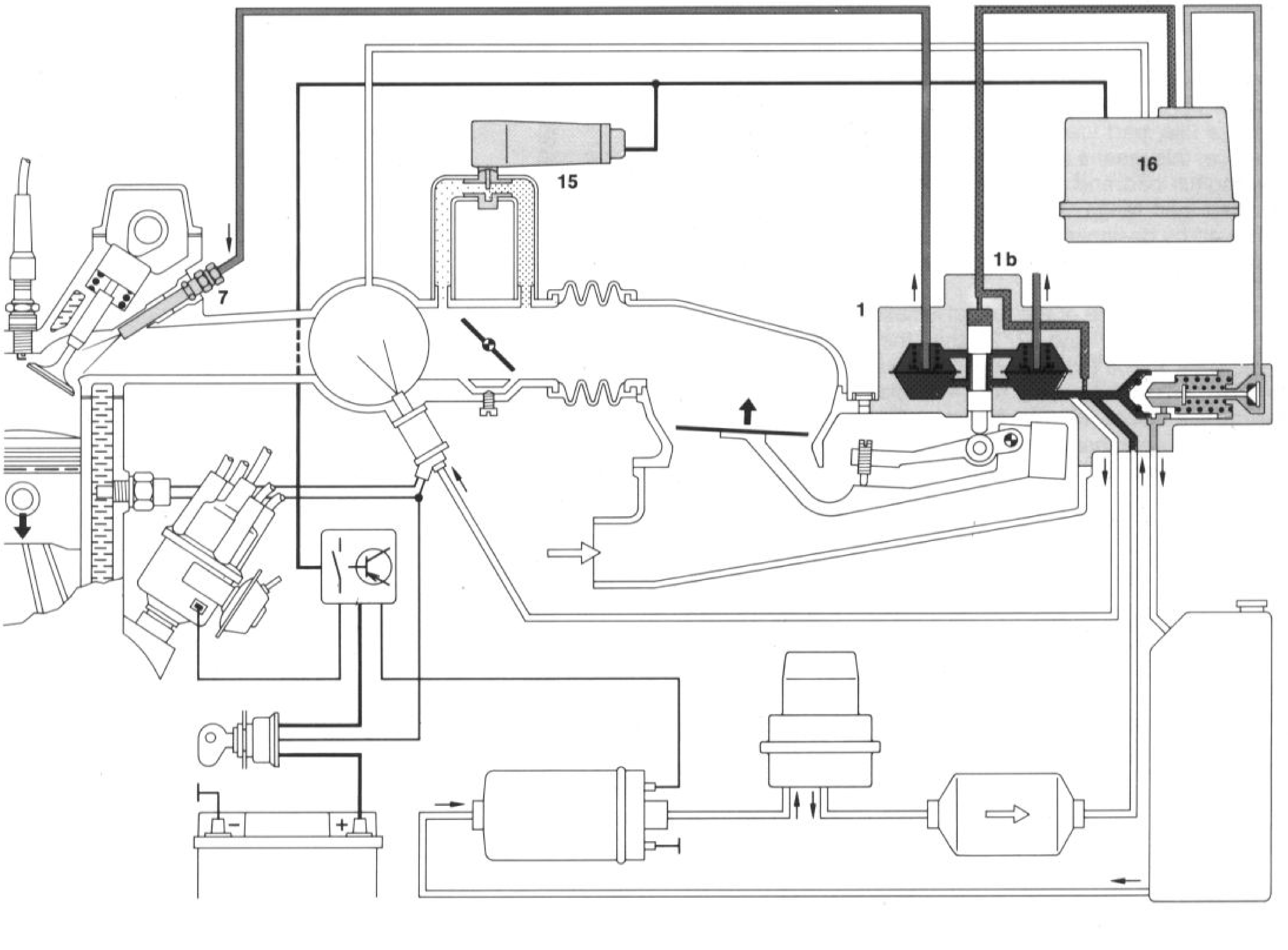


Fig. 30
Warm-up enrichment
1 Mixture-control unit
1b Fuel distributor
7 Fuel-injection valve
15 Auxiliary-air device
16 Warm-up regulator

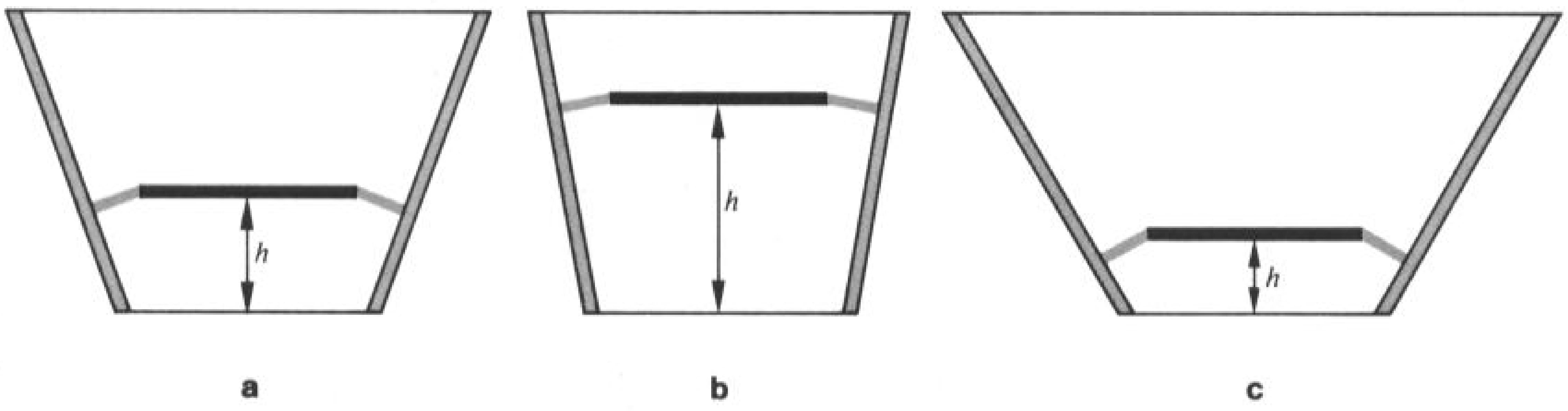


Fig. 31
Influence of the angle of the funnel walls on the deflection of the sensor plate for the same air throughput.
a Basic shape of the air funnel results in sensor-plate deflection "h"
b Steep funnel walls result in increased deflection "h" for the same air throughput
c Flatter funnel shape results in reduced deflection "h" for the same air throughput

▨ Annular area opened by the sensor plate remains the same in a, b and c.

Load conditions

The adaptation, or correction, of the air-fuel mixture to the operating conditions of idle, part load and full load is carried out by means of appropriately shaping the air funnel in the air-flow sensor.

If the funnel had a purely conical shape (as in Fig. 31), the result would be a mixture with a constant air-fuel ratio throughout the whole of the sensor plate range of travel (metering range).

As has already been mentioned though, it is necessary to meter to the engine an air-fuel mixture which is optimal for particular operating conditions such as idle, part load and full load. In practice, this means a richer mixture at idle and full load, and a leaner mixture in the part-load range. This adaptation is achieved by designing the air funnel so that it becomes wider in stages (see Fig. 32).

If the cone shape of the funnel is flatter (as in Fig. 31 "c" and 32 "2") than the basic cone shape (which was specified for a particular mixture, e.g. for $\lambda = 1$) this results in a leaner mixture. If the funnel walls are steeper than in the basic model the sensor plate is lifted further for the same air throughput, more fuel is therefore metered and the mixture is richer.

Hence, the funnel is so shaped that a richer mixture is produced at idle and full load, and a leaner mixture at part load (full-load and idle enrichment).

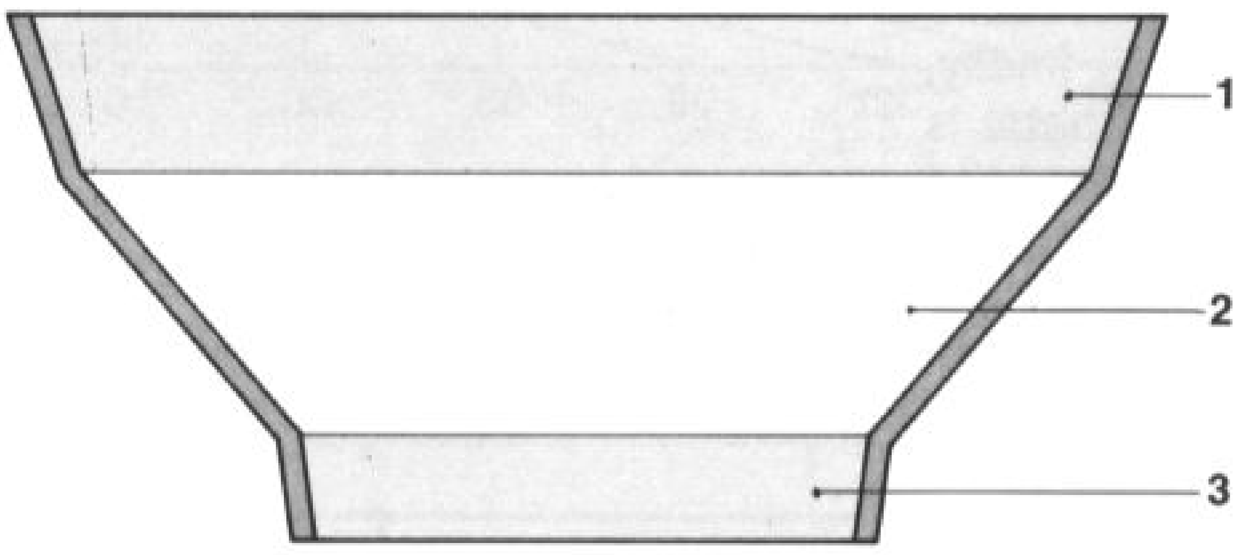


Fig. 32
Adaptation of the funnel shape on the air-flow sensor
1 For full-load
2 For part-load
3 For idle

Mixture enrichment by means of control-pressure reduction

In those cases where engines are operated with a very lean mixture in the part-load range, an extra mixture enrichment must be provided at full load in addition to the mixture adaptation resulting from the shape of the air funnel.

This extra enrichment is carried out by a specially designed warm-up regulator. This regulates the control pressure depending upon the manifold pressure.

In this model of the warm-up regulator, two valve springs are used instead of one. The outer of the two springs is supported on the housing as is the case with the normal-model warm-up regulator. The inner spring though, is supported on a diaphragm which divides the regulator into an upper and a lower chamber. The manifold pressure is effective in the upper chamber which is connected to the intake manifold, behind the throttle valve, by means of a hose. Depending upon the model, the lower chamber is subjected to atmospheric pressure either directly or by means of a second hose leading to the air filter.

Due to the low manifold pressure in the idle and part-load ranges, which is also present in the upper chamber, the diaphragm lifts to its upper stop. The inner spring is now at maximum pretension. The pretension of both springs, as a result, determines the particular control pressure for these two ranges. When the throttle valve is opened further at full load, the pressure in the intake manifold increases, the diaphragm leaves the upper stops and is pressed against the lower stops.

The inner spring is relieved of tension and the control pressure reduced by the specified amount as a result. In this manner, mixture enrichment is achieved.

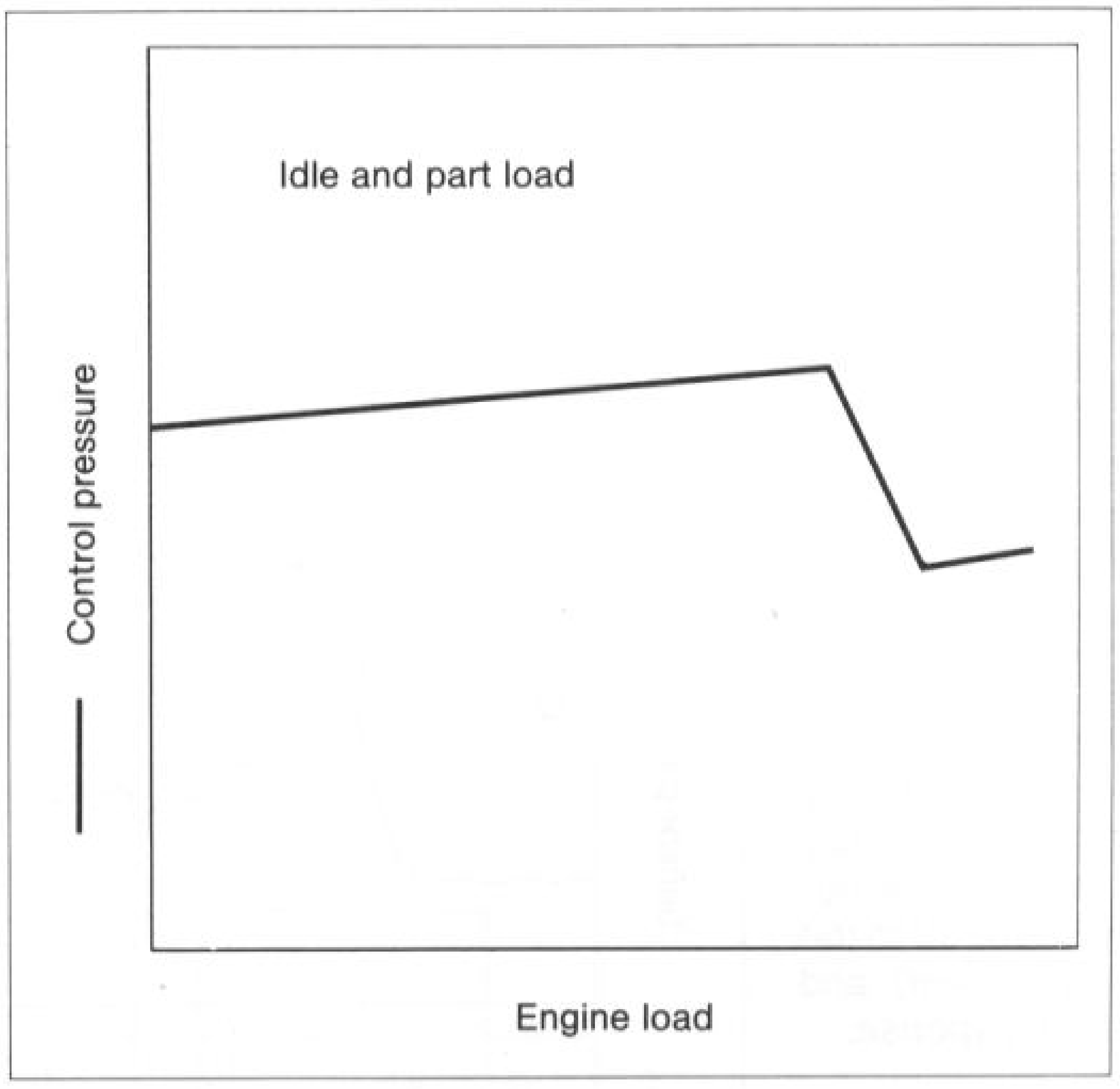


Fig. 33
Dependence of the control pressure on engine load.

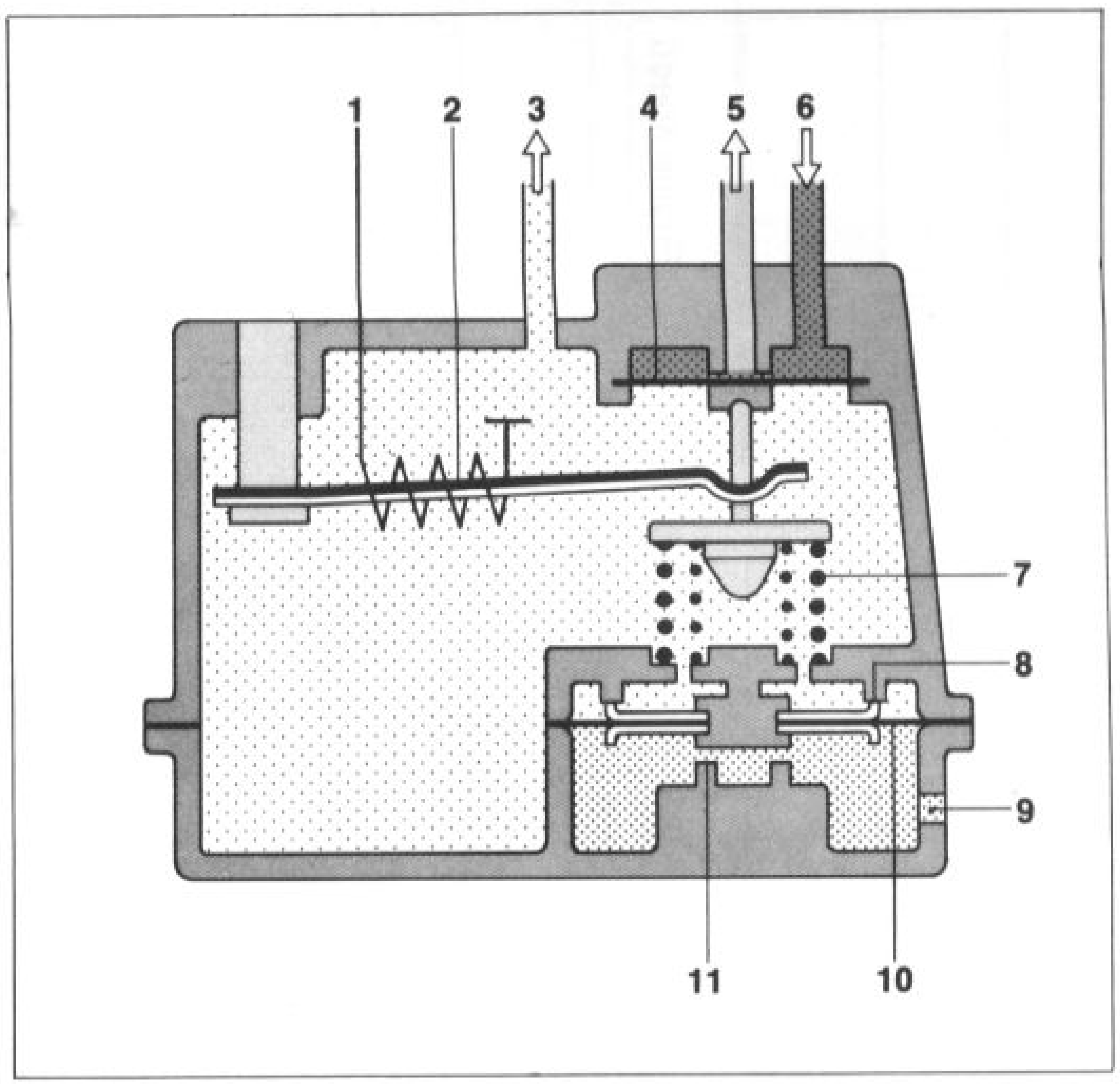


Fig. 34
Warm-up regulator with the full-load diaphragm in the idle and part-load position.

1 Electrical heating
2 Bimetal spring
3 Vacuum connection (from intake manifold)
4 Valve diaphragm
5 Return to fuel tank
6 Control pressure (from fuel distributor)
7 Valve springs
8 Upper stops
9 to atmospheric pressure
10 Diaphragm
11 Lower stops

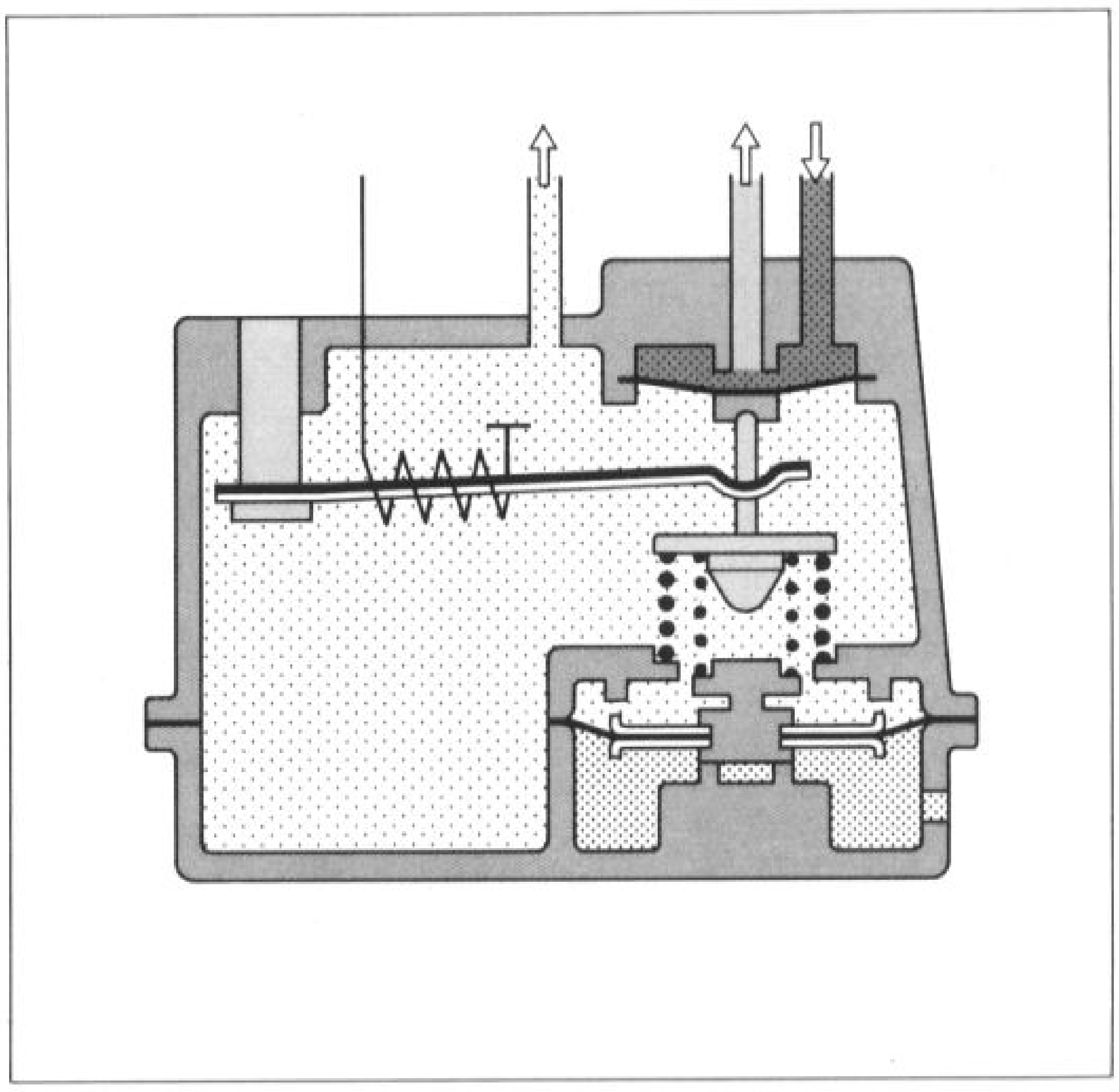


Fig. 35
Warm-up regulator with the full-load diaphragm in the full-load position.

Acceleration response

The good acceleration response is a result of the sensor plate "overswing".

Acceleration
During the transition from one operating condition to the other, changes in the mixture ratio occur which are utilized to improve the driveability.

If at constant engine speed the throttle valve is suddenly opened, the amount of air which enters the combustion chamber, plus the amount of air which is needed to bring the manifold pressure up to the new level, flow through the air-flow sensor. This causes the sensor plate to briefly "overswing" past the fully opened throttle point. This "overswing" results in more fuel being metered to the engine (acceleration enrichment) and ensures good acceleration response.

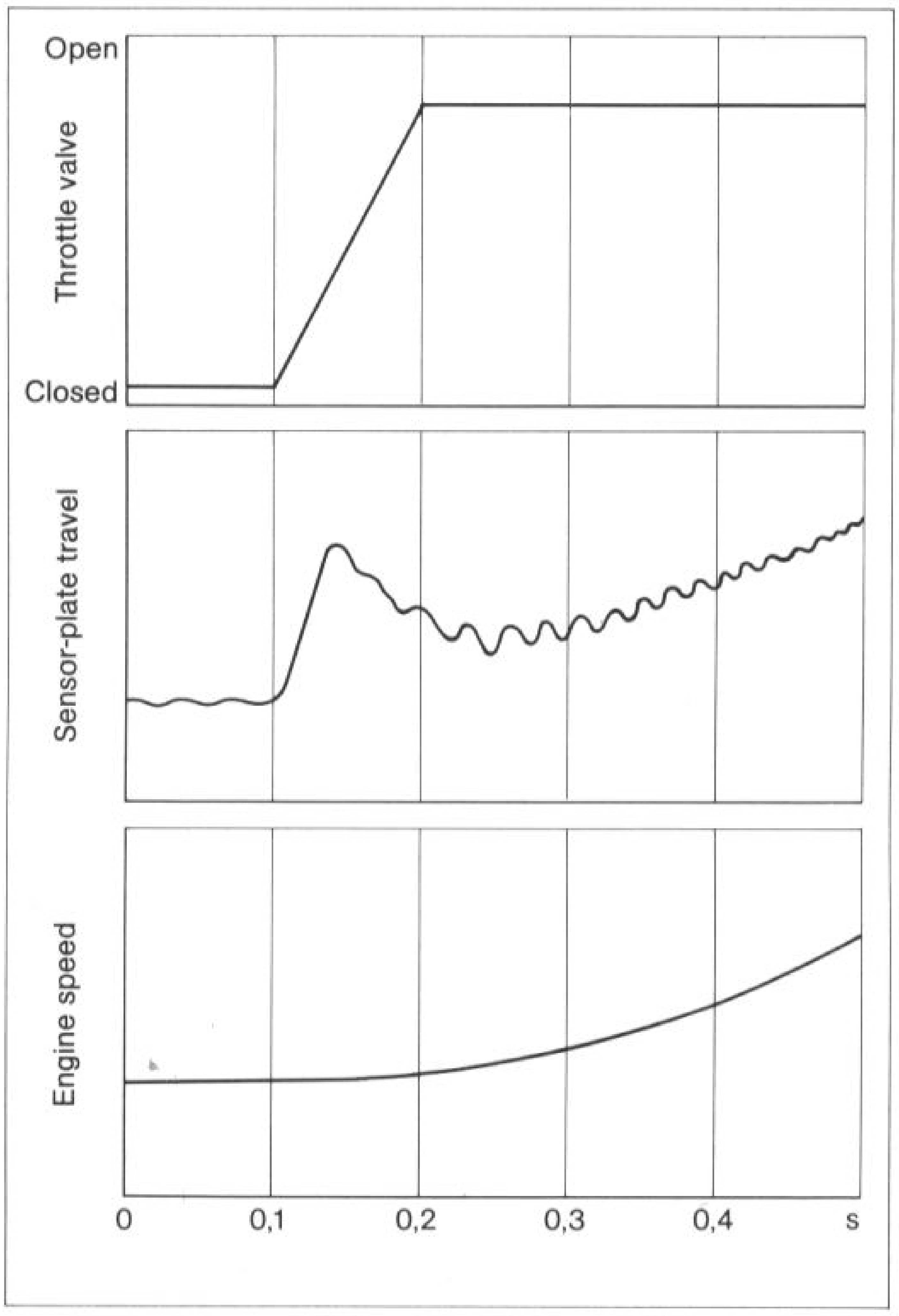


Fig. 36
Acceleration response. Behaviour of the K-Jetronic when the throttle valve is suddenly opened.

Controlling the air-fuel mixture

In order to adapt the injected fuel quantity to the ideal air-fuel ratio of $\lambda = 1$, the pressure in the lower chambers of the fuel distributor is varied. If for instance the pressure is reduced, the differential pressure at the metering slots climbs accordingly with the result that the injected fuel quantity is also increased. In order to be able to vary the pressure in the lower chambers, these are decoupled (in contrast to the conventional K-Jetronic fuel distributor) from the primary pressure. Decoupling is by means of a fixed throttle. A further throttle connects the lower chambers with the fuel return.

This throttle is variable. If it is open, the pressure in the lower chambers can reduce. If it is closed, the primary pressure is present in the lower chambers. If this throttle is opened and closed rapidly, it is possible to vary the pressure in the lower chambers to correspond to the ratio between open time and close time. An electromagnetic valve, the timing valve, is used as the variable throttle. It is controlled by electrical pulses from the Lambda control unit.

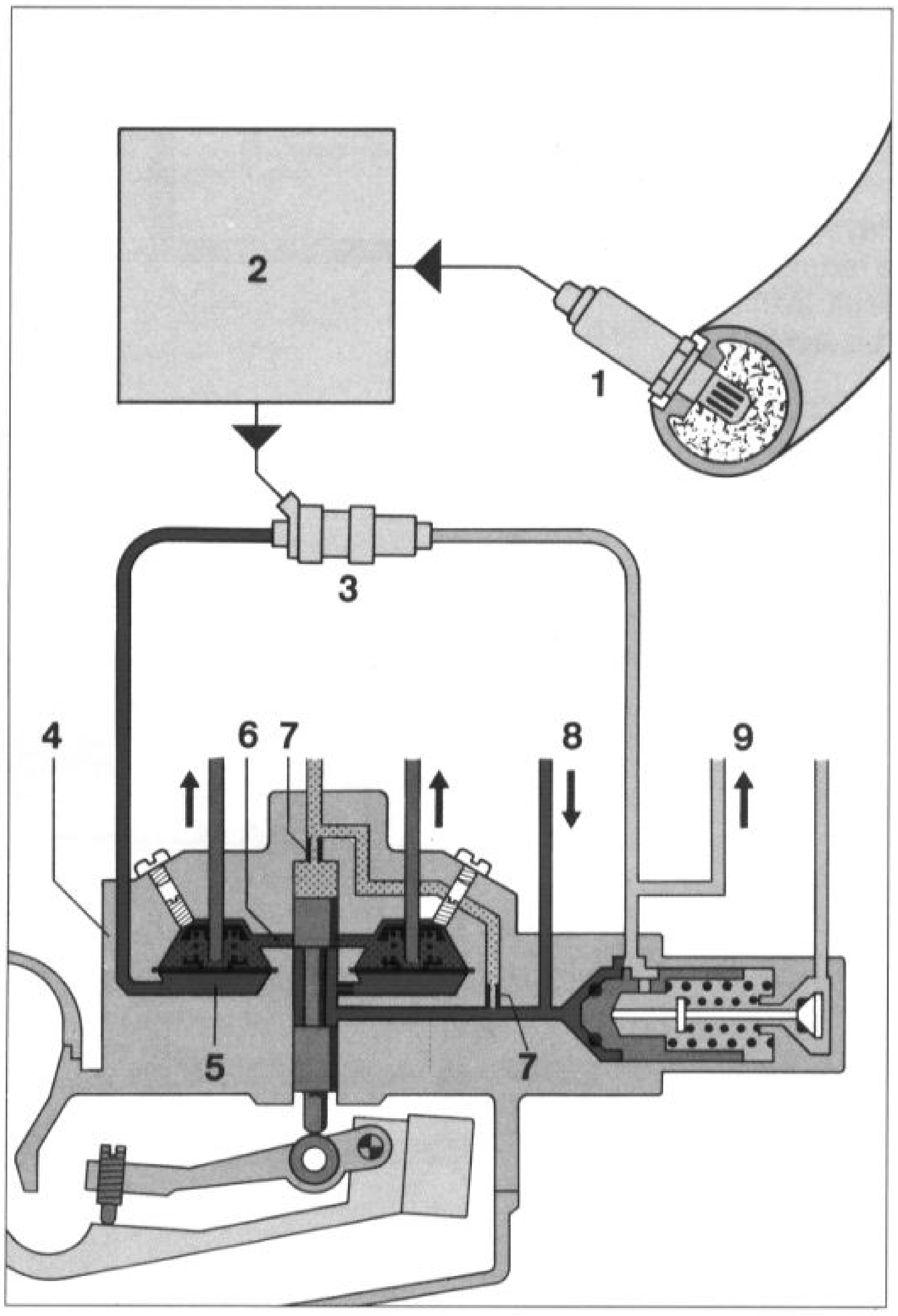


Fig. 37
Additional components required for the Lambda closed-loop control.

1 Lambda sensor
2 Lambda control unit
3 Timing valve (variable throttle)
4 Fuel distributor
5 Lower chambers of the differential-pressure valves
6 Metering slits
7 Decoupling throttle (fixed throttle)
8 Fuel inlet
9 Fuel return

Electrical Circuitry

If the engine stops but the ignition remains switched on, the electric fuel pump is switched off.

The K-Jetronic system is equipped with a number of electrical components, such as electric fuel pump, warm-up regulator, auxiliary-air device, start valve and thermo-time switch. The electrical supply to all of these components is controlled by the control relay which itself is switched by the ignition-start switch.

Apart from its switching functions, the control relay also has a safety function. A commonly used circuit is described in the following.

Function

When cold-starting the engine, voltage is applied to the start valve and the thermo-time switch through terminal 50 of the ignition-start switch. If the cranking process takes longer than between 8 and 15 s, the thermo-time switch switches off the start valve in order that the engine does not "flood". In this case the thermo-time switch performs a time-switch function.

If the temperature of the engine is above about +35 °C when the starting process is commenced, the thermo-time switch will have already open-circuited the connection to the start valve which as a result does not inject extra fuel. In this case the thermo-time switch performs as a temperature switch.

Voltage from the start-ignition switch is still present at the control relay which switches on as soon as the engine runs. The rotational speed reached when the starting motor cranks the engine is high enough to generate the "engine running" signal which is taken from the ignition pulses coming from terminal 1 of the ignition coil.

These pulses are processed by an electronic circuit in the control relay which switches on after the first pulse and applies voltage to the electric fuel pump, the auxiliary-air device and the warm-up regulator. The control relay remains switched on as long as the ignition is switched on and the engine is running. If the pulses from terminal 1 of the ignition coil stop because the engine has stopped turning, for instance in the case of an accident, the control relay switches off about 1 s after the last pulse is received. This safety circuit prevents the fuel pump from pumping fuel when the ignition is switched on but the engine is not turning.

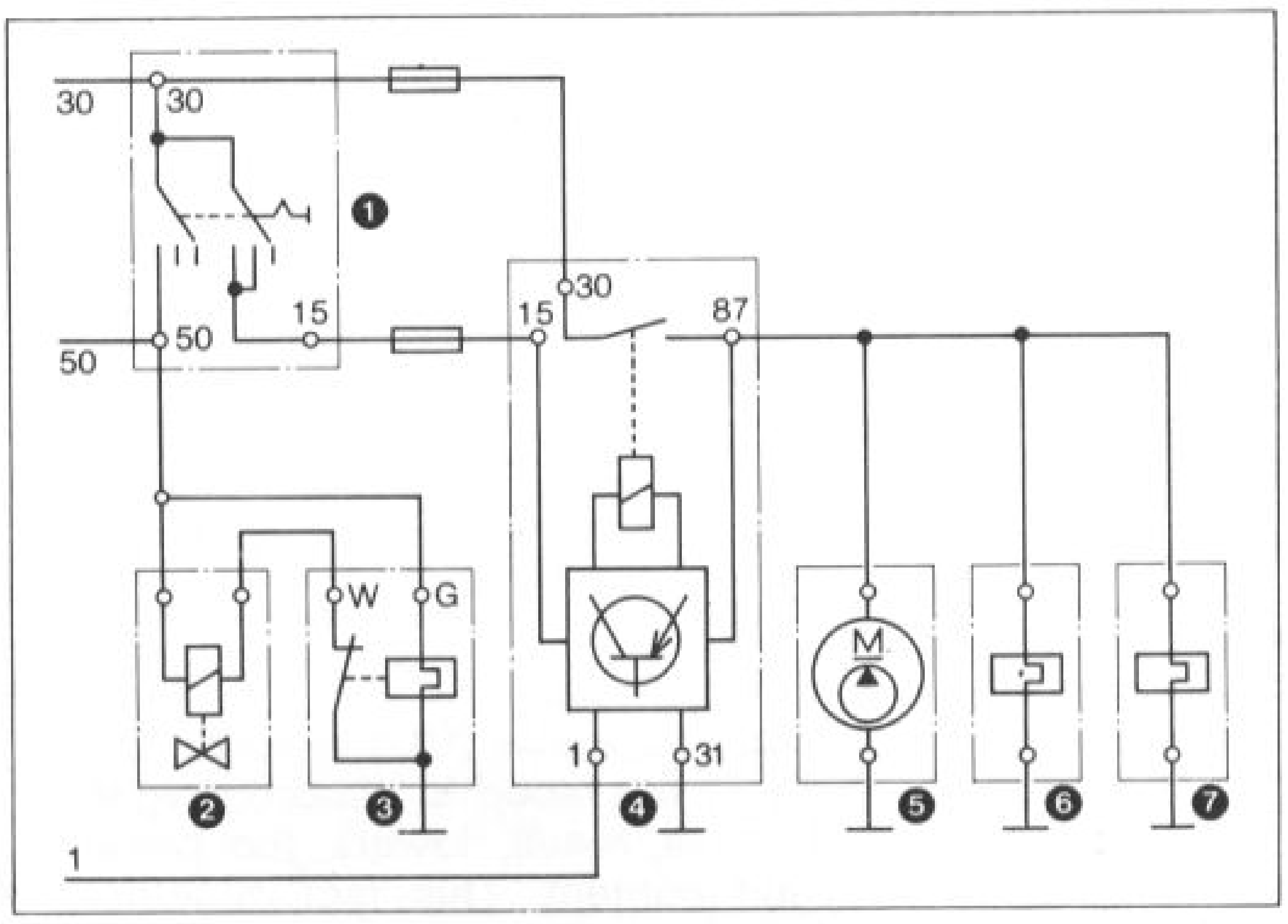


Fig. 38
Circuit without voltage applied
❶ Ignition-start switch
❷ Start valve
❸ Thermo-time switch
❹ Control relay
❺ Electric fuel pump
❻ Warm-up regulator
❼ Auxiliary-air device

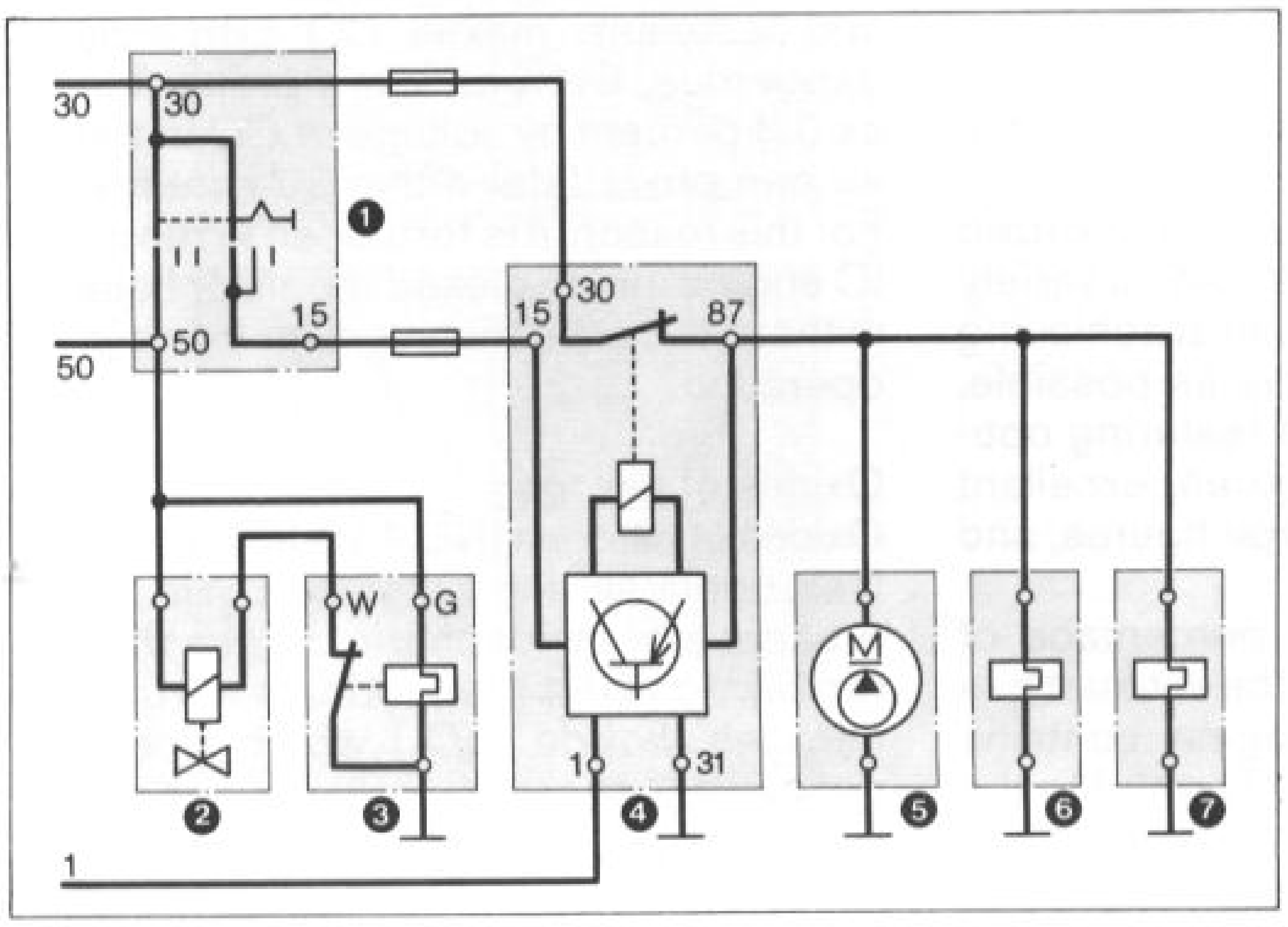


Fig. 39
Starting with the engine cold. Start valve and thermo-time switch are switched on. The engine turns (pulses are taken from terminal 1 of the ignition coil). The control relay, electric fuel pump, auxiliary-air device and warm-up regulator are switched on.

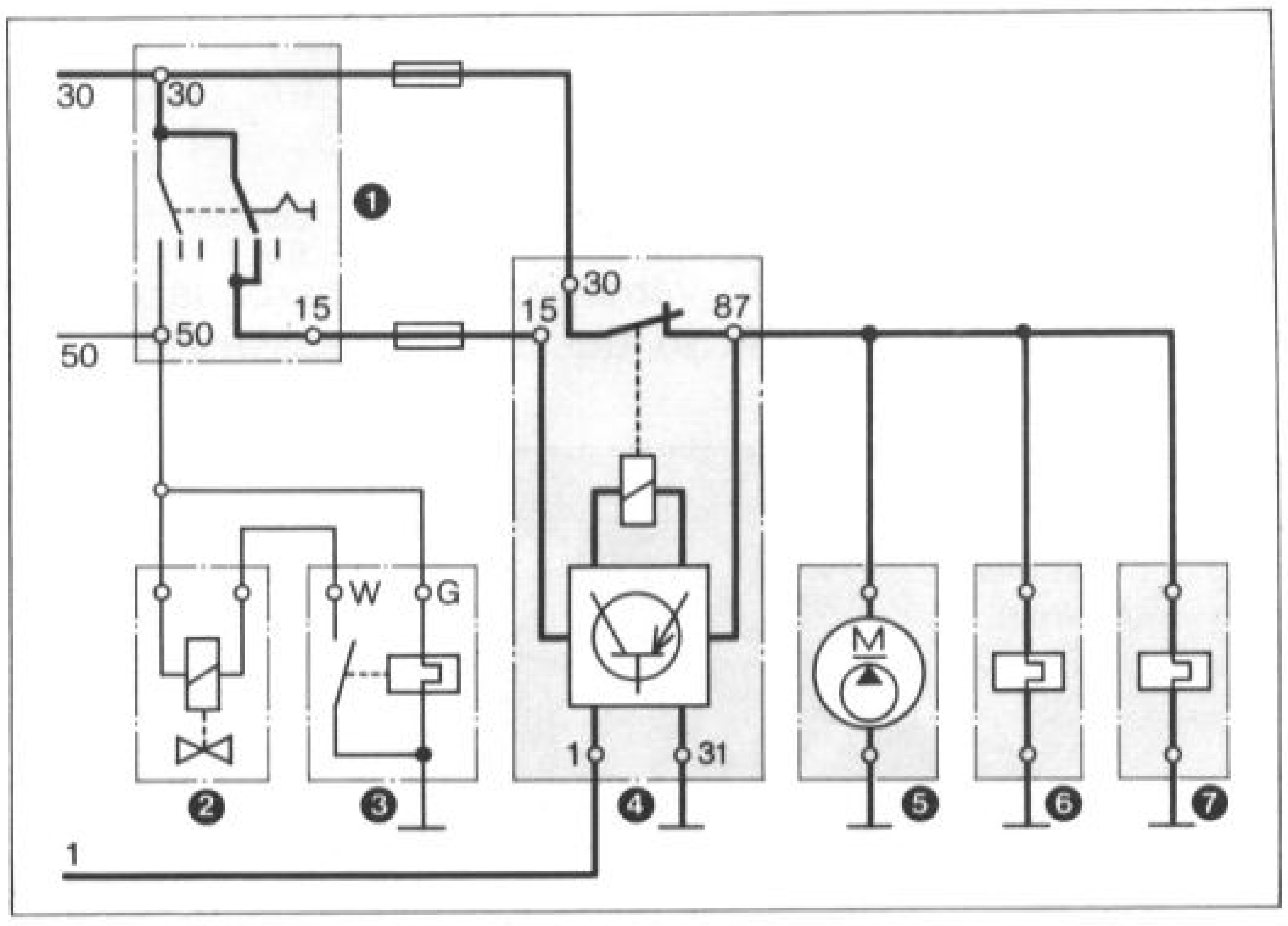


Fig. 40
Operation
Ignition on and engine running. Control relay, electric fuel pump, auxiliary-air device and warm-up regulator are switched on.

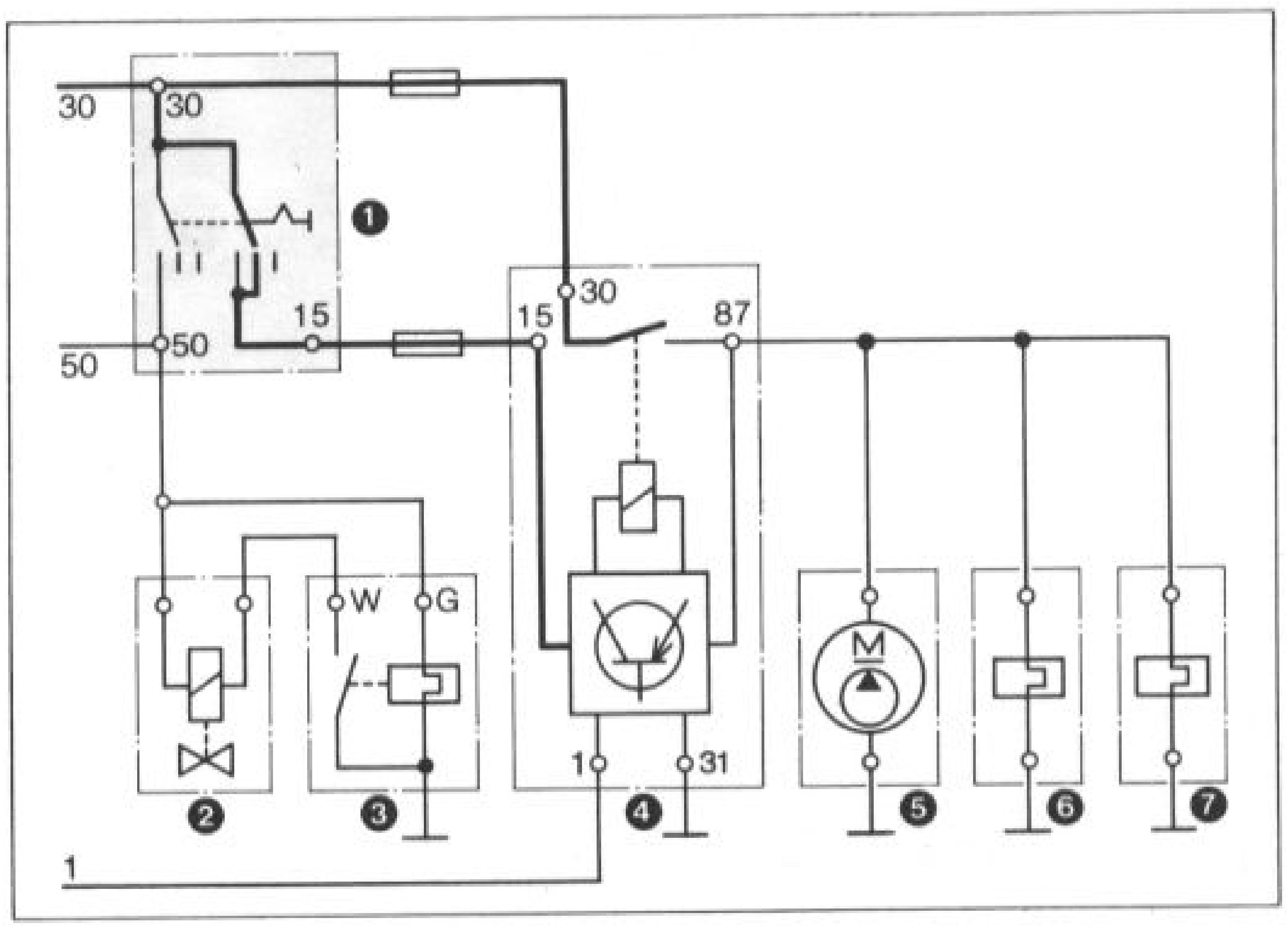


Fig. 41
Ignition on but engine stopped. No pulses can be taken from terminal 1 of the ignition coil. The control relay, electric fuel pump, auxiliary-air device and warm-up regulator are switched off.

Exhaust-gas techniques

Exhaust-gas composition

Fuel combustion in the engine working cylinder is more or less incomplete. The less complete the combustion, the higher is the emission of toxic substances in the exhaust gas. Perfect, or total, combustion of the fuel is impossible even when surplus air is available in plenty. In order to reduce the load on the environment, it is imperative that engine exhaust-gas emissions are reduced drastically.

All measures taken to reduce the toxic emissions in compliance with a variety of legal requirements, aim at achieving as clean an exhaust gas as possible, while at the same time featuring optimum fuel-economy figures, excellent drive ability, high mileage figures, and low installation costs.

In addition to a large percentage of harmless substances, the exhaust gas of a spark-ignition engine contains components which are harmful to the environment when they occur in high concentrations. About 1 % of the exhaust gas is harmful, and consists of carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbons (HC). The major problem in this respect is the fact that although these three toxic substances are dependent upon the air-fuel ratio, when the concentration of CO and HC increases the concentration of NO_x decreases, and vice versa.

Carbon monoxide

Carbon monoxide (CO) reduces the ability of the blood to absorb oxygen and, as a result, lowers the blood oxygen content. This fact, together with it also being colorless, odorless, and tasteless, makes CO extremely dangerous. Even as low a proportion as 0.3 percent by volume of CO in the air can prove fatal within 30 minutes. For this reason, it is forbidden to run an IC engine inside closed rooms or halls without the extraction system being in operation.

Oxides of nitrogen

Oxides of nitrogen (NO_x) are also colorless, odorless, and tasteless, but in the presence of atmospheric oxygen they rapidly convert to reddish brown nitrogen dioxide (NO_2) which smells pungently and causes pronounced irritation of the respiratory system. Due to the fact that NO_2 destroys the lung tissue it is also detrimental to health when encountered in higher concentrations. NO and NO_2 are usually referred to together as NO_x.

Hydrocarbons

A wide variety of hydrocarbons are present in the exhaust gas from IC engines. In the presence of oxides of nitrogen and sunshine they produce products of oxidization. A number of hydrocarbons are detrimental to health.

Catalytic aftertreatment

The toxic emissions of the spark-ignition engine can be considerably reduced by the use of catalytic aftertreatment.

The exhaust-gas emission level of an engine can be influenced at three different points. The first possibility of influencing the emissions is during the mixture-formation stage before the engine. The second possibility is the use of special design measures on the engine itself (for instance, optimized combustion-chamber shape). The third possibility is aftertreatment of the exhaust gases on the exhaust side of the engine, whereby the task is to complete the combustion of the fuel. This is carried out by means of a catalytic converter which has two notable characteristics:

- The catalytic converter promotes the afterburning of CO and HC to harmless carbon dioxide (CO_2) and water (H_2O).
- At the same time, the catalytic converter reduces the nitrogen of oxide

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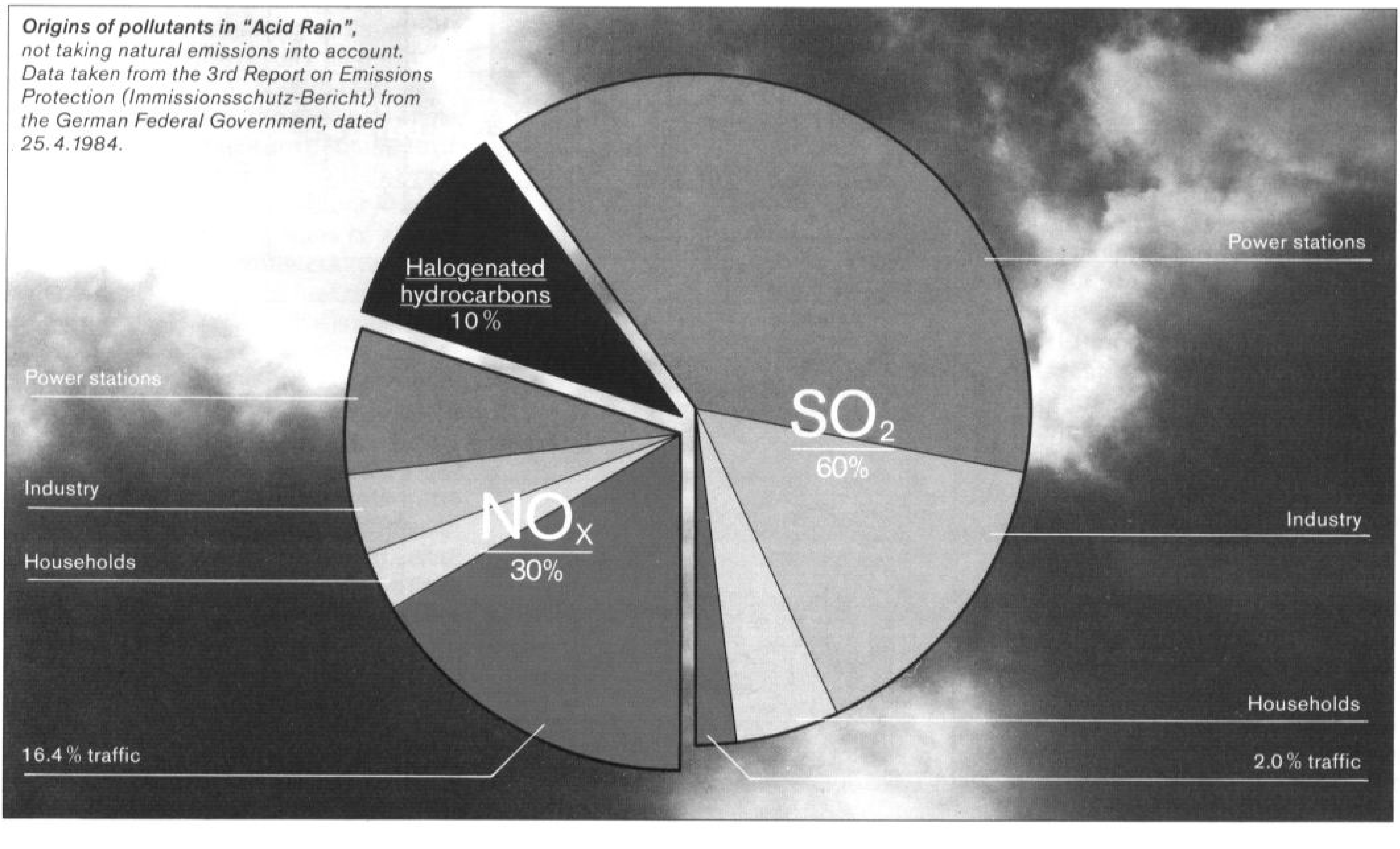


Origins of pollutants in "Acid Rain", *not taking natural emissions into account. Data taken from the 3rd Report on Emissions Protection (Immissionsschutz-Bericht) from the German Federal Government, dated 25.4.1984.*

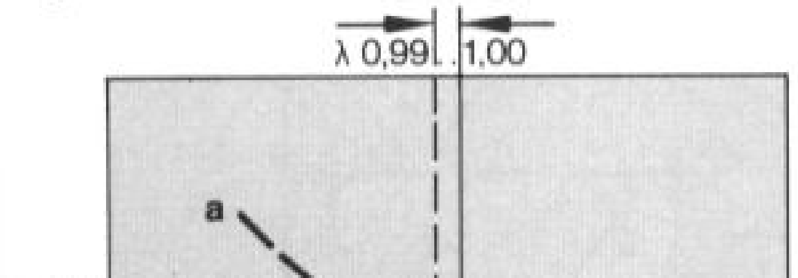
present in the exhaust gas to neutral nitrogen (N).

It is therefore perfectly clear that the catalytic aftertreatment of the exhaust gas is considerably more effective than for instance the purely thermal afterburning of the exhaust gases in a thermal reactor. Using a catalytic converter, more than 90 % of the toxic substances can be converted to harmless substances.

The three-way catalytic converter has come into widespread use (here, the term "3-way" means that all three toxic substances CO, HC, and NO_x are degraded at the same time). The converter shell contains a ceramic "honeycomb" which is coated with a precious metal, preferably with platinum and rhodium. When the exhaust gas flows through this honeycomb, the platinum and rhodium accelerate the chemical degradation of the toxic substances. Only lead-free gasoline may be used with such converters because the lead otherwise destroys the catalytic properties of the noble-metal catalyst. This means that lead-free gasoline is a prerequisite for the employment of catalytic converters. The catalytic conversion principle presupposes that the engine burns an optimum air-fuel mixture. Such an optimum, or stoichiometric, air-fuel mixture is characterized by the excess-air factor of $\lambda = 1.00$, and it is imperative that the excess-air factor is maintained precisely at this figure otherwise the catalytic converter cannot operate efficiently.

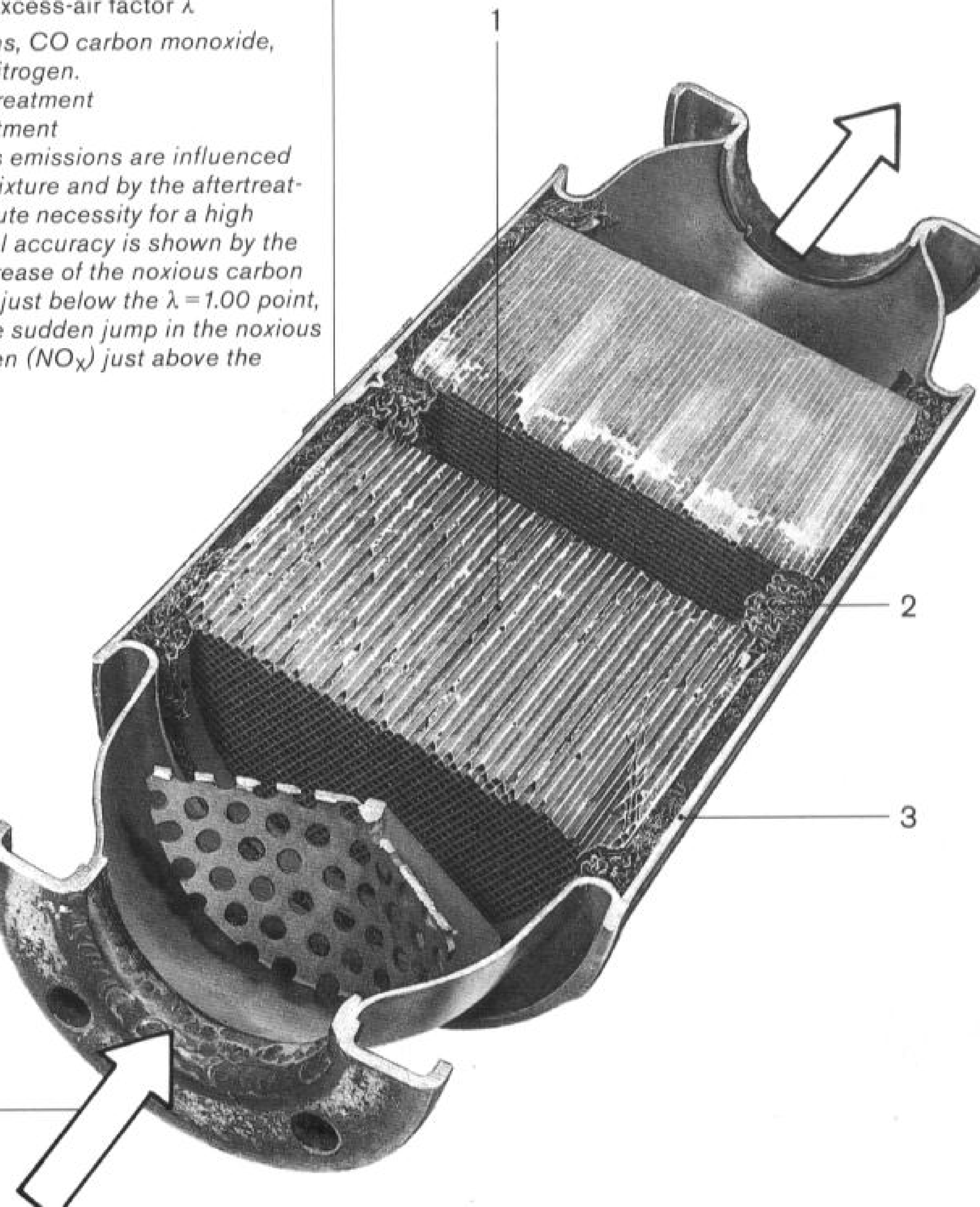
Even a deviation of only 1 % has considerable adverse effects upon the aftertreatment. But the best open-loop control is incapable of holding the air-fuel mixture within such close tolerances, and the only solution is to apply an extremely accurate closed-loop control, featuring almost zero lag, to the air-fuel mixture management system. The reason is that although an open-loop mixture control calculates and meters the required fuel quantity, it does not monitor the results. Here, one speaks of an open control loop. The closed-loop control of the mixture on the other hand measures the composition of the exhaust gas and uses the results to correct the calculated injected fuel quantity. This is referred to as a closed control loop. This form of control is particularly effective on fuel-injection engines because they do not have the additional delay times resulting from the long intake paths typical of carburetor engines.

43 **Effectiveness of the catalytic aftertreatment of exhaust gas using the Lambda closed-loop control.**



CH hydrocarbons, CO carbon monoxide, NO_X oxides of nitrogen.
a: without aftertreatment
b: with aftertreatment
The exhaust-gas emissions are influenced by the air-fuel mixture and by the aftertreatment. The absolute necessity for a high degree of control accuracy is shown by the pronounced increase of the noxious carbon monoxide (CO) just below the $\lambda = 1.00$ point, as well as by the sudden jump in the noxious oxides of nitrogen (NO_X) just above the $\lambda = 1.00$ point.

44) Cataytic converter
When exhaust gases flow through the catalytic converter, the chemical degradation of the noxious substances is accelerated particularly by the platinum and rhodium. 1 Ceramic material coated with catalytically active material, 2 Steel wool for locating purposes, 3 Converter shell.



Lambda closed-loop control

Lambda sensor

The Lambda sensor inputs a voltage signal to the ECU which represents the instantaneous composition of the air-fuel mixture.

The Lambda sensor is installed in the engine exhaust manifold at a point which maintains the necessary temperature for the correct functioning of the sensor over the complete operating range of the engine.

Operation

The sensor protrudes into the exhaust-gas stream and is designed so that the outer electrode is surrounded by exhaust gas, and the inner electrode is connected to the atmospheric air.

Basically, the sensor is constructed from an element of special ceramic, the surface of which is coated with microporous platinum electrodes. The operation of the sensor is based upon the fact that ceramic material is porous and permits diffusion of the oxygen present in the air (solid electrolyte). At higher temperatures, it becomes conductive, and if the oxygen concentration on one side of the electrode is different to that on the other, then a voltage is generated between the electrodes. In the area of stoichiometric air-fuel mixture (λ = 1.00), a jump takes place in the sensor voltage output curve. This voltage represents the measured signal.

Construction

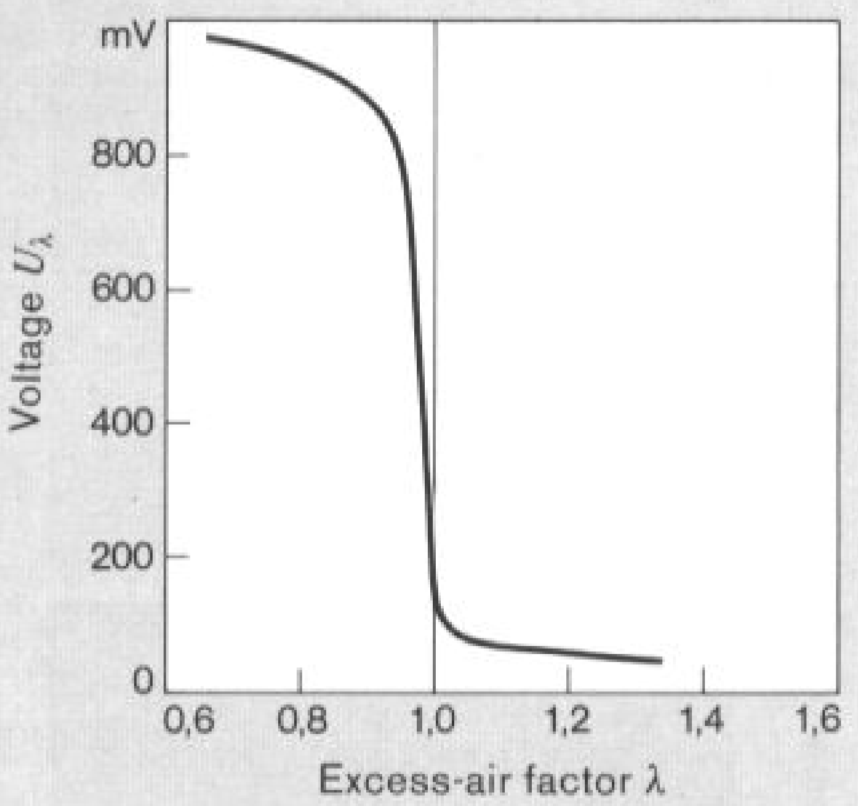
The ceramic sensor body is held in a threaded mounting and provided with a protective tube and electrical connections. The surface of the sensor ceramic body has a microporous platinum layer which on the one side decisively influences the sensor characteristic while on the other serving as an electrical contact. A highly adhesive and highly porous ceramic coating has been applied over the platinum layer at the end of the ceramic body that is exposed to the exhaust gas. This protective layer prevents the solid particles in the exhaust gas from eroding the platinum layer. A protective metal sleeve is fitted over the sensor on the electrical connection end and crimped to the sensor housing. This sleeve is provided with a bore to ensure pressure compensation in the sensor interior, and also serves as the support for the disc spring. The connection lead is crimped to the contact element and is led through an insulating sleeve to the outside of the sensor. In order to keep combustin deposits in the exhaust gas away from the ceramic body, the end of the exhaust sensor which protrudes into the exhaust-gas flow is protected by a special tube having slots so designed that the exhaust gas and the solid particles entrained in it do not come into direct contact with the ceramic body.

In addition to the mechanical protection thus provided, the changes in sensor temperature during transition from one operating mode to the other are effectively reduced.

The voltage output of the λ sensor, and its internal resistance, are dependent upon temperature. Reliable functioning of the sensor is only possible with exhaust-gas temperatures above 350 °C (unheated version), and above 200 °C (heated version).

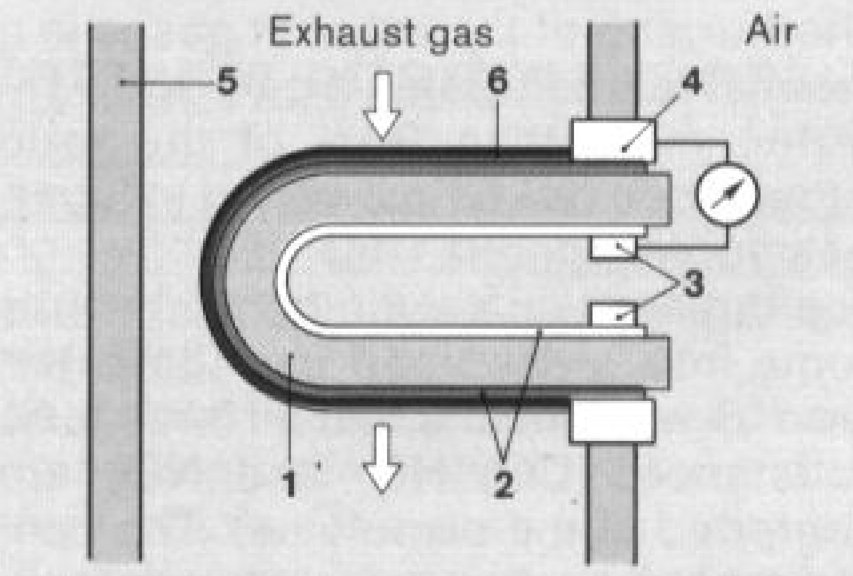
45

Voltage curve of the Lambda sensor at an operating temperature of 600 °C.



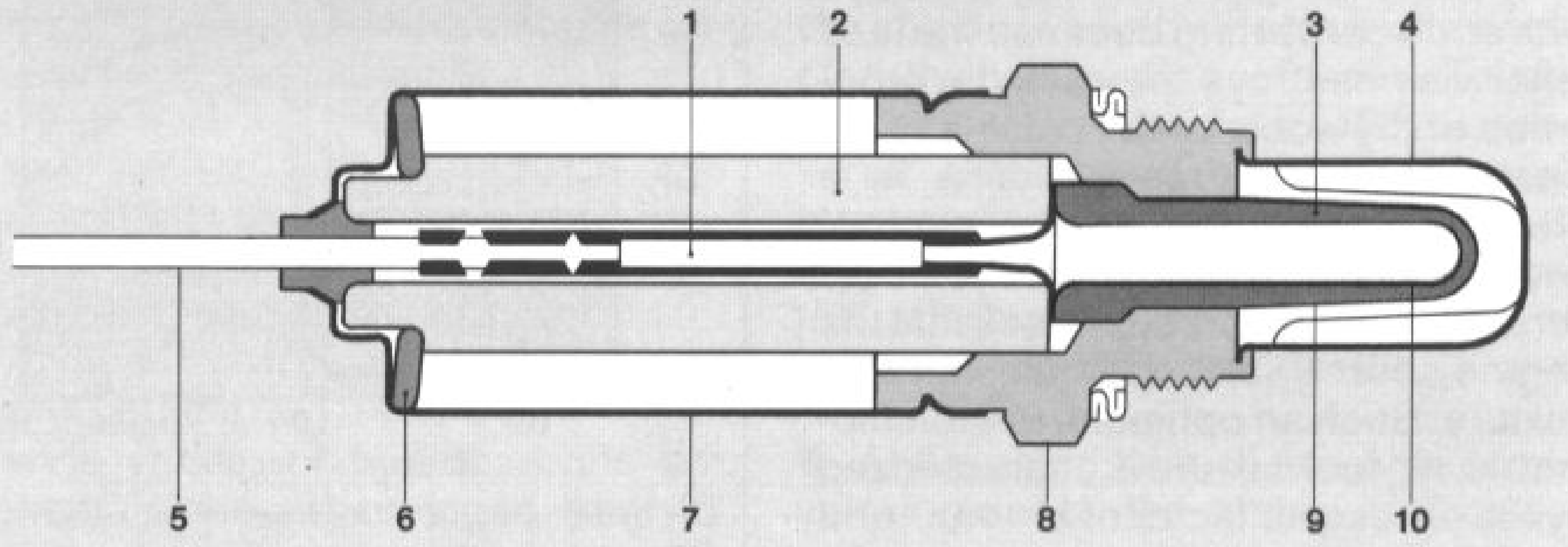
46

Location of the Lambda sensor in the exhaust manifold (shown schematically).
1 Sensor ceramic, 2 Electrodes, 3 Contacts, 4 Electrical contacting to the housing, 5 Exhaust manifold, 6 Protective ceramic layer (porous).



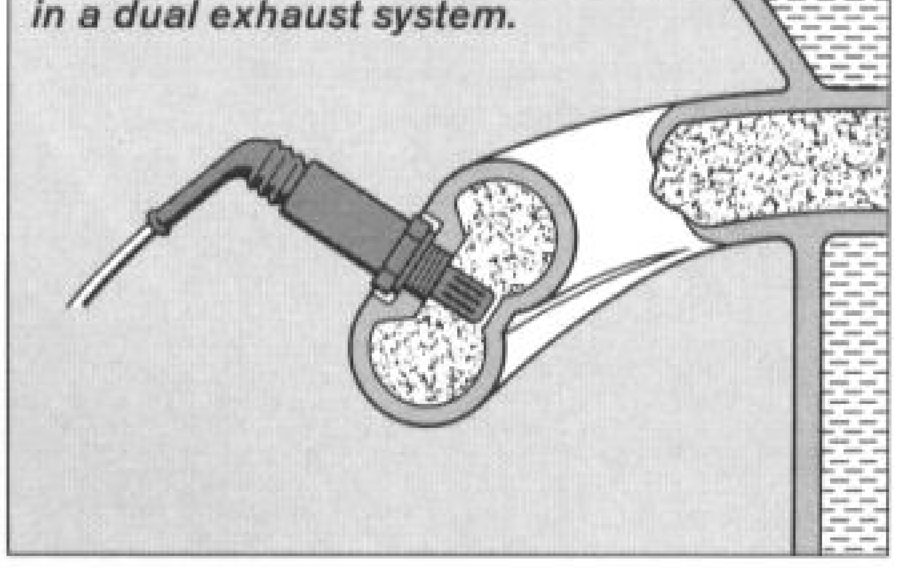
47

Lambda sensor.
1 Contact element, 2 Protective ceramic element, 3 Sensor ceramic, 4 Protective tube (exhaust end), 5 Electrical connection, 6 Disc spring, 7 Protective sleeve (atmosphere end), 8 Housing (−), 9 Electrode (−), 10 Electrode (+).



48

Positioning of the Lambda sensor in a dual exhaust system.



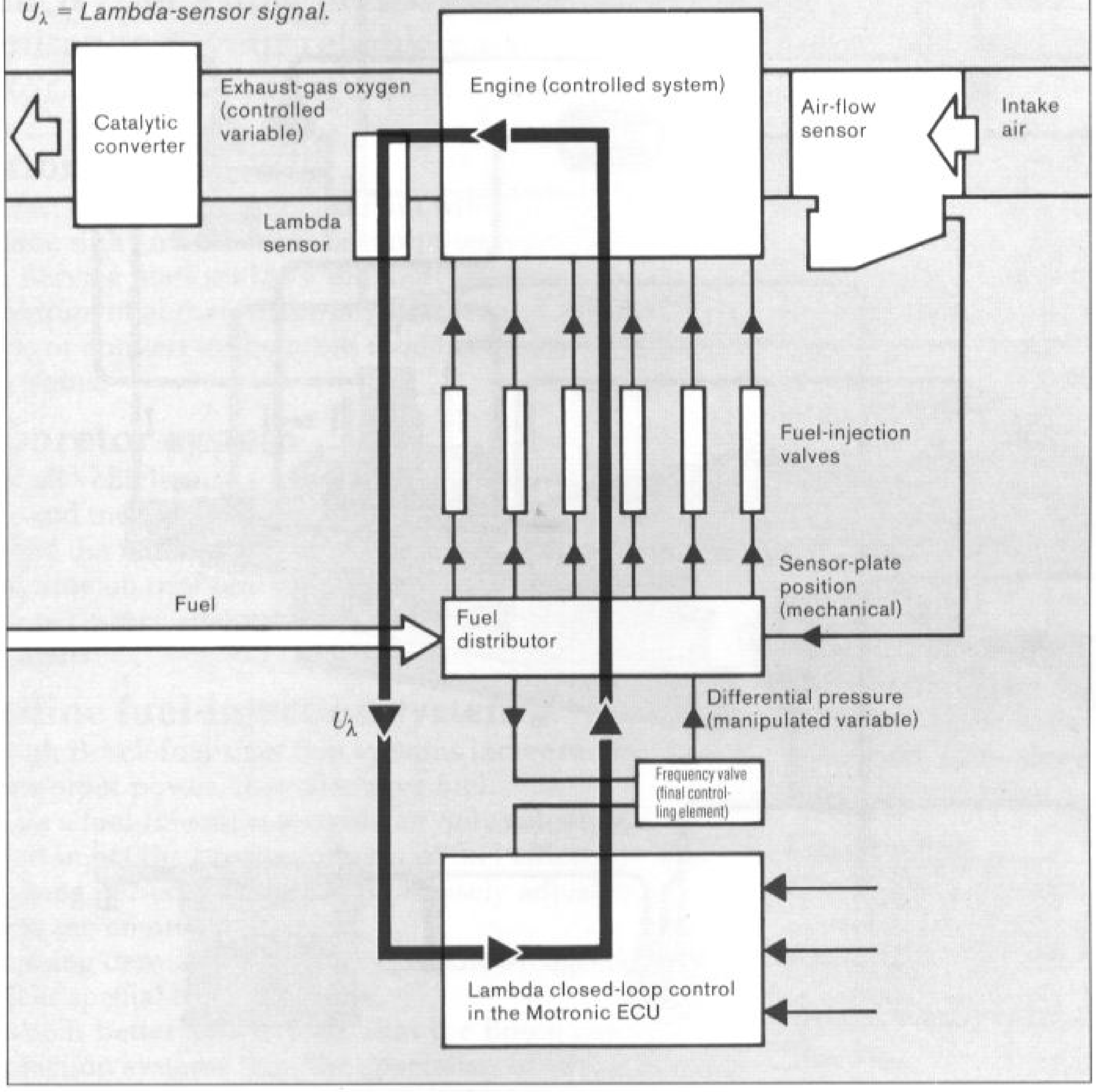
Heated Lambda oxygen sensor

To a large extent, the design principle of the heated Lambda sensor is identical to that of the unheated sensor.

The active sensor ceramic is heated internally by a ceramic heating element with the result that the temperature of the ceramic body always remains above the function limit of 250 °C.

The heated sensor is equipped with a protective tube having a smaller opening. Amongst other things, this prevents the sensor ceramic from cooling down when the exhaust gas is cold. Among the advantages of the heated Lambda sensor are the reliable and efficient control at low exhaust-gas temperatures (e.g. at idle), the minimum effect of exhaust-gas temperature variations, the rapid coming into effect of the Lambda control following engine start, short sensor-reaction which avoids extreme deviations from the ideal exhaust-gas composition, versatility regarding installation because the sensor is now independent of heating from its surroundings.

49 *Lambda closed control-loop.*
The Lambda closed control-loop is superimposed upon the air-fuel mixture control. The fuel quantity to be injected, as determined by the air-fuel mixture control, is modified by the Lambda closed-loop control in order to provide optimum combustion.
U_λ = Lambda-sensor signal.



Lambda closed-loop control circuit

By means of the Lambda closed-loop control, the air-fuel ratio can be maintained precisely at λ = 1.00.

The Lambda closed-loop control is an add-on function which, in principle, can supplement every controllable fuel-management system. It is particularly suitable for use with Jetronic gasoline-injection systems or Motronic. Using the closed-loop control circuit formed with the aid of the Lambda sensor, deviations from a specified air-fuel ratio can be detected and corrected. This control principle is based upon the measurement of the exhaust-gas oxygen by the Lambda sensor. The exhaust-gas oxygen is a measure for the composition of the air-fuel mixture supplied to the engine. The Lambda sensor acts as a probe in the exhaust pipe and delivers the information as to whether the mixture is richer or leaner than λ = 1.00.

In case of a deviation from this λ = 1.00 figure, the voltage of the sensor output signal changes abruptly. This pronounced change is evaluated by the ECU which is provided with a closed-loop control circuit for this purpose.

The injection of fuel to the engine is controlled by the fuel-management system in accordance with the information on the composition of the air-fuel mixture received from the Lambda sensor. This control is such that an air-fuel ratio of λ = 1 is achieved. The sensor voltage is a measure for the correction of the fuel quantity in the air-fuel mixture. The signal which is processed in the closed-loop control circuit is used to control the actuators of the Jetronic installation.

In the fuel-management system of the K-Jetronic (or carburetor system), the closed-loop control of the mixture takes place by means of an additional control unit and an electromechanical actuator (frequency valve).

In this manner, the fuel can be metered so precisely that depending upon load and engine speed, the air-fuel ratio is an optimum in all operating modes.

Tolerances and the ageing of the engine have no effect whatsoever. At values above λ = 1.00, more fuel is metered to the engine, and at values below λ = 1.00, less.

This continuous, almost lag-free adjustment of the air-fuel mixture to λ = 1.00, is one of the prerequisites for the efficient aftertreatment of the exhaust gases by the downstream catalytic converter.

Control functions at various operating modes

Start

The Lambda sensor must have reached a temperature of above 350 °C before it outputs a reliable signal. Until this temperature has been reached, the closed-loop mode is suppressed and the air-fuel mixture is maintained at a mean level by means of an open-loop control. Starting enrichment is by means of appropriate components similar to the Jetronic installations not equipped with Lambda control.

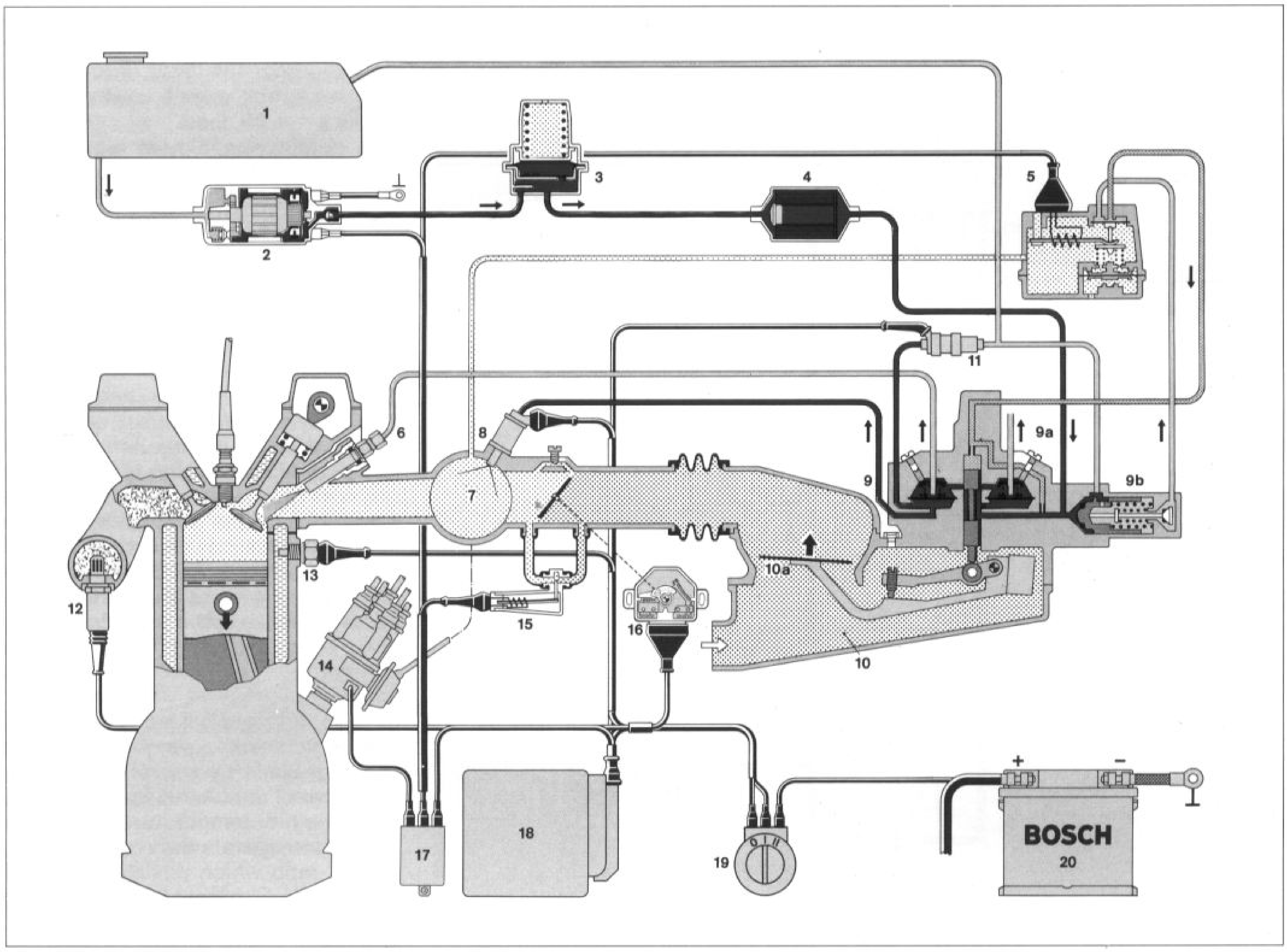
Acceleration and full load (WOT)

The enrichment during acceleration can take place by way of the closed-loop control unit. At full load, it may be necessary for temperature and power reasons to operate the engine with an air-fuel ratio which deviates from the λ = 1 figure. Similar to the acceleration range, a sensor signals the full-load operating mode to the closed-loop control unit which then switches the fuel-injection to the open-loop mode and injects the corresponding amount of fuel.

Deviations in air-fuel mixture

The Lambda closed-loop control operates in a range between λ = 0.8 ... 1.2, in which normal disturbances (such as the effects of altitude) are compensated for by controlling λ to 1.00 with an accuracy of ±1 %. The control unit incorporates a circuit which monitors the Lambda sensor and prevents prolonged marginal operation of the closed-loop control. In such cases, open-loop control is selected and the engine is operated at a mean λ-value.

Installation schematic



1 Fuel tank
2 Electric fuel pump
3 Fuel acumulator
4 Fuel filter
5 Warm-up regulator
6 Fuel-injection valve
7 Intake manifold
8 Solenoid-operated start valve
9 Mixture-control unit
9a Fuel distributor
9b Primary-pressure regulator
10 Air-flow sensor
10a Sensor plate
11 Frequency valve
12 Lambda sensor
13 Thermo-time switch
14 Ignition distributor
15 Auxiliary-air device
16 Throttle-valve switch
17 Control relay
18 Control unit
19 Ignition and starting switch
20 Battery