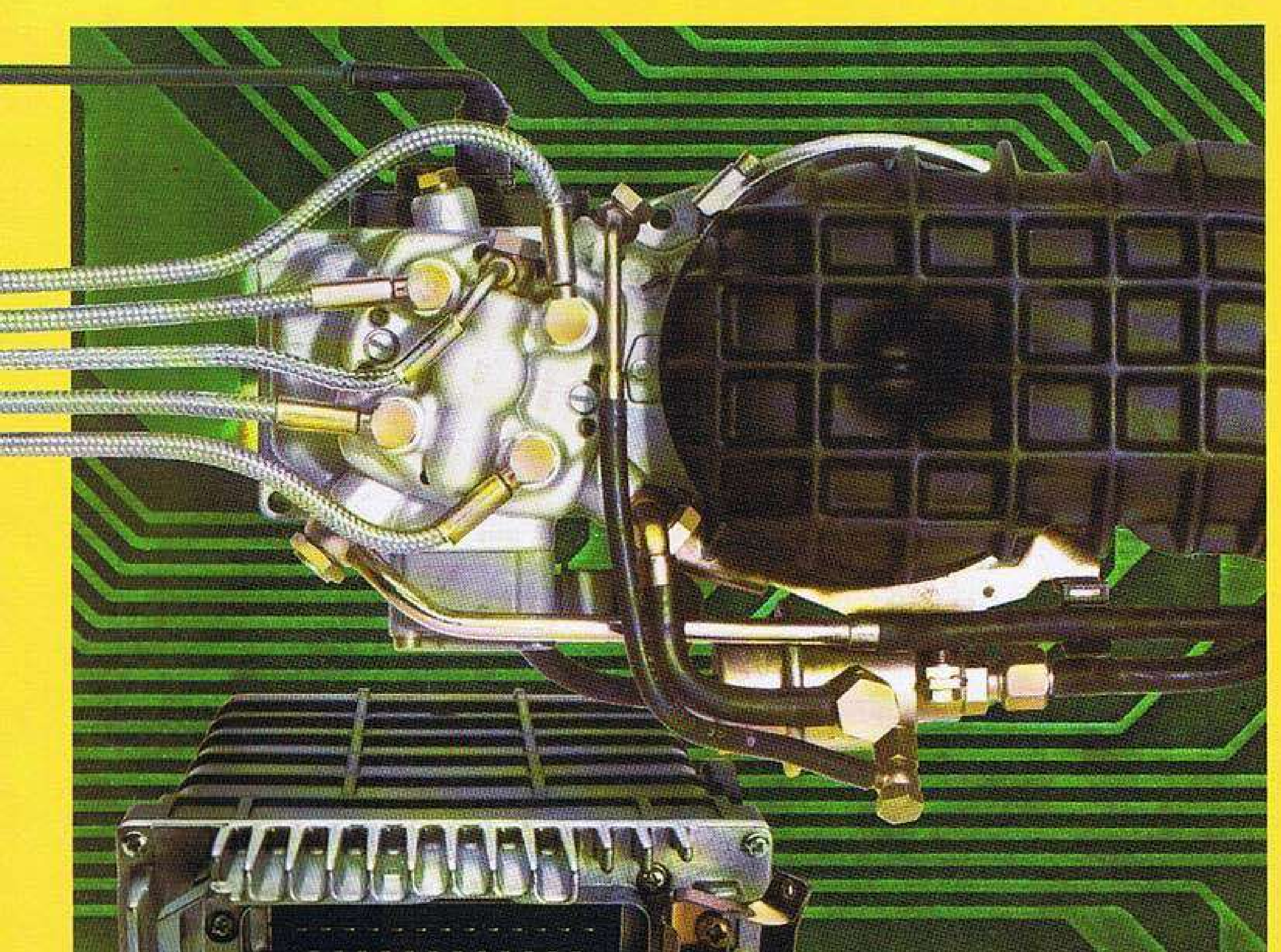
For catalytic converter operation

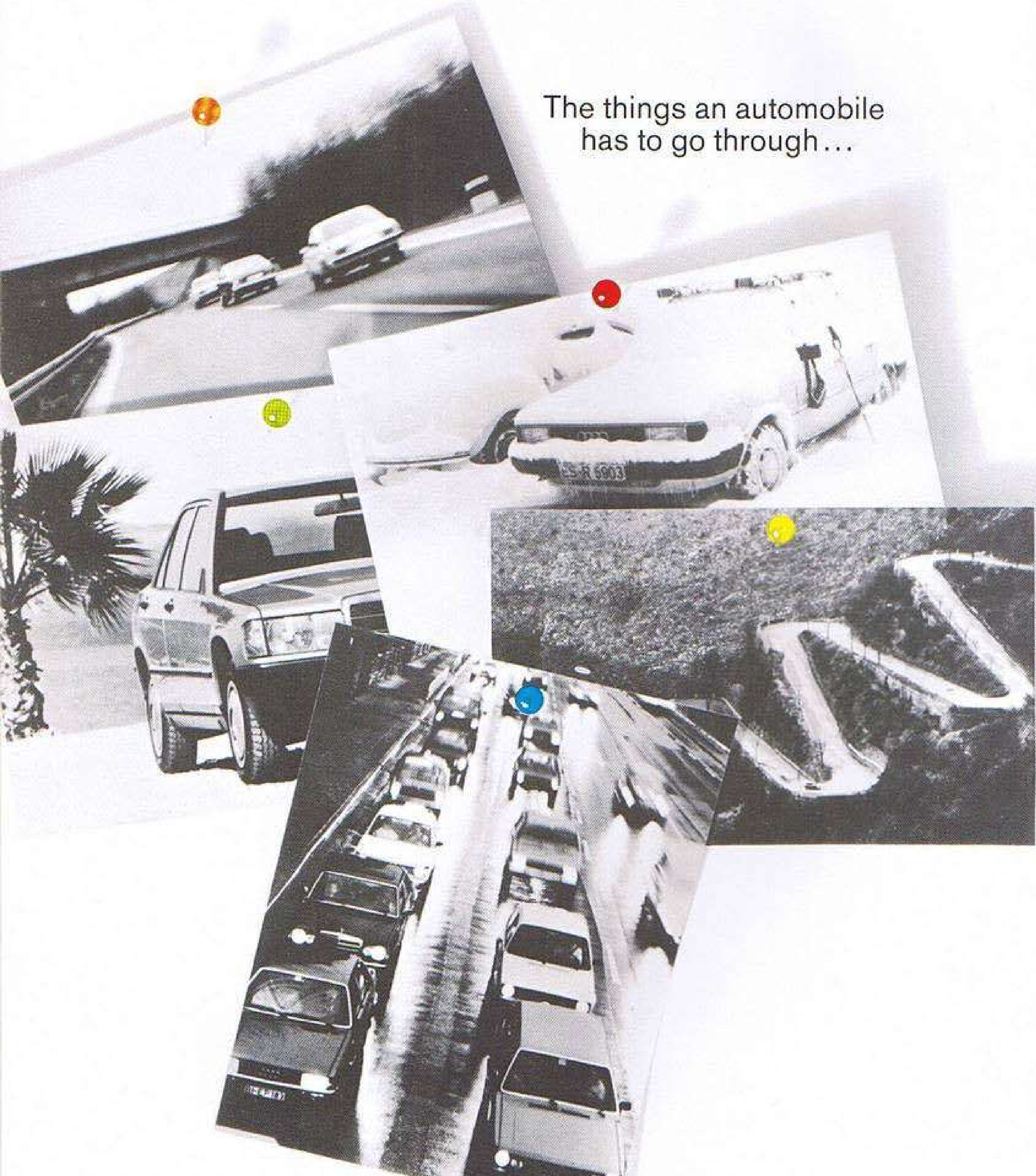
BOSCH

Electronically Controlled Gasoline Fuel-Injection System with Lambda Closed-Loop Control

KE-Jetronic



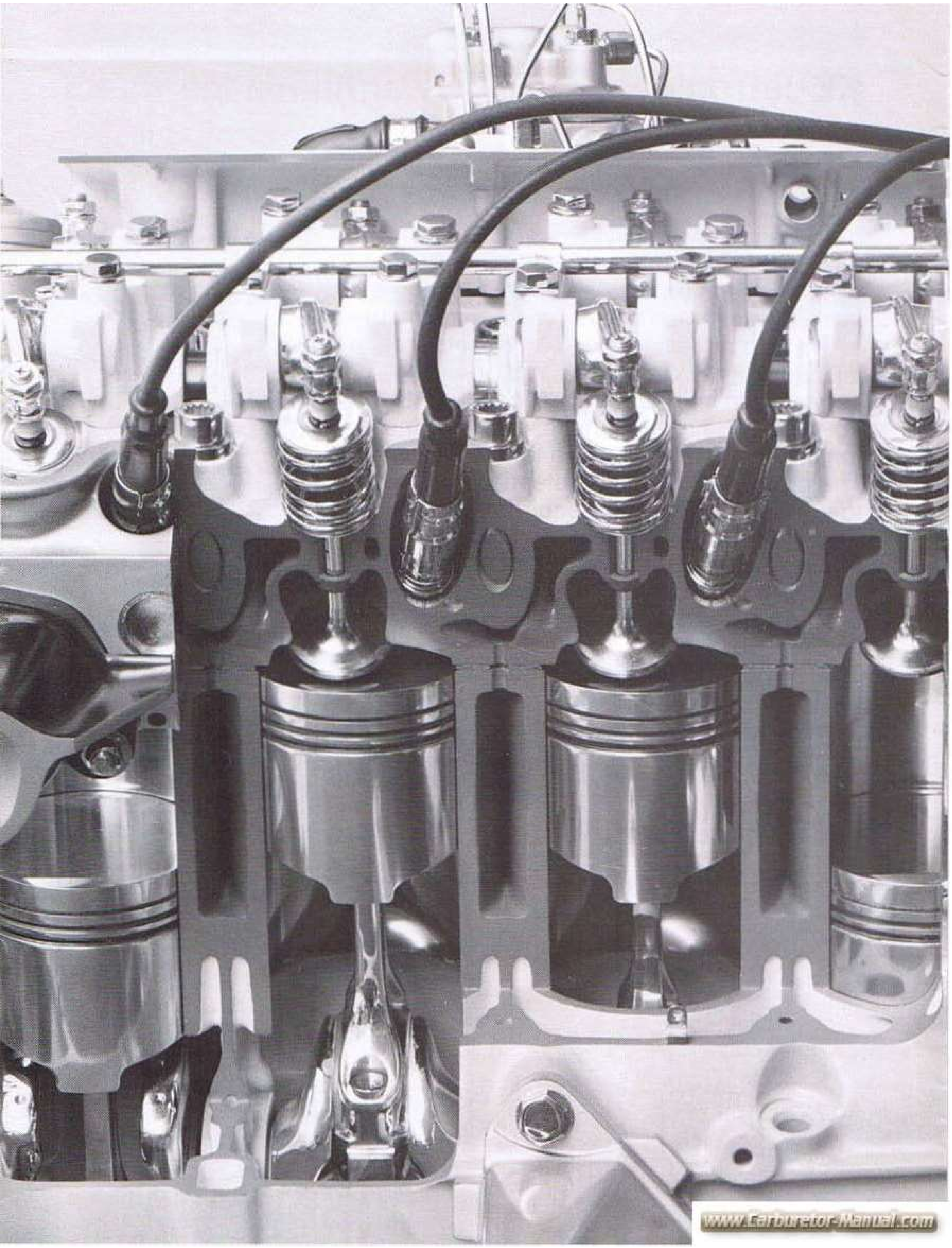
The things an automobile
has to go through…



KE-Jetronic

A gasoline injection system must inject precisely the correct amount of fuel for the various operating conditions. Whereas the increase in engine power was the main object at the start of development work on gasoline injection, today we are spurred on by the necessity to improve the fuel-consumption figures and to reduce the toxic emissions in the exhaust gas to as low a level as possible. The purely mechanical systems are not able to fulfill these stringent requirements. For this reason, the well-proven K-Jetronic was retained as the basic injection system but was uprated to a more intelligent and more efficient system by the addition of electronic circuitry.
This synthesis, comprising the mechanical basic functions coupled with electronic adaptation and optimization functions, is the KE-Jetronic.

The front cover shows the mixture-control unit together with the air-flow sensor, integral fuel distributor, electro-hydraulic pressure actuator, and electronic control unit (ECU).



The Spark-Ignition Engine

The spark-ignition engine, also known as the Otto-cycle engine*), is an engine with externally supplied ignition that converts the energy contained in the fuel into work.

In the spark-ignition engine, a fuel-induction system outside the combustion chamber forms an air-fuel mixture. This mixture, drawn in by the piston's downward (intake) stroke, flows into the combustion chamber. During the upward (compression) stroke of the piston this mixture is compressed, and timed external ignition from a spark plug initiates its combustion. The heat energy released by this combustion increases the compressed gas's pressure, and it is this combustion pressure which delivers the mechanical work through the piston and the crankshaft when the piston is forced downward again during its combustion (power) stroke.
After each combustion (power) stroke, the piston again reverses its direction and during its upward (exhaust) stroke forces out the burned gases. The 4-stroke cycle has now been completed, and begins again when the piston draws a fresh charge of air-fuel mixture into the combustion chamber during its next downward (intake) stroke. In motor vehicles, the gas cycle takes place predominantly using the 4-stroke cycle described above; one cycle taking place every two revolutions of the crankshaft.

1) left: Section through a spark-ignition engine fitted with KE-Jetronic (Photo: Daimler-Benz AG).

The 4-stroke cycle in detail

1st stroke: intake
2nd stroke: compression
3rd stroke: combustion (power)
4th stroke: exhaust
Control of the gas cycle in a 4-stroke spark-ignition engine is by means of valves which open the intake and exhaust passages in accordance with the camshaft position.

Intake stroke

Intake valve: open
Exhaust valve: closed
Piston movement: downward
Combustion: none
As it moves downward, the piston enlarges the cylinder volume and draws in fresh air-fuel mixture through the open intake valve.

Compression stroke

Intake valve: closed
Exhaust valve: closed
Piston movement: upward
Combustion: initial phase (ignition)
As it moves upward, the piston reduces the cylinder volume and compresses the air-fuel mixture. The compression ratio is in the order of between 8:1 and 12:1 depending upon engine design. The higher the compression, the higher the engine's thermal efficiency and the better the fuel is utilized. The compression ratio is limited by the engine's octane requirement (knocking limit). Knocking is the irregular, uncontrolled combustion of the ignited mixture accompanied by a large pressure increase. Knock leads to engine damage. By means of uniform air-fuel mixture distribution in the cylinder, and utilization of the flow effects in the intake passage, as well as appropriate combustion-chamber design, the knocking limit can be shifted to permit higher maximum compression ratios. Just before the piston reaches TDC, the spark plug ignites the compressed air-fuel mixture and initiates the combustion.

Combustion(power) stroke

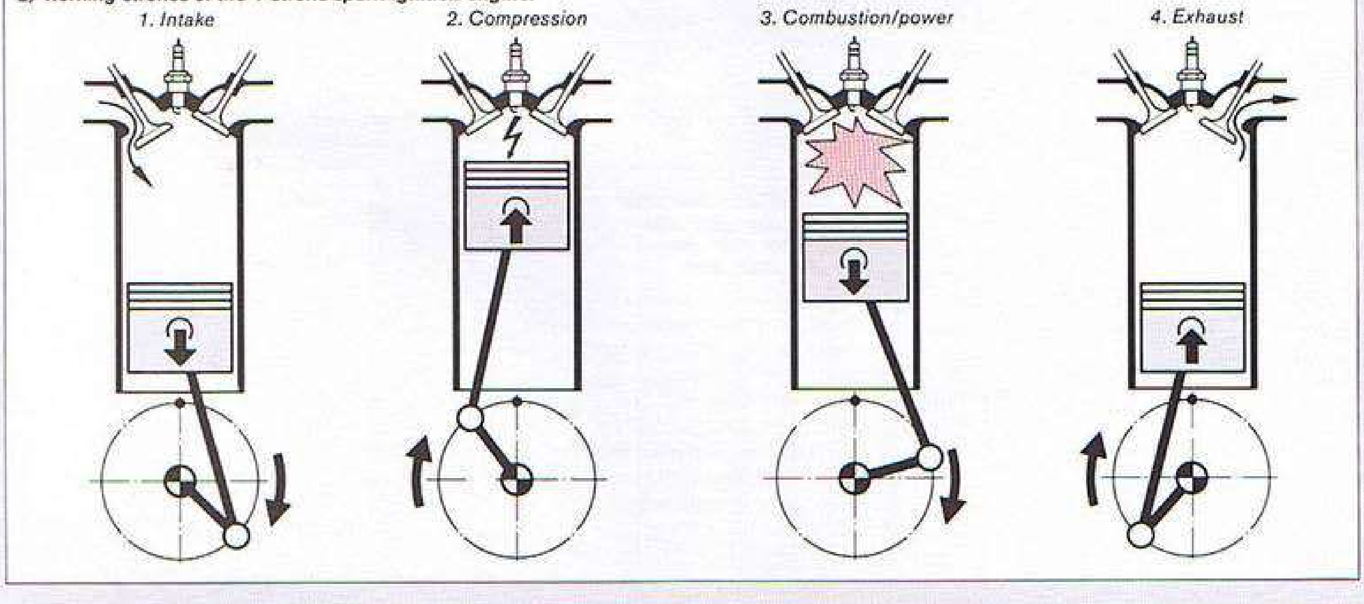
Intake valve: closed
Exhaust valve: closed
Piston motion: downward
Combustion: burn-through phase
After the spark plug has ignited the compressed air-fuel mixture, the temperature and the pressure increase rapidly. The pressure drives the piston downward, and delivers work to the crankshaft by way of the connecting rod. This work is available as engine power output. Power increases along with increasing engine speed, and for this reason it is necessary to use a gearbox to efficiently match the engine speed to the vehicle speed.

Exhaust stroke

Intake valve: closed
Exhaust valve: open
Piston motion: upward
Combustion: none
Moving upward, the piston forces out the burned (exhaust) gases through the open exhaust valve. After this fourth stroke, the cycle starts again. In practice, the valves' opening times overlap somewhat in order to utilize gas flow and hydrodynamic pulsations for better charging and purging of the cylinder.

*) Named after Nikolaus August Otto, 1832-1891. Otto showed the first gas engine with compression operating according to the 4-stroke principle at the 1878 Paris World's Fair.

2) Working strokes of the 4-stroke spark-ignition engine.



Fuel management

Air-fuel mixture

The spark-ignition engine requires a specific air-fuel ratio for its operation. The theoretical air-fuel ratio is 14.7:1. Correction of the air-fuel ratio is required for the various operating conditions.

The specific fuel consumption of a spark-ignition engine is dependent principally upon the air-fuel ratio. Theoretically, for full combustion and therefore minimum fuel consumption, the greatest possible amount of excess air would be desirable; but for reasons of flammability and the limited time available for combustion, this is not possible. For contemporary engines, maximum fuel economy occurs at an air-fuel ratio of approximately 15 ... 18 kg air to 1 kg fuel. In other words, some 10,000 liters of air are necessary for the combustion of 1 liter of fuel. The chemical minimum for complete combustion is termed the stoichiometric ratio, and is 14.7:1.
Because vehicle engines are operated most of the time at part load, they are designed for maximum fuel economy in this range. For the other operating conditions, such as idle and full load, mixtures are called for that are richer in fuel. The fuel-management system must be able to meet these varying requirements.

Air ratio

To indicate how far the actual air-fuel ratio deviates from the theoretical (14.7:1), the air ratio, denoted by the Greek letter λ (Lambda) has been chosen:

$$\lambda = \frac{\text{actual inducted air quantity}}{\text{theoretical air requirement}}$$

$\lambda = 1$
The actual inducted air quantity equals the theoretical air requirement.

$\lambda < 1$
Shortage of air, or mixture too rich, increased power at $\lambda = 0.85 \ldots 0.95$.

$\lambda > 1$
Excess air, or lean mixture at $\lambda = 1.05 \ldots 1.3$, reduced fuel consumption and reduced power.

$\lambda > 1.3$
The mixture will no longer ignite, the misfire limit has been exceeded.

$\lambda = 0.95 \ldots 0.85$
Spark-ignition engines develop their maximum power at 5 ... 15% air shortage.

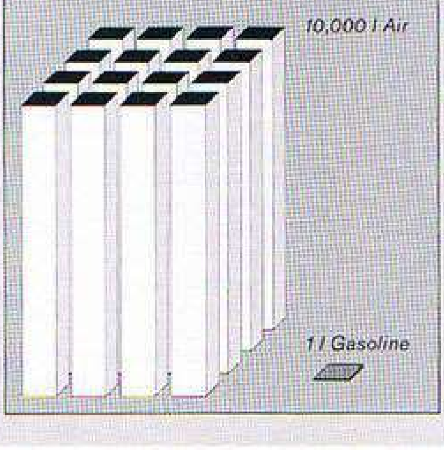
$\lambda = 1.1 \ldots 1.2$
Maximum fuel economy occurs at about 20% excess air.

λ approx. 1.0
Perfect idle operation at stoichiometric ratio.

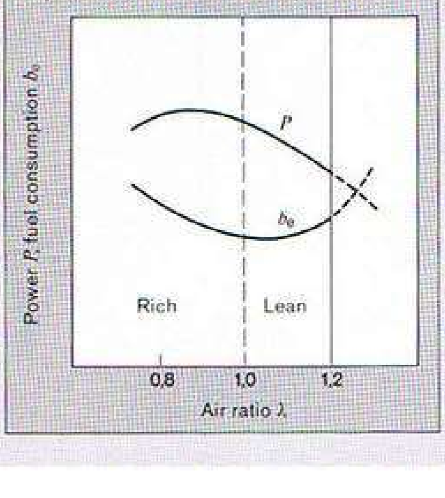
$\lambda = 0.85 \ldots 0.75$
Good transitions at 15 ... 25% air shortage. "Transition" is defined as the change from a given load range to another. For instance, from idle to part or full load. Good transition is usually synonymous with good acceleration.
The illustrations show the dependence of power, specific fuel consumption, and pollutants emission on the air ratio. As can be seen, there is no single optimum air ratio at which all factors are ideal.

$\lambda = 0.9 \ldots 1.1$
In practice, air ratios of $\lambda = 0.9 \ldots 1.1$ have proved to be the most practical.

3) Stoichiometric air-fuel ratio for ideal combustion.



4) Influence of the air ratio (λ) on power (P) and fuel consumption (b_e).



Fuel-Management Systems

Fuel-management systems, whether of the carburetor or fuel-injection type, have the task of producing the best-possible air-fuel mixture for the particular operating conditions of the engine.

The carburetor or the fuel-injection system prepares the air-fuel mixture for the spark-ignition engine. During the last few years, the trend has become stronger towards manifold fuel-injection. This trend is supported by the advantages offered by fuel injection in connection with the demands for economy, efficiency, excellent driveability, and low-pollution exhaust gas.
The reasons for these advantages lie in the fact that manifold injection permits extremely precise metering of the fuel as a factor of the operating and loading conditions of the engine, while at the same time taking environmental condiderations into account. In the process, the composition of the mixture is controlled so precisely that the pollutant level in the exhaust gas remains low. Furthermore, the allocation of an injection valve to each cylinder results in improved distribution of the mixture. Since the carburetor can be dispensed with, this means that the induction paths can be designed to achieve the best-possible charging of the cylinder with air-fuel mixture. This leads to a higher torque.

Mechanical fuel-injection systems

The K-Jetronic is today the most widespread mechanical fuel-injection system. It requires no drive, and injects the fuel continuously. The K-Jetronic system is described in detail in the booklet "K-Jetronic" in the Bosch Technical Instruction series.

Combined mechanical-electronic fuel-injection system

The basic mechanical system from the K-Jetronic serves as the basis for the KE-Jetronic. Due to the extended processing of operational data, electronically controlled auxiliary functions were incorporated to adapt the injected fuel quantity to the various engine operating conditions.

Electronic fuel-injection systems

The L-Jetronic and its variants are electronically controlled fuel-injection systems. Solenoid-operated injection valves meter the fuel intermittently to the intake ports. The system is described in the booklet "L-Jetronic" in the Bosch Technical Instruction series.

Combined ignition system and fuel-injection system "Motronic"

Gasoline injection systems can only provide the answers to some of the problems. In order to improve the overall combustion process, the ignition point must also be adapted to the engine operating conditions. The Motronic combines the ignition system and the fuel-injection system, both of which are controlled by a single computer in accordance with common optimization criteria. For more details, refer to the booklet "Motronic" in the Bosch Technical Instruction series.

Advantages of fuel injection

- Increased fuel economy

With a carburetor, or carburetors, the air-fuel mixtures arriving at the individual cylinders are different due to the air-fuel separation which occurs in the respective intake passages. By forming a mixture that provides even the most unfavorably located cylinder with sufficient fuel, the typical carburetor meters too much fuel overall. Apart from this, during load changes a film of fuel is deposited on the intake-passage walls which is subsequently vaporized again. This leads to further unwanted variations in the mixtures arriving at the cylinders, and the result is excessive fuel consumption and uneven cylinder loading. On the other hand, both the K- and L-Jetronic systems allocate an individual injection valve to each cylinder.
These valves are centrally controlled, and this ensures that all cylinders are provided with the same, precisely controlled fuel quantity at all times and under all conditions. No more and no less than is absolutely necessary.

- Higher power output

Jetronic fuel-injection systems permit optimum intake-passage design, and by virtue of the improved cylinder filling this provides higher torque. The overall results are higher specific power output and a torque curve which better satisfies practical driving requirements.

- Immediate throttle response

Jetronic systems respond to changing load conditions virtually without any lag at all, because the injection valves inject the fuel directly at the engine's intake valves.

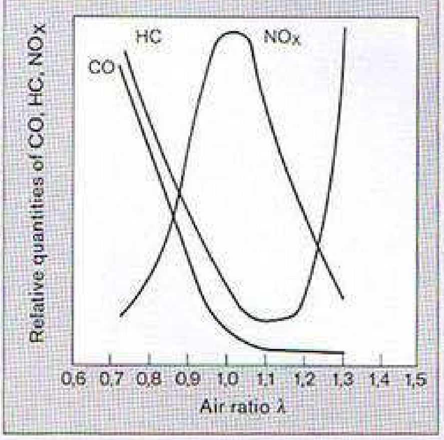
- Improved cold start and warm-up

Due to the precise metering of the fuel in accordance with the engine temperature and the cranking speed, starting times are short and the run-up to idle speed presents no problems.
During warm-up, the precise adaptation of the injected fuel quantity results in smooth running and immediate throttle response along with minimum fuel consumption.

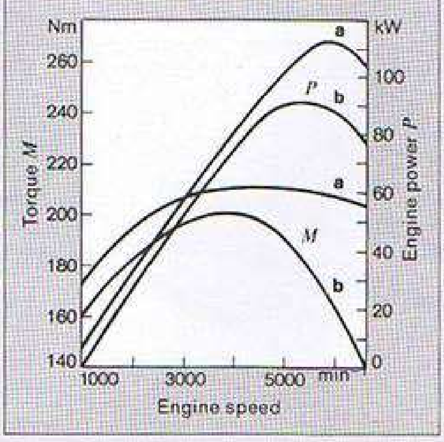
- Low exhaust emissions

The pollutant concentrations in the exhaust gas are directly related to the air-fuel ratio. If one wants to operate the engine at the minimum emissions point, the fuel-management system must be capable of exactly maintaining the corresponding air-fuel ratio. The K- and L-Jetronic systems are so accurate that they provide the precision of mixture control which is necessary to comply with the particular emission regulations.

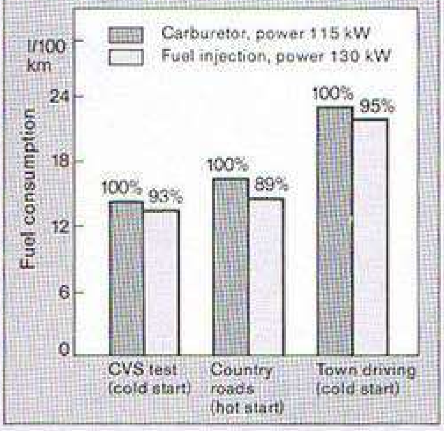
5) Influence of the air ratio (λ) on the exhaust-gas composition.



6) Power and torque curves. a = with Jetronic, b = with carburetor



7) Fuel consumption. Comparison between Jetronic and carburetor-powered engines.



The KE-Jetronic gasoline injection system

System overview

A mechanical hydraulic injection system provides the basis for the KE-Jetronic the same as it does for the K-Jetronic (see the publication "K-Jetronic" from the Bosch Technical Instruction series). The stream of air drawn in by the engine deflects a sensor plate, which in turn controls the fuel-metering plunger. Depending upon its position, this plunger opens or closes the fuel-metering slits. The basic function of the KE-Jetronic is to meter the fuel to the engine dependent upon the quantity of air drawn in by the engine (the main actuating variable). But in contrast to the K-Jetronic, the KE-Jetronic also takes a number of additional engine operating data into account by means of sensors. The output signals from these sensors are processed by an electronic control unit (ECU) which controls an electrohydraulic pressure actuator which adapts the injected fuel quantity to the various operating conditions. In case of malfunction, the KE-Jetronic operates solely with the basic function, and the driver then has a system at his disposal which provides good limp-home capabilities when the engine is warm.

Advantages of the KE-Jetronic

Lower fuel-consumption

With conventional fuel-management systems, the differences in the lengths of the intake ports result in different air-fuel mixtures at the individual cylinders. With the KE-Jetronic, each cylinder is allocated its own fuel-injection valve which injects continually onto the intake valve. The injected fuel vaporizes and mixes intensively with the air drawn in by the piston. This means that in addition to the precise metering, the fuel is evenly distributed between the individual engine cylinders. Being as the intake manifolds only serve to carry the intake air to the cylinders, the condensation of the fuel on the manifold walls, a phenomenon in conventional systems which increases the fuel consumption, is practically ruled out. The KE-Jetronic system ensures that considerably less fuel is used particularly during the warm-up phase, during acceleration enrichment, at full-load, and during overrun when it switches off the fuel supply.

Rapid adaptation to operating conditions

The fuel requirement differs greatly from the normal figures during the poststart period, during warm-up, and during acceleration and full-load. By means of commands received from its ECU, the KE-Jetronic intervenes in the preparation of the air-fuel mixture and increases or decreases the injected fuel quantity accordingly. The KE-Jetronic system incorporates additional sensors for the registration of the engine temperature, the throttle-valve position (load signal), and the sensor-plate deflection (corresponds approximately to the change in engine power over time). With the aid of these sensors, the ECU commands the hydraulic pressure actuator to either "lean-off" the mixture or "richen" it as appropriate. The KE-Jetronic responds rapidly to the variations in engine operating conditions, and improves the torque characteristics as well as the engine flexibility. This results in distinct advantages when driving at energy-efficient low engine speeds and in as high a gear as possible, and also in an improvement of driveability. Reliable starting is another of the outstanding features of the KE-Jetronic.
The overrun fuel cut-off responds to engine speed and temperature and cuts off the supply of fuel during deceleration. There are no unpleasent jerks when the fuel supply cuts back in again. This system results in a reduction of the fuel consumption and, being as combustion ceases during fuel cut-off, there is no emission of toxic exhaust gases.

Cleaner exhaust gases

The prerequisite for minimum pollutants in the exhaust gas is the practically complete combustion of the fuel. The KE-Jetronic supplies each cylinder with precisely that amount of fuel which is appropriate for the particular engine operating condition and for changes in loading. For instance, the required air-fuel mixture is precisely maintained at the level necessary for minimum toxic emissions by reducing the post-start enrichment as soon as possible, or by the rapid response of the acceleration enrichment. Further improvements in the exhaust gas can be achieved by employing the Lambda closed-loop control together with exhaust-gas aftertreatment using a catalytic converter.

Higher power output per liter

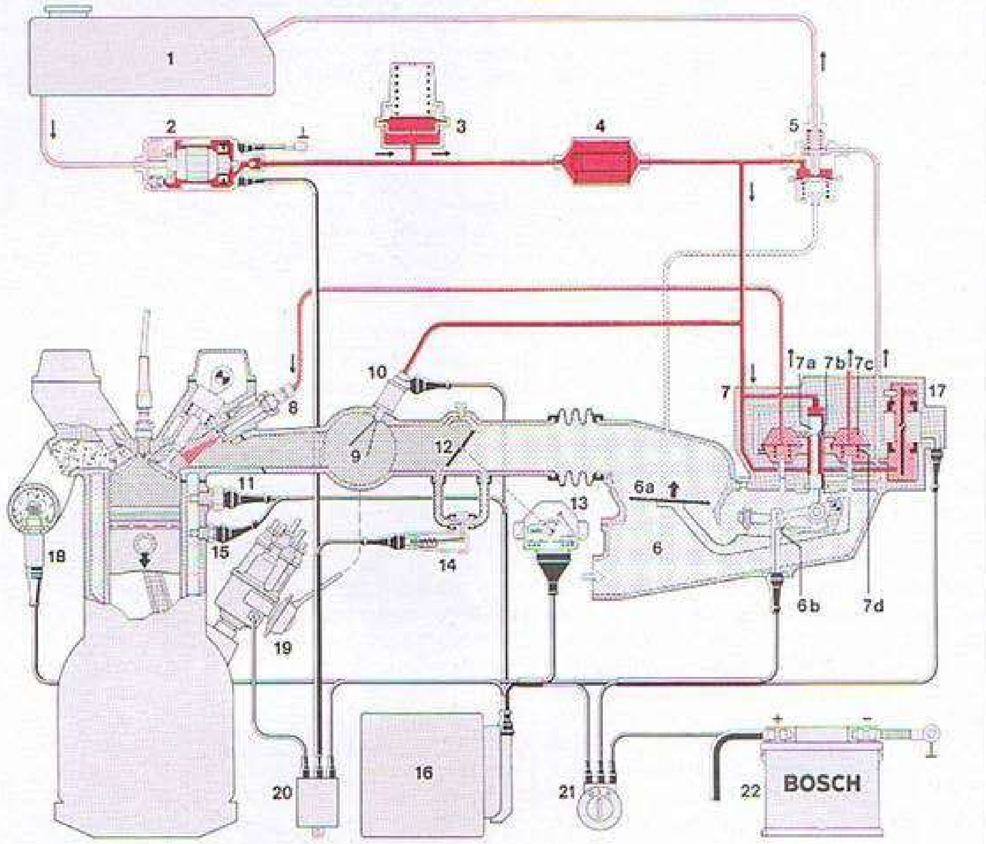
The efficiently designed air-intake system of the KE-Jetronic permits an increase in power due to improved cylinder charge. The fuel-injection paths are shorter, with the result that there are no flat spots when acceleration is needed. Similar to all the other Jetronic systems, the KE-Jetronic achieves a pronounced increased in engine power for the same piston displacement, but not at the cost of increased fuel consumption. It allows economical engines to be designed which feature high power-output per liter, while at the same time displaying good flexibility coupled with excellent driveability.

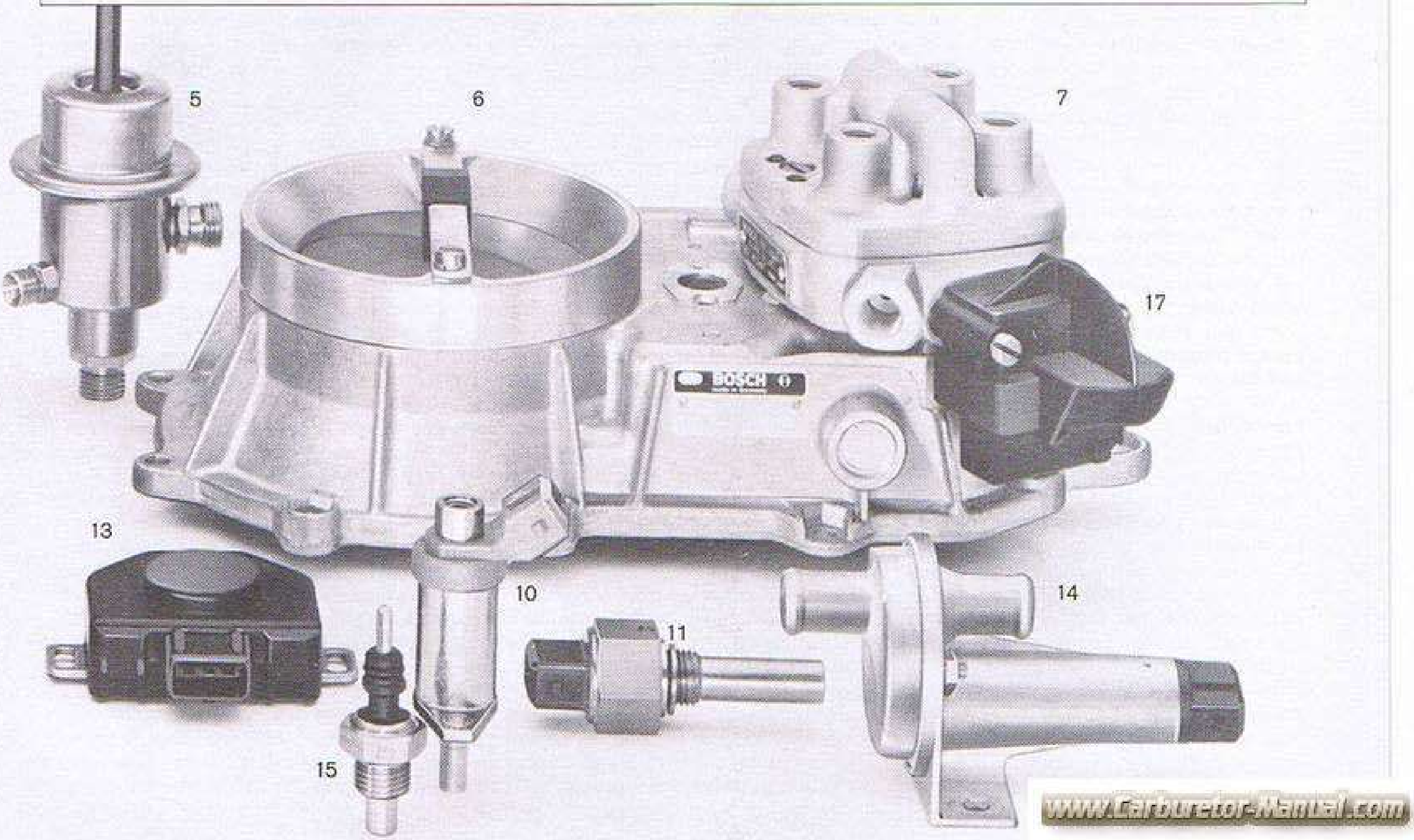
8) KE-Jetronic components
See Fig. 9 for key to numbers

9) KE-Jetronic system overview

- Primary pressure
- Injection pressure
- Pressure in upper chamber
- Pressure in lower chamber
- Atmospheric pressure
- Intake-manifold pressure
- Suction line or return

1 Fuel tank
2 Electric fuel pump
3 Fuel accumulator
4 Fuel filter
5 Primary-pressure regulator
6 Air-flow sensor
6a Sensor plate
6b Potentiometer
7 Fuel distributor
7a Control plunger
7b Control edge
7c Upper chamber
7d Lower chamber
8 Fuel-injection valve
9 Intake manifold
10 Start valve
11 Thermo-time switch
12 Throttle valve
13 Throttle-valve switch
14 Auxiliary-air device
15 Engine-temperature sensor
16 Electronic control unit (ECU)
17 Electro-hydraulic pressure actuator
18 Lambda sensor
19 Ignition distributor
20 Control relay
21 Ignition/starting switch
22 Battery





Basic functions

Fuel supply

The fuel system consists of an electric fuel pump, fuel accumulator, fuel filter, and primary-pressure regulator

The KE-Jetronic fuel system differs only slightly from that of the familiar K-Jetronic. An electric roller-cell pump feeds fuel from the tank to the pressure accumulator at a pressure of 5.4 bar, and from there through the fuel filter to the fuel distributor (in some cases, the pressure is even higher, e.g. 5.5 ... 6.5 bar). The primary-pressure regulator maintains the supply pressure in the system constant, and returns the surplus fuel to the tank. Due to the constant flow of fuel through the fuel-supply system, cool fuel is always available. This prevents the formation of vapor bubbles and ensures good hot-starting properties.

Electric fuel pump

The electric fuel pump draws the fuel out of the tank and delivers it to the fuel distributor.

The fuel pump itself is an electrically driven roller-cell pump. It is self-priming, and is fitted in a common housing together with the permanent-magnet electric motor (Fig. 10). The motor is cooled by the fuel which permanently surrounds it and the pump.

The fuel pump always delivers more fuel than the engine needs, so that there is always sufficient pressure in the fuel system under all conditions.

The roller-cell pump itself consists of a hollow cylindrical chamber in which the eccentric rotor plate rotates. The rollers ride in grooves located around the rotor's periphery, and the centrifugal force resulting from rotation forces them outwards so that they function as seals. The pumping action takes place when the rollers, after having closed the inlet bore, force the trapped fuel around in front of them until it can escape from the pump through the outlet bore (Fig. 11). A non-return valve in the pump (Fig. 10) prevents fuel from flowing back to the tank, as well as decoupling the fuel system from the tank.

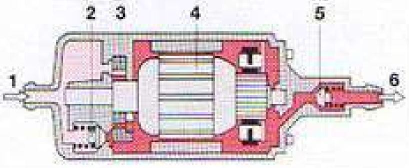
Fuel filter

The fuel filter keeps impurities in the fuel out of the primary-pressure regulator, the fuel distributor, and the injection valves.

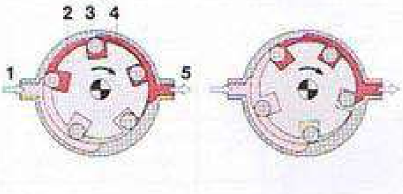
It contains a paper element with a medium pore size of 4 µm, which is backed up by a fluff strainer (Fig. 12). This combination ensures a high degree of filtration. A support plate secures the filter in its metal housing. Filter life is dependent upon fuel cleanliness.

The filter is installed in the fuel line downstream of the fuel accumulator (Fig. 9). When the filter is changed, it is imperative that the throughflow direction as indicated by the arrow on the housing is complied with.

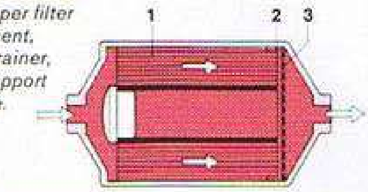
10) Electric fuel pump
1 Suction side, 2 Pressure limiter, 3 Roller-cell pump, 4 Motor armature, 5 Non-return valve, 6 Pressure side.



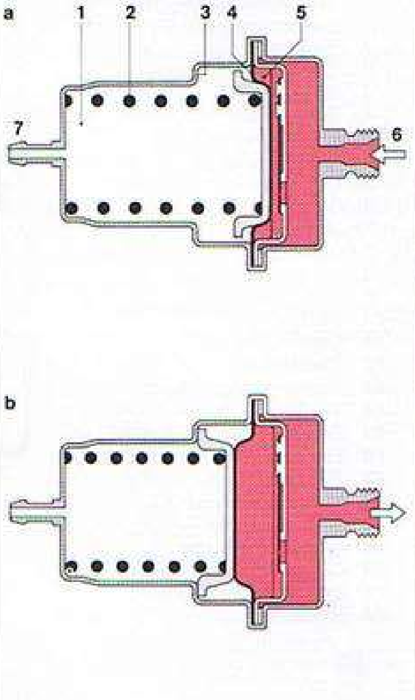
11) Operation of roller-cell pump
1 Suction side, 2 Rotor plate, 3 Roller, 4 Roller race plate, 5 Pressure side.



12) Fuel filter
1 Paper filter element, 2 Strainer, 3 Support plate.



13) Fuel accumulator
a: empty, b: full
1 Spring chamber, 2 Spring, 3 Stop, 4 Diaphragm, 5 Accumulator volume, 6 Fuel inlet or outlet, 7 Connection to the atmosphere.



Fuel accumulator

The fuel accumulator maintains the pressure in the fuel system for a certain time after the engine has been switched off.

After switch-off, the fuel accumulator maintains the pressure in the fuel system in order to facilitate restarting, particularly when the engine is hot. The design of the accumulator housing is such that it deadens the sound of 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 for the fuel, while the other represents the compensation volume and is connected to the atmosphere, by means of a vent fitting, either directly or through the fuel-tank ventilation system. During operation, the accumulator chamber is filled with fuel and the diaphragm is caused 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.

The fuel pump starts to pump as soon as the ignition/start switch is turned, and continues to run when the engine starts. A safety circuit prevents pumping when the ignition is on and the engine stationary. For example after an accident. The pump is mounted in the immediate vicinity of the fuel tank and is maintenance-free.

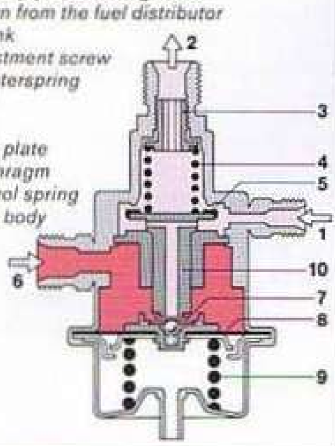
Primary-pressure regulator

The primary-pressure regulator maintains the supply pressure constant.

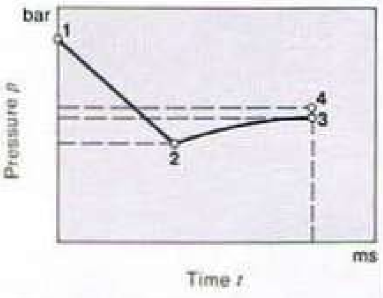
In contrast to the K-Jetronic, in which a warm-up regulator regulates the control pressure, the hydraulic counterpressure acting upon the control plunger in the KE-Jetronic (see Page 11), is identical to the primary pressure. The control pressure must be held constant, even when fuel delivery from the supply pump, and injected fuel quantity, vary considerably. This is due to the fact that any variation of the control pressure has a direct effect upon the air-fuel ratio.

Fig. 14 shows a section through the pressure regulator. The fuel enters on the left, and on the right is the return fuel connection from the fuel distributor. The return line to the tank is connected at the top. When the fuel pump starts, it generates pressure and this forces the control diaphragm of the pressure accumulator

14) Primary-pressure regulator.
1 Return from the fuel distributor
2 To tank
3 Adjustment screw
4 Counterspring
5 Seal
6 Inlet
7 Valve plate
8 Diaphragm
9 Control spring
10 Valve body



15) Pressure curve after engine switch-off.
First of all, the pressure drops from the normal primary pressure (1) to the closing pressure of the pressure regulator (2). It then climbs again, due to the effect of the fuel accumulator, to the value (3) which is still below the injection-valve opening pressure (4).



downward. The pressure of the counterspring forces the valve body to follow the diaphragm until, after a very short distance, it comes up against a stop and the pressure-control function starts. The fuel returning from the fuel distributor, comprising the fuel flowing through the pressure actuator plus the control-plunger leakage, can now flow back through the open valve seat to the tank together with the excess fuel. When the engine is switched off, the fuel pump also stops and the system pressure drops. As a result, the valve plate moves back up again and subsequently pushes the valve body upward against the force of the counterspring until the seal closes the return to the tank. The pressure in the system then sinks rapidly to below the injection-valve opening pressure with the result that the valves then close. The system pressure then increases again to the value determined by the fuel accumulator.

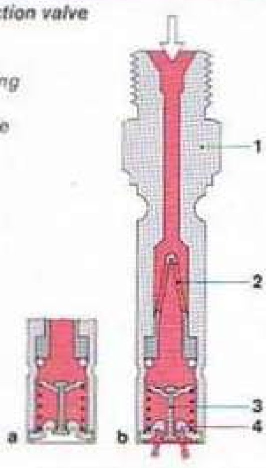
Fuel-injection valves

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

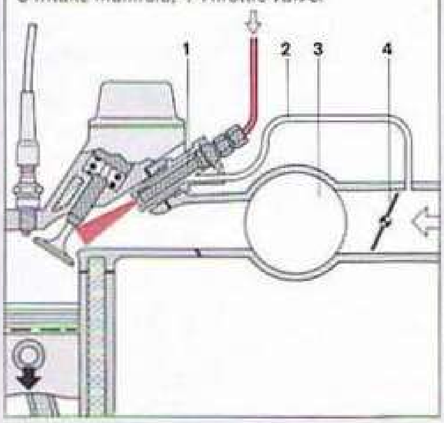
16) Spray patterns from a KE-Jetronic fuel-injection valve, with air-shrouding (below) and without (above). The air has a permanent effect and atomizes the fuel even better (below).

The injection valves inject the fuel allocated by the fuel distributor into the intake ports directly in front of the cylinder intake valves. The injection valves are secured in a special holder in order to insulate them from the engine heat. This 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, for instance, 3.5 bar is exceeded. They are fitted with a valve needle which vibrates ("chatters") audibly at high frequency when fuel is being injected. This results in excellent fuel atomization, even with the smallest of injected quantities. When the engine is switched off, the injection valves close tightly as soon as the fuel-system pressure drops below their opening pressure. This means that no more fuel can enter the intake ports once the engine has been switched off.

17) Fuel-injection valve
a: Closed
b: Open
1 Valve housing
2 Filter
3 Valve needle
4 Valve seat



18) Air-shrouded fuel-injection valve.
1 Fuel-injection valve, 2 Air-supply line, 3 Intake manifold, 4 Throttle valve.



Air-shrouded fuel-injection valves

Air-shrouded injection valves improve the mixture preparation particularly at idle (Fig. 16). The air-shrouding principle is based upon the fact that a portion of the air drawn in by the engine enters through the fuel-injection valves (Fig. 18) with the result that the fuel is especially well atomized at the point of exit. Air shrouding is particularly effective when combined with the thin, continuously operating K-Jetronic valves, and results in a reduction of fuel consumption and a lower level of toxic emissions.

Fuel metering

Basically, fuel metering takes place through the air-flow sensor and the fuel distributor. In a number of operating modes however, the amount of fuel required deviates greatly from the "standard" quantity, and it becomes necessary to intervene in the fuel-management system. Such measures are dealt with in the chapter on "Mixture adaptation".

Air-flow sensor

The quantity of air drawn in by the engine is a precise measure for its operating load. The air-flow sensor operates according to the suspended-body principle, and measures the amount of air drawn in by the engine.

The intake air quantity serves as the main actuating variable for determining the basic injection quantity. It is the appropriate physical quantity for deriving the fuel requirement, and changes in the induction characteristics of the engine have no effect upon the formation of the air-fuel mixture. Since the air drawn in by the engine must pass through the air-flow sensor before it reaches the engine, this means that it has been measured and the control signal generated before it actually enters the engine cylinders. The result is that in addition to other measures described below, the correct mixture adaptation takes place at all times. The air-flow sensor is located upstream of the throttle valve so that it measures all the air which enters the engine cylinders. It comprises an air funnel in which the sensor flap (suspended body) is free to pivot. The air flowing through the funnel deflects the sensor plate by a given amount out of its zero position, and this movement is transmitted by a lever system to a control plunger which determines the basic injection quantity required for the basic functions. Considerable pressure shocks can occur in the intake system if backfiring takes place in the intake manifold. For this reason, the air-flow sensor is so designed that the sensor plate can swing back in the opposite direction in case of misfire, and past its zero position to open a relief cross-section in the funnel. In the case of the down-draft air-flow sensor, an extension spring compensates for the weight of the sensor plate and the lever mechanism. An adjustable leaf spring is fitted to ensure the correct zero position in the switched-off phase.

Fuel distributor

Depending upon the position of the plate in the air-flow sensor, the fuel distributor meters (allocates) the basic injection quantity to the individual engine cylinders.

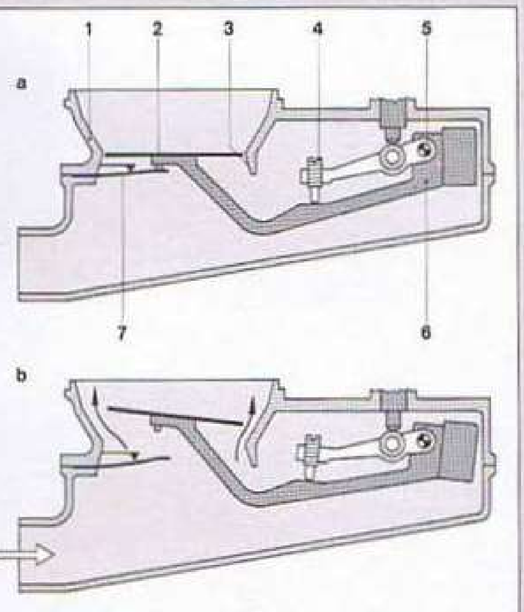
As already mentioned, the position of the sensor plate is a measure of the amount of air drawn in by the engine. The position of the plate is transmitted to the control plunger by a lever. Depending upon its position in the so-called barrel with metering slits (see Fig. 24), the control plunger opens 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.

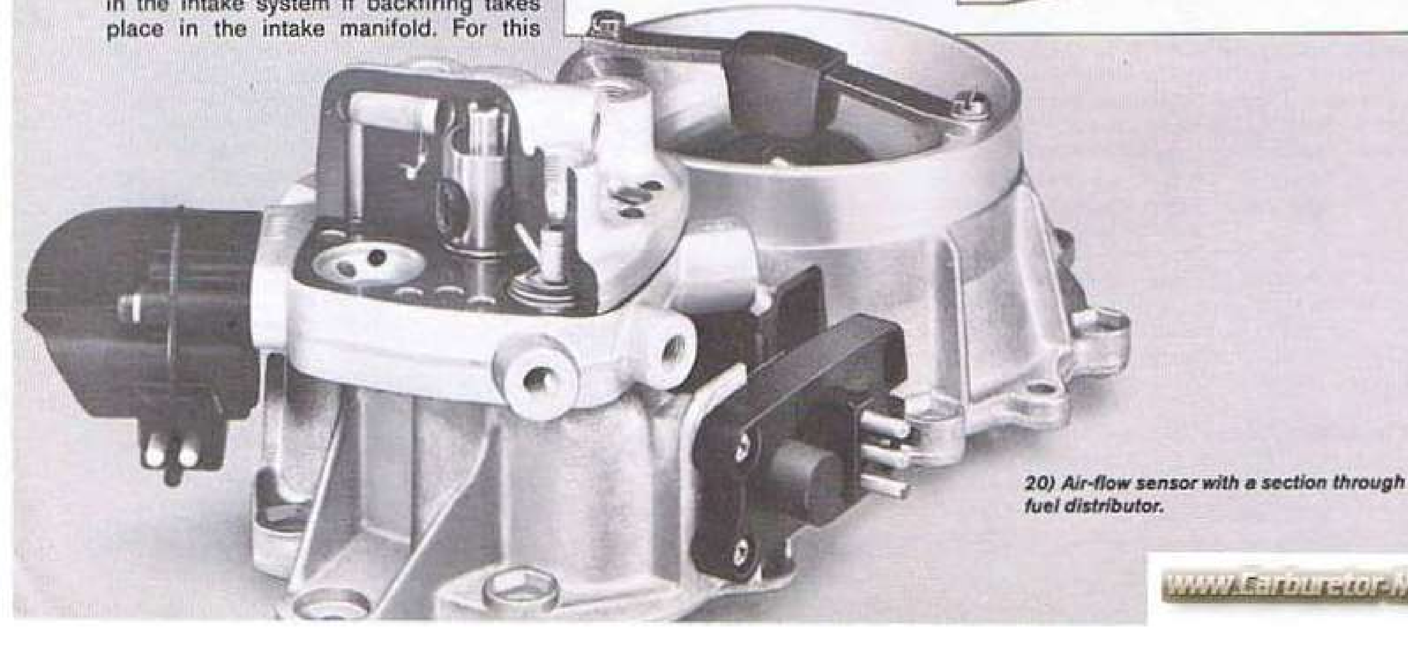
If sensor-plate travel is only very small, the control plunger is only lifted slightly and, as a result, only a small section of the slits is opened for the passage of fuel. On the other hand, with a larger plunger travel, the plunger opens a larger section of the slits and more fuel can flow. There is a linear relationship between sensor-plate travel and the slit section in the barrel which is opened for fuel flow.

A hydraulic force is applied to the control plunger, and acts in opposition to the movement resulting from the sensor-plate deflection. A constant air-fuel pressure drop at the sensor plate is the result, and this ensures that the control plunger always follows the movement of the sensor-plate lever. In some versions, a pressure spring is used to assist this hydraulic

19) Updraft air-flow sensor.
a: Sensor plate in its zero position
b: Sensor plate in its operating position

1 Air funnel
2 Sensor plate
3 Relief cross-section
4 Idle-mixture adjusting screw
5 Main lever
6 Lever
7 Leaf spring





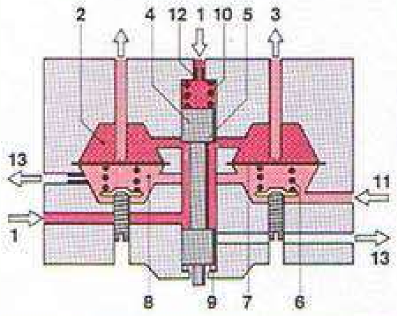
20) Air-flow sensor with a section through the fuel distributor.

force (Fig. 21). It prevents the control plunger from being drawn up due to vacuum effects when the system cools down.
It is imperative that the primary pressure is accurately controlled, otherwise variations would have a direct effect upon the air-fuel ratio (λ-value). A damping throttle (Fig. 21) serves to dampen oscillations that could be caused by sensor-plate forces. When the engine is switched off, the control plunger sinks until it comes to rest against an axial seal ring (Fig. 24). This is secured by an adjustable screw and can be set to the correct height to ensure that the metering slits are closed correctly by the plunger when it is in its zero position. Whereas with the K-Jetronic, the zero position of the plunger is determined by it abutting against the sensor-plate lever, with the KE-Jetronic the plunger rests upon the axial seal ring due to the force applied to it by the residual primary pressure. This measure serves to prevent pressure loss due to leakage past the control plunger, and thus prevents the fuel accumulator from emptying through the control-plunger gap. The fuel accumulator must remain full, because it has the job of maintaining the primary pressure above that fuel-vapor pressure which is applicable for the particular fuel temperature prevailing when the engine is switched off.

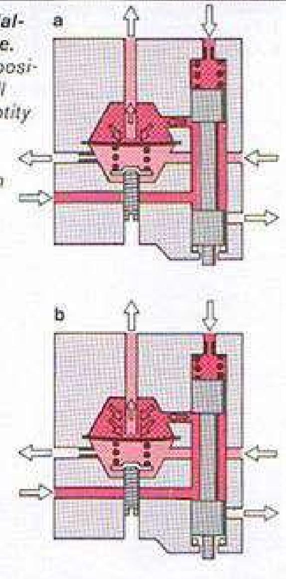
Differential-pressure valves

The differential-pressure valves in the fuel distributor serve to generate a given pressure drop at the metering slits.
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 the basic injection quantity in the same relationship, then a constant pressure drop must be guaranteed at the metering slits independent of the amount of fuel flowing through them (Fig. 24). The differential-pressure valves maintain the drop in pressure between the upper and lower chambers constant, independent of fuel throughflow. The difference in pressure is usually 0.2 bar, and this ensures a high degree of metering accuracy. The differential-pressure valves are of the flat-seat type, and are located in the fuel distributor. The upper and lower chambers are separated by means of a diaphragm (Fig. 21). The lower chambers of all the valves are provided with a helical spring and are connected to one another by means of a ring main, as well as to the electro-hydraulic pressure actuator. The valve seat is located in the upper chamber, and 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 pressure differential at the metering slits is determined by the force of the helical spring in the lower chamber, together with the effective diaphragm diameter and the electro-hydraulic pressure actuator.
If a large basic injection quantity flows into the upper chamber, the diaphragm bends downwards and opens the outlet cross-section of the valve until the set differential pressure is reached again. If the through-flow quantity drops, the valve cross-section is reduced due to the equilibrium of forces at the diaphragm until a pressure differential of 0.2 bar prevails again. This means that an equilibrium of forces exists at the diaphragm which can be maintained for every basic injection quantity by controlling the valve cross-section. An additional fine filter with a separator for ferromagnetic contamination is fitted in the fuel line to the electro-hydraulic pressure actuator.

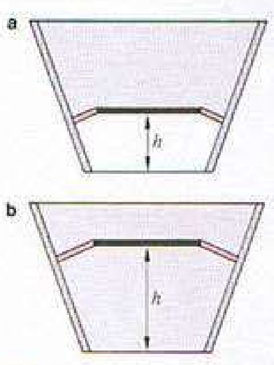
21) Fuel distributor with differential-pressure valves.
1 Fuel inlet (primary pressure), 2 Upper chamber of differential-pressure valve, 3 Line to the fuel-injection valve, 4 Control plunger, 5 Control edge and metering slit, 6 Valve spring, 7 Valve diaphragm, 8 Lower chamber of differential-pressure valve, 9 Axial seal ring, 10 Pressure spring, 11 Fuel from the electro-hydraulic pressure actuator, 12 Throttling restriction, 13 Return line.



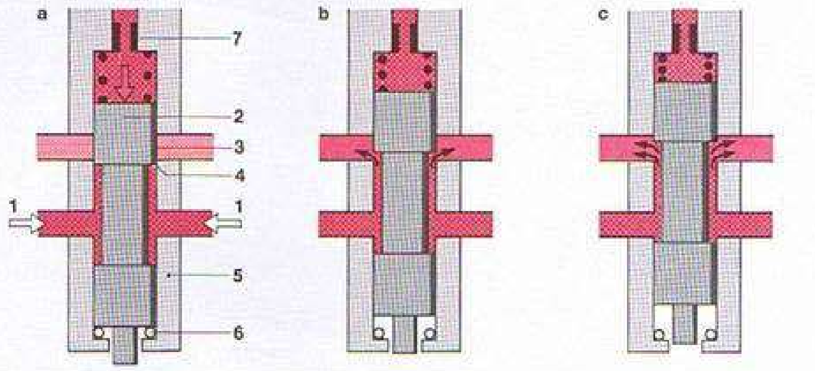
22) Differential-pressure valve.
a: Operating position with small injection quantity
b: Operating position with large injection quantity.



23) Principle of the air-flow sensor.
a: Small amount of air drawn in: sensor plate only lifted slightly. b: Large amount of air drawn in: sensor plate is lifted considerably further.



24) Barrel with metering slits and control plunger.
a: Zero (inoperated position), b: part load, c: full load. 1 Fuel inlet, 2 Control plunger, 3 Metering slit in the barrel, 4 Control edge, 5 Barrel, 6 Axial seal, 7 Throttling restriction.



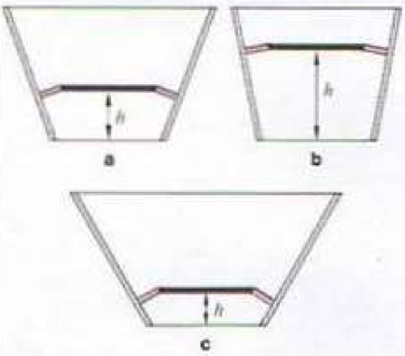
Mixture adaptation

Basic mixture adaptation

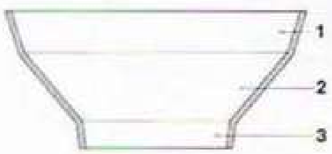
The basic adaptation of the air-fuel mixture to the operating conditions of idle, part load, and full load, is by appropriately shaping the air funnel in the air-flow sensor.

For each operating mode it is necessary to carry out mixture adaptation in order to provide the engine with the optimal air-fuel mixture. In practice, this means that a richer mixture is required at idle and full-load, and a leaner mixture for the part-load range. As stated above, the basic adaptation is by appropriate shaping of the air-funnel. For instance, if the funnel is flatter (Fig. 26c) than the basic form (which was specified originally for a given mixture, e.g. at $\lambda = 1$), then the mixture is leaner. If, on the other hand, the funnel walls are steeper (Fig. 26a, b) than in the basic form, the mixture is richer because the sensor plate deflects further for the same air throughflow and the control plunger meters more fuel. It is possible to shape the air funnel so that an air-fuel mixture corresponding to the sensor-plate position (idle, part load, and full load) can be metered to the engine. In the case of the KE-Jetronic, the air funnel is preferably so shaped that an air-fuel mixture with $\lambda = 1$ results across the whole operating range.

26) Influence of funnel-wall angle upon the sensor-plate deflection for identical air throughput.
a: The basic funnel shape results in stroke "h".
b: Steep funnel walls result in increased stroke "h" for identical air throughput.
c: Flatter funnel shape results in reduced deflection "h" for identical air throughput.
Annular area opened by the sensor plate (identical in "a", "b", and "c").



Adaptation of the air-funnel shape.
1 For maximum power, 2 For part load, 3 For idle.



Electronic control unit

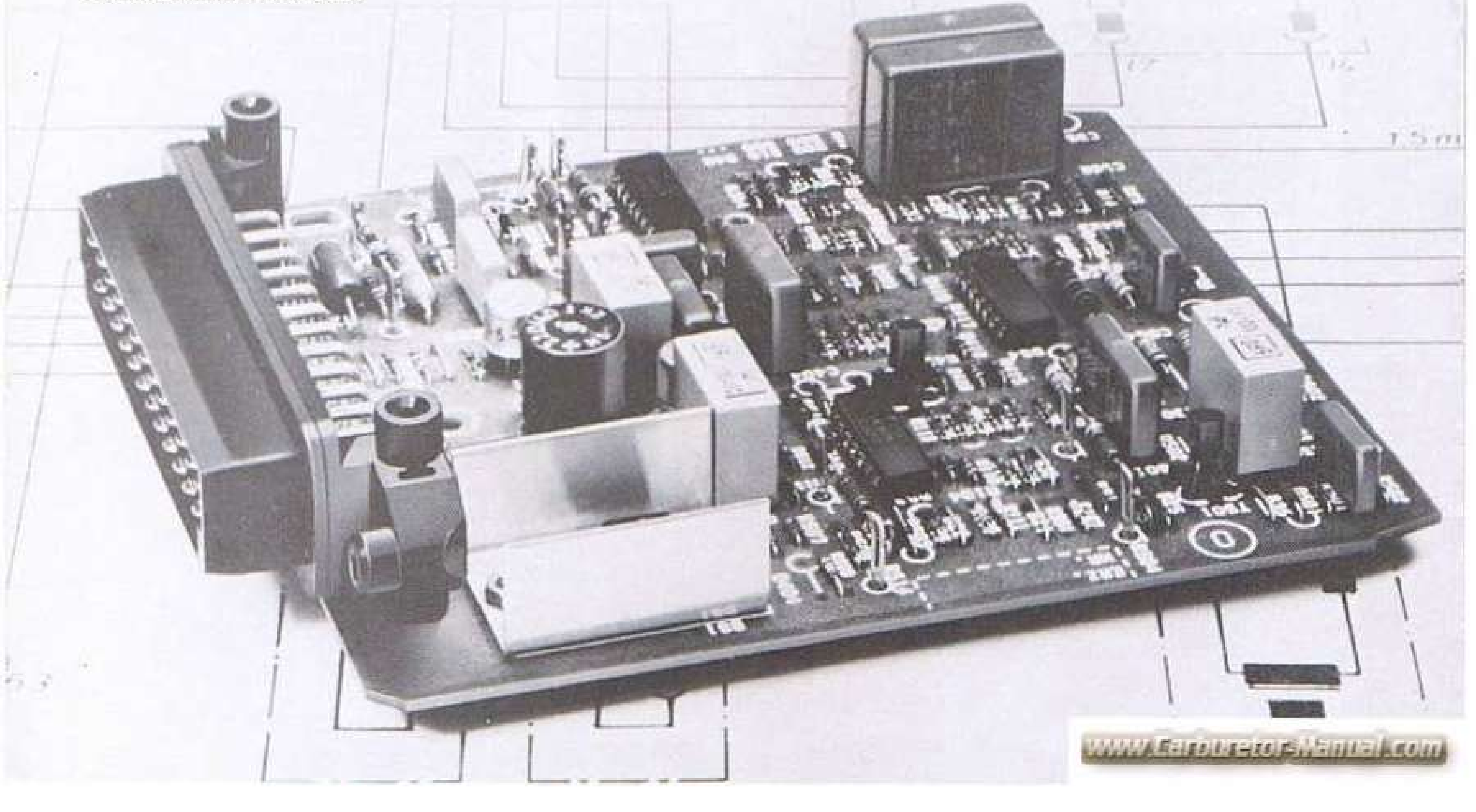
The electronic control unit evaluates the data delivered by the various sensors concerning the engine operating conditions, and from this data generates a control signal for the electro-hydraulic pressure actuator.

Sensors for the registration of operating data

Additional criteria, above and beyond the information coming from the intake air quantity, are required in order to determine the optimal fuel quantity required by the engine. These must be registered by sensors and reported to the ECU. The sensors are described with reference to the corresponding adaptation function.

Characteristic operating values	Sensor
Full load Idle	Throtte-valve switch
Engine speed	Ignition-triggering system (usually in ign. distributor)
Start	Ignition/start switch
Engine temperature	Engine-temperature sensor
Air pressure	Aneroid-box sensor
Air-fuel mixture	Lambda sensor

25) Electronic control unit (ECU)



Design and function

Depending upon the functional scope, the electronic circuitry uses either analog techniques or mixed analog/digital techniques. Starting with the "Europe" unit, the modules for idle-mixture control and for Lambda closed-loop control can be added. ECU's with a more extensive range of functions are designed using digital techniques. The electronic components are installed on a PC-board and include IC's (e.g. operational amplifiers, comparators, and voltage stabilizers), transistors, diodes, resistors, and capacitors. The PC-boards are inserted in the ECU housing which can be equipped with a pressure-equalization element. The ECU is connected to the battery, to the sensors, and to the actuator by a 25-pole plug.
The ECU processes the incoming signals from the different sensors, and from them calculates the control current for the electro-hydraulic pressure actuator.

Voltage stabilization

The ECU must be powered by a stable voltage, which remains constant independent of the voltage of the vehicle electrical system. The current applied to the pressure actuator, which depends upon the incoming sensor signals carrying the data on the engine operating conditions, is generated from this stabilized voltage, the stabilization of which takes place in a special IC.

Input filters

These filter out any interference which may be present in the incoming signals from the sensors.

Adder

Here, the evaluated sensor signals are combined. The electrically processed corrective signals are added in an operational circuit and then transmitted to the current regulator.

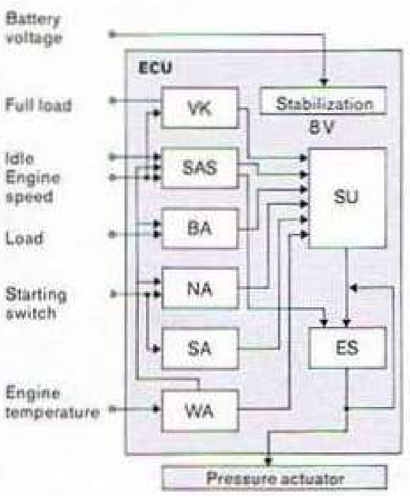
Output stage

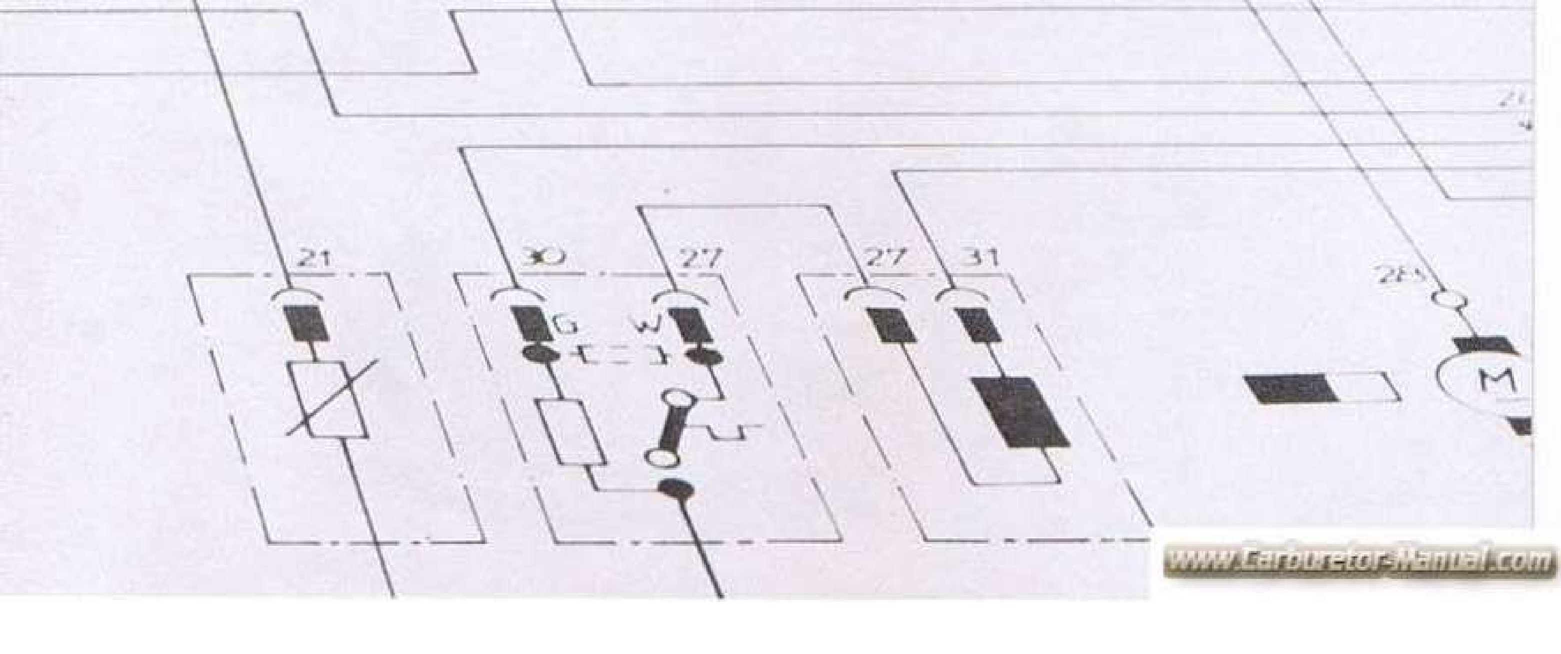
The output stage generates the control signal for the pressure actuator, whereby it is possible to input opposing currents into the pressure actuator in order to increase or decrease the pressure drop.
The magnitude of the current in the pressure actuator can be adjusted at will in the positive direction by means of a permanently triggered transistor. The current is reversed during "overrun" (overrun fuel cut-off), and influences the differential pressure at the differential-pressure valves so that the flow of fuel to the injection valves is interrupted.

Additional output stages

If necessary, additional output stages can be incorporated. These can serve to trigger the valves for EGR, and to control the bypass cross-section around the throttle valve as required for idle-mixture control, to name but two applications.

27) Block diagram of the KE-Jetronic ECU, using analog techniques.
The correcting signals from the individual blocks are combined in an adder stage. They are then amplified in the output stage and transmitted to the electro-hydraulic pressure actuator.
VK Full-load correction
SAS Overrun fuel cut-off
BA Acceleration enrichment
NA Post-start enrichment
SA Starting-fuel increase
WA Warm-up enrichment
SU Adder stage
ES Output stage





Electro-hydraulic pressure actuator

Depending upon the operating conditions of the engine, and the resulting current signal received from the ECU, the electro-hydraulic pressure actuator varies the pressure in the lower chambers of the differential-pressure valves. This changes the amount of fuel delivered to the injection valves.

Design

The electro-hydraulic pressure actuator (Fig. 30) is mounted on the fuel distributor. The actuator is a differential-pressure controller which functions according to the nozzle/baffle plate principle, and its pressure drop is controlled by the current input from the ECU. In a housing of nonmagnetic material, an armature is suspended on frictionless taut-band suspension elements, between two double magnetic poles. The armature is in the form of a diaphragm plate made from resilient material.

Function

The magnetic flux of a permanent magnet (broken lines Fig. 30), and that of an electromagnet (unbroken lines Fig. 30), are superimposed upon each other in the magnetic poles and their air gaps. The permanent magnet is actually turned through 90° referred to the focal plane.

The paths taken by the magnetic fluxes through the two pairs of poles are symmetrical and of equal length, and flow from the poles, across the air gaps to the armature, and then through the armature.

In the two diagonally opposed air gaps (Fig. 30, L2,L3), the permanent-magnet flux, and the electro-magnet flux resulting from the incoming ECU control signal, are added, whereas in the other two air gaps (Fig. 30, L1,L4) the fluxes are subtracted from each other. This means that in each air gap the armature, which moves the baffle plate, is subjected to a force of attraction proportional to the square of the magnetic flux.

Being as the permanent-magnet flux remains constant, and is proportional to the control current from the ECU flowing in the electromagnet coil, the resulting torque is proportional to this control current. The basic moment of force applied to the armature has been selected so that when no current is applied from the ECU, there results a basic differential pressure which corresponds preferably to $\lambda = 1$. This also means that in case of control current failure, limp-home facilities are available without any further correction measures being necessary.

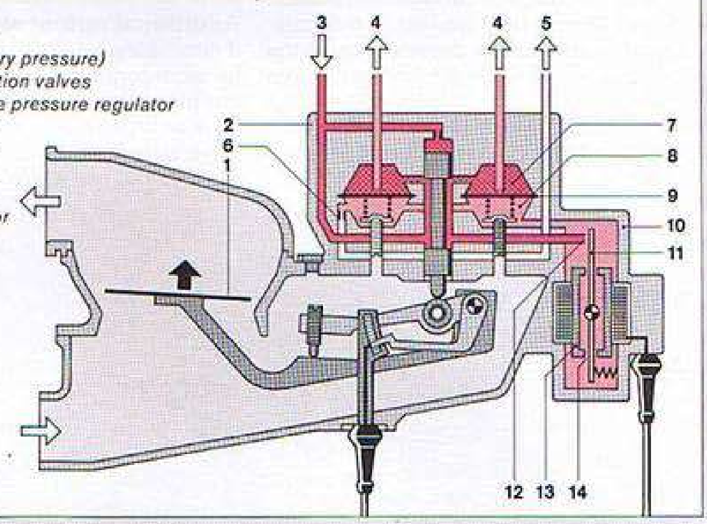
The jet of fuel which enters through the nozzle attempts to bend the baffle plate away against the prevailing mechanical and magnetic forces. Taking a fuel throughflow which is determined by a fixed restriction located in series with the pressure actuator, the difference in pressure between the inlet and outlet (Fig. 28, 3 & 5) is proportional to the control current applied from the ECU. This means that the variable pressure drop at the nozzle is also proportional to this ECU control current, and results in a variable lower-chamber pressure. At the same time, the pressure in the upper chambers changes by the same amount. This in turn results in a change in the difference at the metering slits between the upper-chamber pressure and the primary pressure, and this is applied as a means for varying the fuel quantity delivered to the injection valves.

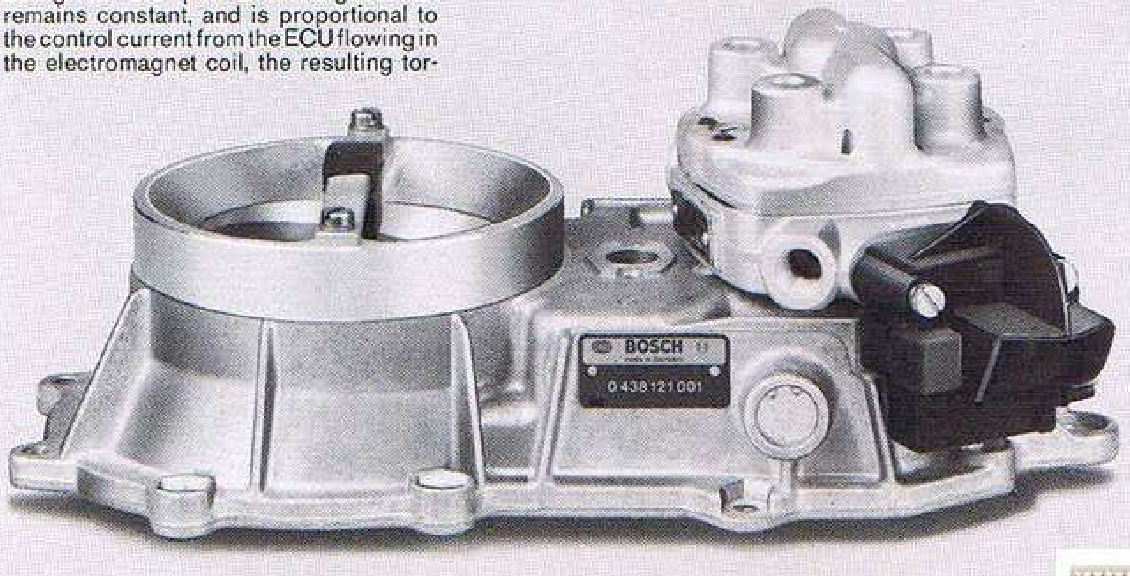
As a result of the small electromagnetic time constants, and the small masses which must be moved, the pressure actuator reacts extremely quickly to variations in the control current from the ECU.

If the direction of the control current is reversed, the armature pulls the baffle plate away from the nozzle and a pressure drop of only a few hundredths of a bar occurs at the pressure actuator. This can be used for auxiliary functions such as overrun fuel cut-off and engine-speed limitation. The latter function takes place by interrupting the flow of fuel to the injection valves (see Page 21).

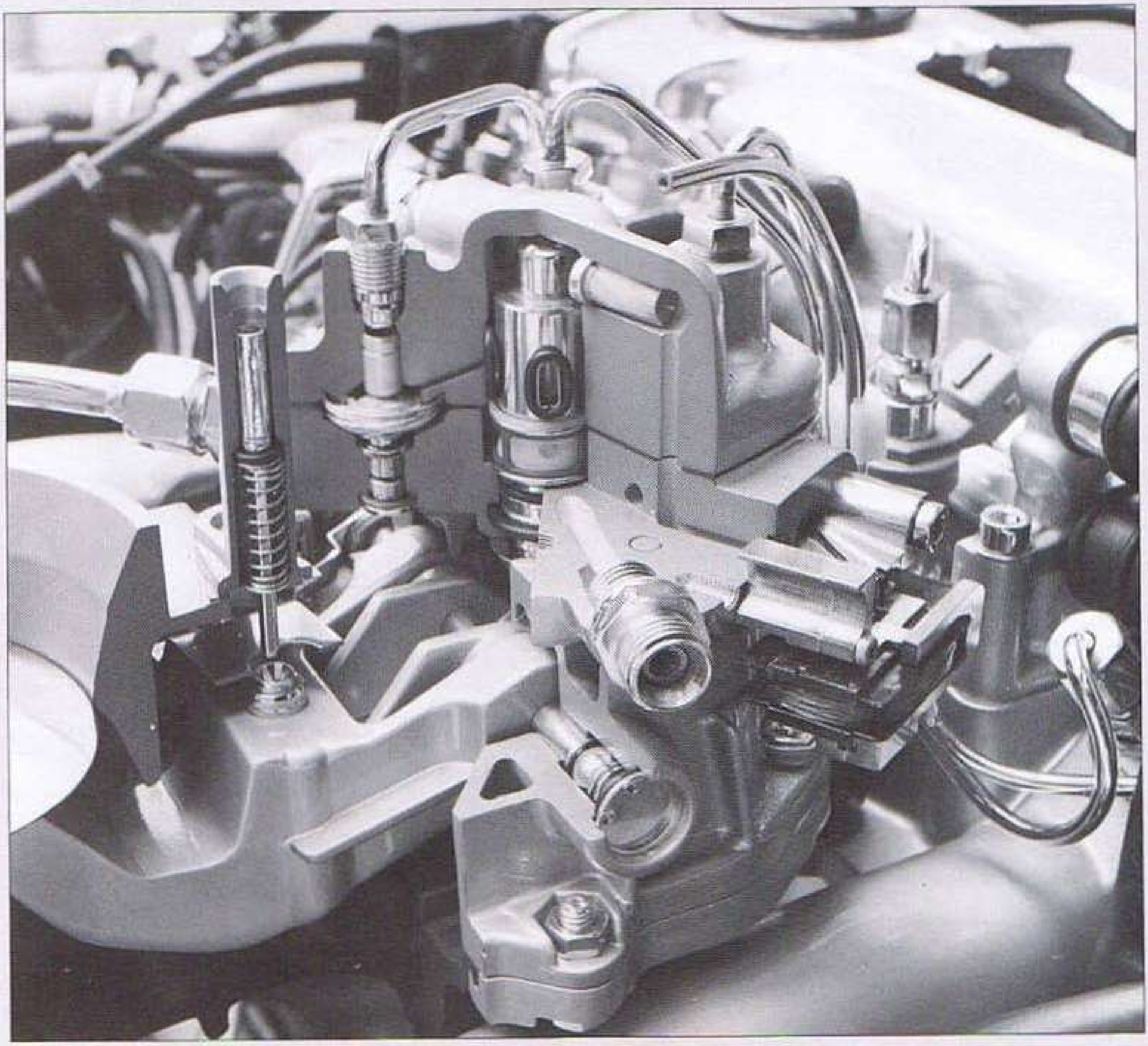
28) Electro-hydraulic pressure actuator fitted to the fuel distributor.
The control signal from the ECU influences the position of the baffle plate (11). This in turn varies the fuel pressure in the upper chambers of the differential-pressure valves and, as a result, the quantity of fuel delivered to the injection valves. Using this principle, adaptation and correction functions can be incorporated.

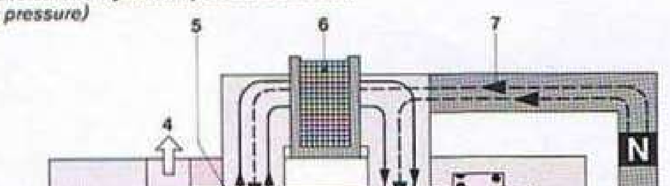
1 Sensor plate
2 Fuel distributor
3 Fuel inlet (primary pressure)
4 Fuel to the injection valves
5 Fuel return to the pressure regulator
6 Fixed restriction
7 Upper chamber
8 Lower chamber
9 Diaphgragm
10 Pressure actuator
11 Baffle plate
12 Nozzle
13 Magnetic pole
14 Air gap





29) Mixture-control unit with electro-hydraulic pressure actuator.





30) Section through the electro-hydraulic pressure actuator.

1 Fuel inlet (primary pressure)
2 Nozzle
3 Baffle plate
4 Fuel outlet
5 Magnetic pole
6 Electromagnet coil
7 Permanent-magnet flux
8 Permanent magnet (turned through 90° from the focal plane)
9 Adjustment screw for basic moment of force
10 Electro-magnetic flux
11 Armature (L1 to L4 = air gaps).

31) Above:
The importance of high-precision engineering down to the finest detail is demonstrated clearly by this section through the fuel-distributor. As a result of long years of experience, every component in the injection system incorporates state-of-the-art techniques and is backed up by most modern manufacturing technology. Countless checks and tests during production guarantee the high standard of quality, which applies both to every individual component as well as to the installation as a whole. This quality is not only guaranteed by the relentless pursuit of quality in all areas from R&D through to actual manufacture, but also by our worldwide customer-service organisation (Photo: Daimler-Benz AG).

Cold start

Depending upon the engine temperature, during starting the KE-Jetronic injects an additional quantity of fuel for a limited period of time.

Cold-start enrichment

During a cold start, the air-fuel mixture drawn in by the engine leans off. This is due to the low turbulence at cranking speeds causing poor mixture of the fuel particles with the air, and to the minimal evaporation of the fuel and wetting of the cylinder walls and intake ports with fuel at low temperatures. In order to compensate for these phenomena, and thus facilitate starting the cold engine, additional fuel must be injected during cranking. Due to the pronounced variations in engine speed during starting, which would result in an inaccurate air-flow signal, the ECU provides a fixed load signal which is weighted with a factor related to the engine temperature.

Cold-start valve

During cold starting, the cold-start valve sprays additional fuel into the intake manifold for a short period.

Being as the amount of fuel required during a cold start is considerably above the "normal" quantity, additional fuel is provided by a special cold-start valve. This sprays into the intake manifold at a central point for all injection valves, and its duration of injection is limited by a thermo-time switch. This cold-start enrichment provides a "richer" mixture in the cylinders and thus provides for better combustion conditions.
The cold-start valve (Fig. 32) is a solenoid-operated valve. The solenoid coil is located inside the valve, and when the valve is closed it is sealed off by its movable armature being pressed against the seal by a spring.
When the solenoid is energized, the armature is lifted from its seat and permits fuel to flow. Fuel now flows tangentially into a so-called swirl nozzle which causes it to rotate. The result is that the fuel is atomized extremely finely and enriches the mixture in the intake manifold downstream of the throttle valve. The cold-start valve is so positioned in the inlet manifold that a favorable distribution of the air-fuel mixture to all cylinders is ensured.

Thermo-time switch

The thermo-time switch limits the duration of cold-start valve operation, depending upon temperature.

The thermo-time switch (Fig. 33) consists of an electrically heated bimetal strip which, depending upon its temperature, opens or closes a contact. It is brought into operation by the ignition/starter switch, and is mounted at a spot which is representative of engine temperature. During a cold start, it limits the "on" period of the cold-start valve. In case of repeated start attempts, or when starting takes too long, the cold-start valve ceases to inject.
Its "on" period is determined by the thermo-time switch which is heated by engine heat as well as by its own built-in heater. Both these heating effects are necessary in order to ensure that the "on" period of the cold-start valve is limited under all conditions, and engine flooding prevented. During an actual cold start, the heat generated by the built-in heater is mainly responsible for the "on" period (switch off, for instance, at −20 °C after 7.5 secs). With a warm engine, the thermo-time switch has already been heated up so far by engine heat that it remains open and prevents the cold-start valve from going into action.

Post-start phase

Enriching the fuel after starting at low temperatures improves engine running in the post-start phase.

After starting at low temperatures, it is necessary to enrich the mixture for a short period in order to compensate for poor mixture formation and wetting of cylinder and intake-port walls with fuel. In addition, the richer mixture results in higher torque and therefore better off-idle throttle response.

Post-start enrichment

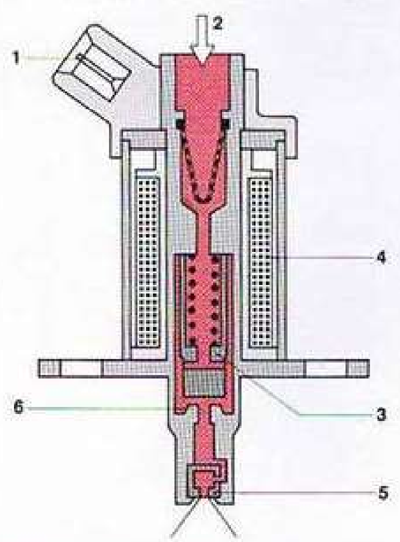
This function is calibrated to give satisfactory throttle response at all temperatures together with minimum fuel consumption. Post-start enrichment is dependent upon temperature and time and, starting from a temperature-dependent initial value is decreased practically linearly with time. This means that the enrichment duration is a function of the initial temperature. The ECU maintains the temperature-dependent mixture enrichment at its maximum level for about 4.5 secs and then reduces it to zero. For instance, following a start at 20 °C, the reduction to zero takes 20 secs.

Engine-temperature sensor

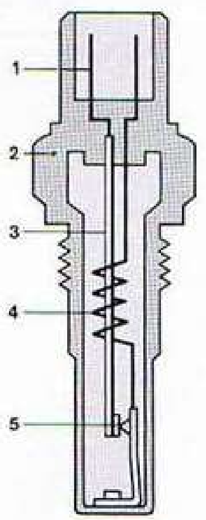
The engine-temperature sensor measures the temperature of the engine and converts this into an electrical signal for the ECU.

The temperature sensor (Fig. 34) is mounted in the engine block. With water-cooled engines it projects into the coolant.
The sensor "reports" the particular engine temperature to the ECU in the form of a resistance value. The ECU then signals the electro-hydraulic pressure actuator which carries out the appropriate adaptation of the injected fuel quantity during the post-start and warm-up periods. The temperature sensor consists of an NTC resistor imbedded in a threaded sleeve.

32) Cold-start valve in operation.
1 Electrical connection, 2 Fuel inlet with strainer, 3 Valve (solenoid armature), 4 Solenoid coil, 5 Swirl nozzle, 6 Valve seat.



33) Thermo-time switch
1 Electrical connection, 2 Housing, 3 Bimetal strip, 4 Heater element, 5 Electrical contact.



NTC stands for Negative Temperature Coefficient, the decisive characteristic of this resistor. When the temperature increases, the electrical resistance of the semiconductor resistor decreases.

Warm-up

Warm-up enrichment

During warm-up, the engine receives extra fuel depending upon the temperature, the load, and the engine speed.

The warm-up phase follows the cold-start and the post-start phases. The engine needs extra fuel because some of the fuel condenses on the still cold cylinder walls. At low temperatures, mixture formation is poor due to the large fuel droplets concerned, and due to their inefficient mixing with the air drawn in by the engine. The result is that fuel condenses on the intake valves and in the intake manifold, and only evaporates at higher temperatures. The above factors all contribute to an increasing enrichment of the mixture along with decreasing temperature. The engine temperature sensor registers the coolant temperature and reports this to the ECU which then converts this data into a control signal for the electro-hydraulic pressure actuator. Hereby, the mixture adaptation through the pressure actuator (see Page 14) is so arranged that perfect combustion is achieved at all temperatures while at the same time keeping the fuel enrichment as low as possible.

Acceleration

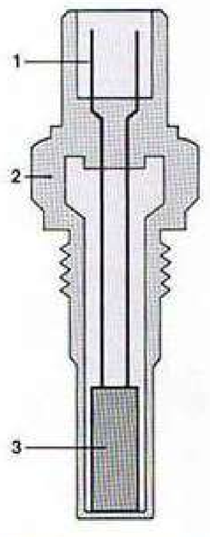
During acceleration, the KE-Jetronic meters additional fuel to the engine as long as it is still cold.

Acceleration enrichment by means of the pressure actuator

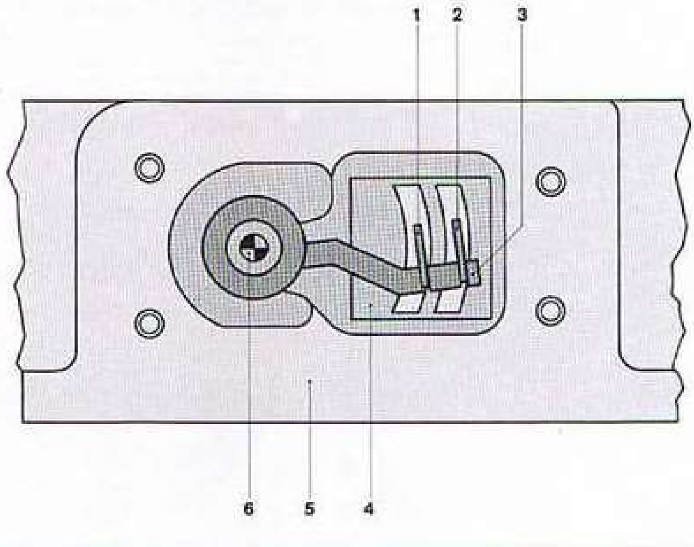
If the throttle is opened abruptly, the air-fuel mixture is momentarily leaned-off, and a short period of mixture enrichment is needed to ensure good transitional response.
As a result of the change in the load signal (referred to time), the ECU recognises when acceleration is taking place and, as a result, triggers the acceleration enrichment. This prevents the familiar "flat spot". When the engine is cold, it requires additional enrichment due to the less than optimum air-fuel mixing and due to the possibility of fuel being deposited on the intake-manifold walls.
The maximum value for acceleration enrichment is a function of the temperature. The acceleration enrichment is triggered at ≤ 80 °C by a needle-shaped enrichment pulse with a duration of 1 s. The enrichment quantity is higher the colder the engine, and is also dependent upon changes in load.
The speed with which the pedal is depressed when accelerating is determined from the deflection of the air-flow sensor. This has only a very slight lag referred to the throttle-plate movement. This signal, which corresponds to the change in the intake-air quantity and therefore approximately to the engine power, is registered by the potentiometer in the air-flow sensor and passed to the ECU which controls the pressure actuator accordingly. The potentiometer curve is non-linear, so that the acceleration signal is a maximum when accelerating from idle. It decreases along with the increase in engine power. The result is a reduction in the ECU circuit outlay.

Sensor-plate potentiometer
The potentiometer in the air-flow sensor (Fig. 35) is manufactured using film techniques on a ceramic base.
A brush-type wiper moves across the potentiometer track. The brushes consist of a number of fine wires which are welded to a lever. The individual wires apply only a very low pressure to the potentiometer track with the result that wear is extremely low. Due to the large number of wires in the brush, excellent electrical contact is guaranteed even on a rough track surface and also when the wiper moves quickly.
The potentiometer lever is attached to the sensor-plate shaft but is electrically insulated from it. The wiper volttage is tapped-off by a second wiper brush which is electrically connected to the main wiper. The wiper is designed to travel past the ends of the tracks in both directions so far that damage is ruled out when backfiring occurs in the intake manifold. A fixed film resistor is included in series with the wiper to prevent damage in case of short-circuit.

34) Temperature sensor.
1 Electrical connection, 2 Housing, 3 NTC resistor.



35) Potentiometer for determining the sensor-plate position.
1 Pickoff brush, 2 Main brush, 3 Wiper lever, 4 Potentiometer plate (shifted out of the focal plane), 5 Air-flow sensor housing, 6 Sensor-plate shaft.



Full load

The engine delivers its maximum power at full load, when the air-fuel mixture must be enriched compared to that at part-load.

Full-load enrichment by means of the pressure actuator

In contrast to part load, where the calibration is for minimum fuel consumption and low emissions, at full load it is necessary to enrich the air-fuel mixture. This enrichment is programmed to be engine-speed dependent. It provides maximum possible torque over the entire engine-speed range, and this ensures optimum fuel-economy figures in the full-load mode. At full load, e.g. in the engine speed ranges between 1500 and 3000 min^{-1}, and above 4000 min^{-1}, the KE-Jetronic enriches the air-fuel mixture. The full-load signal is delivered by a full-load switch on the throttle valve, or by a microswitch on the accelerator-pedal linkage. The information on engine speed is taken from the ignition. From this data, the ECU calculates the additional fuel quantity needed, and this is put into effect by the pressure actuator.

Throttle-valve switch

The throttle-valve switch communicates the "idle" and "full load" throttle positions to the ECU.

The throttle-valve switch (Fig. 36) is mounted on the throttle body and actuated by the throttle-valve shaft. A separate contact is closed for each of the throttle-valve end positions, i.e. at idle and at full load.

36) Throttle-valve switch for end-position signal.

Idle

In addition to the efficiency of the engine, the fuel consumption at idle is determined principally by the engine idle speed.

Controlling the idle speed by means of the auxiliary air device

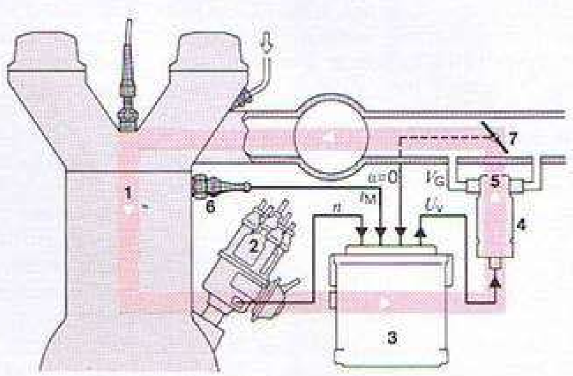
The higher frictional resistances in the cold engine must be overcome by increasing the air-fuel mixture input. In order to achieve smoother running at idle, the idle-speed control increases the idle speed. This also leads to a more rapid warm-up of the engine. Depending upon engine temperature, an electrically heated auxiliary-air device in the form of a bypass around the throttle plate allows the engine to draw in more air. This auxiliary air is also measured by the air-flow sensor, and leads to the KE-Jetronic providing the engine with more fuel. Precise adaptation is by means of the electrical heating facility. The engine temperature then determines how much auxiliary air is fed in initially through the bypass, and the electrical heating is mainly responsible for subsequently reducing the auxiliary air as a function of time.

The auxiliary-air device incorporates a perforated plate (Figs. 38, 39, 42) which is actuated by the bimetallic strip and which controls the cross section of the bypass passage. Initially, the bypass cross section opened by the perforated plate is determined by the engine temperature, so that during a cold start the bypass opening is adequate for the auxiliary air required. The opening closes steadily along with increasing engine temperature until finally it is closed completely. The bimetal strip is electrically heated and this limits the opening time, starting from the initial setting which is dependent upon engine temperature. The auxiliary-air device is fitted in the best possible position on the engine for it to assume engine temperature. It does not function when the engine is warm.

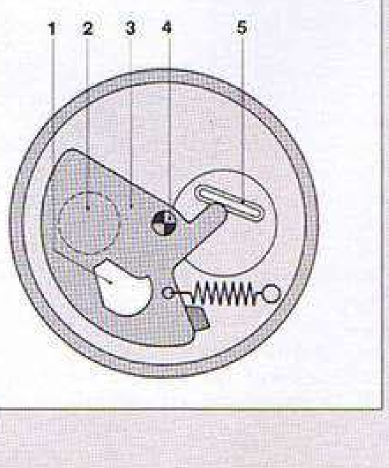
37) Control circuit for the closed-loop idle-speed control.

In contrast to the open-loop idle-speed control, the closed-loop control measures the actual engine speed. This figure is then compared with the set value and, in case of deviation, the rotating slide in the idle-speed rotary actuator is adjusted accordingly.

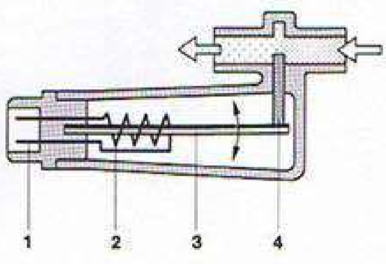
1 Controlled system: engine,
2 Controlled variable: engine speed (n),
3 Controller: control unit (delivers the control voltage U_v),
4 Final controlling element: idle speed rotary actuator,
5 Manipulated variable: bypass cross-section (intake-air quantity V_G)
6 Auxiliary actuating variable: engine temperature (t_M),
7 Auxiliary actuating variable: throttle-valve end position ($\alpha = 0$).



38) Electrically heated auxiliary-air device (section). *1 Plate opening, 2 Air passage, 3 Perforated plate, 4 Pivot, 5 Electrical heating.*



39) Electrically heated auxiliary-air device. *1 Electrical connection, 2 Electrical heating, 3 Bimetal strip, 4 Perforated plate.*



Idle Speed Stabilizer

Idle-mixture control by means of the rotary idle actuator

The idle-mixture control stabilizes the idle speed, and thus reduces fuel consumption at idle, particularly in town traffic.

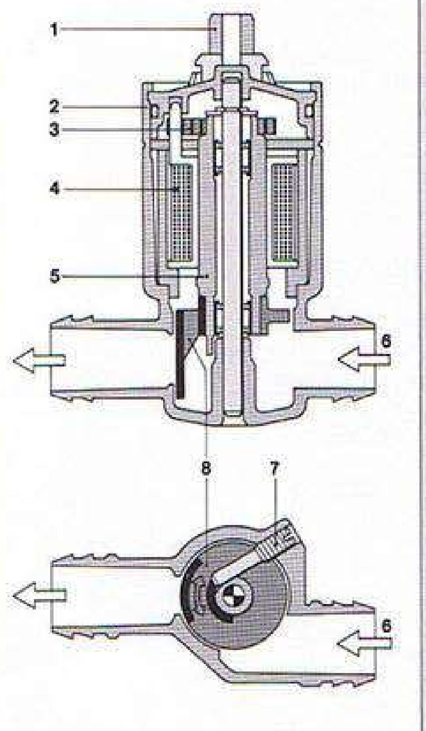
Excessive idle speed increases the fuel consumption at idle and, as a result, the vehicle's overall fuel consumption. This problem is addressed by the idle-mixture control, which always provides exactly the right amount of mixture in order to maintain the idle speed, no matter what the engine load (e.g. cold engine with increased frictional resistance). Furthermore, the emission figures remain constant in the long term without having to adjust the idle speed. To a certain extent, the idle-mixture control also compensates for changes in the engine which are attributable to ageing. It also stabilizes the idle speed throughout the entire service life of the engine.
Depending upon the signal applied to it, the rotary idle actuator opens or closes the bypass passage around the throttle valve. Due to the fact that the KE-Jetronic registers the resulting extra air with its sensor plate, the injected fuel quantity changes accordingly. In contrast to other idle-speed controls on the market, this idle-mixture device controls the idle speed efficiently due to it actually carrying out a comparison between desired and actual values and, in case of deviation, correcting accordingly.

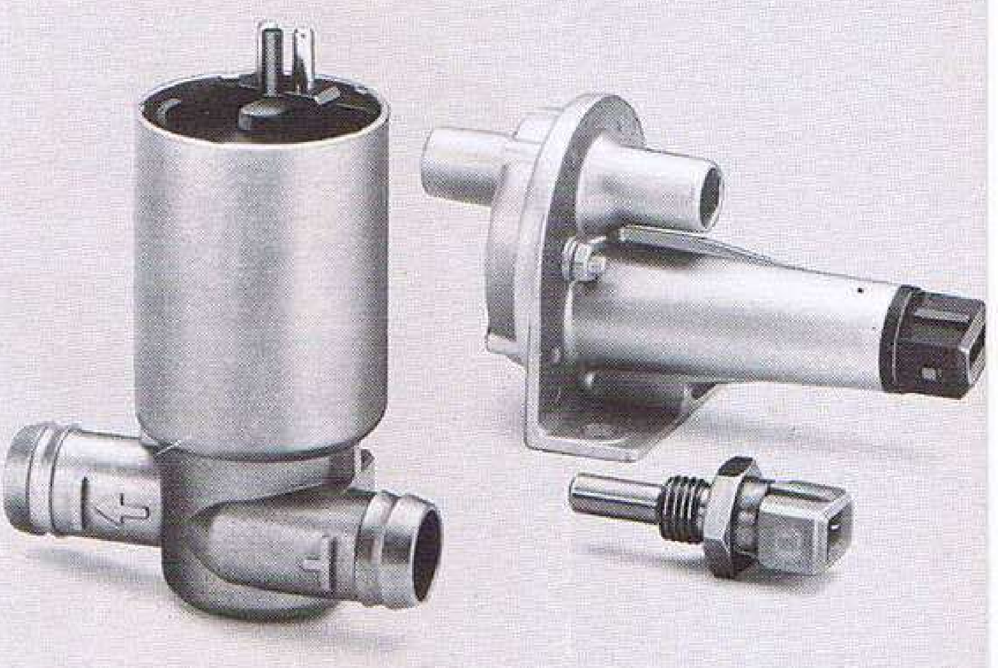
Rotary idle actuator

Depending upon the deviation of the idle speed from the set value, the rotary idle actuator supplies the engine with more or less intake air through a bypass around the throttle valve. It takes over the function of the auxiliary-air device which is no longer needed.

The rotary idle actuator of the KE-Jetronic (Figs. 40, 41) receives its control signal from the ECU. This control signal depends upon engine speed and temperature, and causes the rotating plate in the idle actuator to change the bypass opening.
The rotary idle actuator is powered by a rotary-magnet drive comprising a winding and a magnetic circuit. Its rotational range is limited to 60°. The rotating slide is attached to the armature shaft and opens the bypass passage far enough for the specified idle speed to be maintained independent of engine loading. The closed-loop control circuit in the ECU, which is provided by the engine-speed sensor with the necessary information concerning engine speed, compares this with the programmed specified idle speed and adjusts the air throughflow by means of the idle actuator until the actual idle speed coincides with the set idle speed. With the engine warm and unloaded, the bypass opening is very near to its lower limit.
Further inputs from the ECU, such as temperature and throttle-valve position, ensure that errors do not occur at low temperatures or due to accelerator-pedal movements. The ECU transforms the engine-speed signal into a voltage signal which it compares with a voltage corresponding to the set value. The ECU generates a control signal from the difference voltage, and inputs this to the rotary idle actuator. A pulsating DC is applied to the winding of the coil and causes a torque at the rotating armature which acts against the return spring. The resulting bypass opening depends on the strength of the current. In the absence of current (vehicle malfunction), the return spring forces the rotating slide against an adjustable stop and provides an emergency opening. At the maximum on/off ratio of the applied pulsating DC, the bypass is fully opened.

40) Rotary idle actuator (single-winding rotary actuator).
1 Electrical connection, 2 Housing, 3 Return spring, 4 Winding, 5 Rotating armature, 6 Air passage as bypass around the throttle plate, 7 Adjustable stop, 8 Rotating slide.





41) Rotary idle actuator (single-winding rotary actuator).

42) Auxiliary-air valve (top) and temperature sensor for idle-speed control.

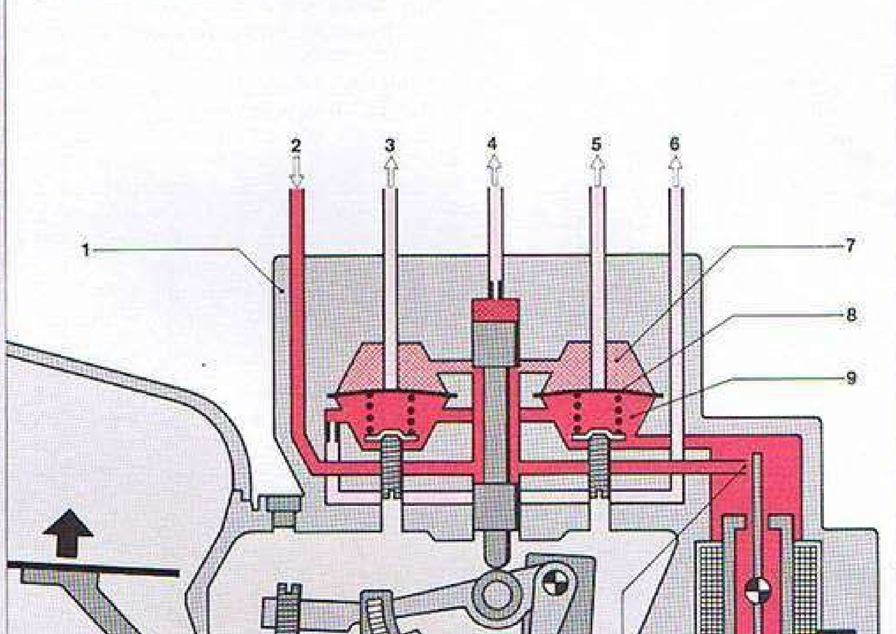
Supplementary functions

Overrun (deceleration)

Overrun fuel cut-off is the complete interruption of the supply of fuel to the engine during deceleration. This results in a reduction of fuel consumption in town traffic as well.

Cutting off the fuel during deceleration reduces fuel consumption not merely on long downhill runs and during braking, but also in town traffic. Because no fuel is burned, there are no emissions.
When the driver takes his foot off the accelerator pedal while driving, the throttle valve returns to the zero position. The throttle-valve switch reports the "throttle-valve closed" condition to the ECU, which at the same time receives from the ignition the data concerning the engine speed. If the actual engine speed is within the operating range of the overrun cut-off (that is, above idle), the ECU reverses the current in the electro-hydraulic pressure actuator. The pressure drop at the actuator is then practically zero. This means that in the fuel distributor, the differential-pressure valves are closed by the springs in their lower chambers (Fig. 44) and interrupt the flow of fuel to the injection valves.
Being as the injection valves inject continuously, the overrun fuel cut-off operates perfectly smoothly. Its response is also dependent upon the coolant temperature (Fig. 46), and in order to avoid continuous switching in and out at a given engine speed, a different switching point is specified depending upon whether the engine speed is decreasing or increasing. The switching thresholds are chosen to be as low as possible for the warm engine in order that maximum fuel savings are achieved. On the other hand, with a cold engine the thresholds are somewhat higher so that the engine does not stop when the clutch pedal is suddenly pressed.

44) Fuel distributor

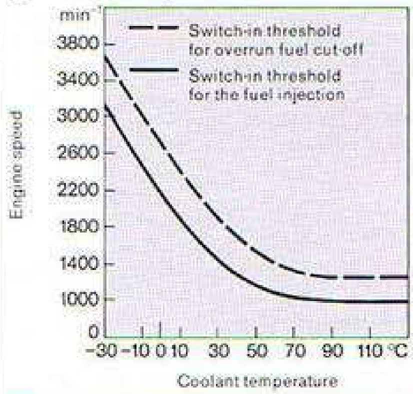


Text to Fig. 43)
When the driver takes his foot off the accelerator pedal, the overrun fuel cut-off responds and stops the flow of fuel to the injection valves.

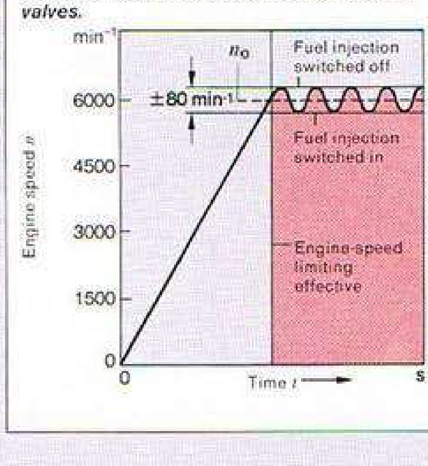
Text to Fig. 44)
Fuel cut-off effective during overrun: When the current is reversed through the winding (11) in the pressure actuator, the baffle plate (12) is pulled away from the nozzle (10). This causes the lower-chamber pressure to rise almost to the level of the primary pressure, and the springs in the lower chambers close the inlets (3 and 5) to the injection valves with the diaphragm (8).
1 Fuel distributor, 2 Fuel inlet, 4 to the cold-start valve, 6 to the primary-pressure regulator, 7 Upper chamber, 9 Lower chamber.

45)

46) *The lowest engine speed for the overrun fuel cut-off facility depends upon coolant temperature.*



47) *Limiting the maximum engine speed n_0 by stopping the flow of fuel to the injection valves.*



Engine-speed limiting

When a preset engine speed is reached, the ECU suppresses the fuel-injection pulses.

Conventional mechanical engine-speed limiters have a distributor rotor arranged to short-circuit the ignition when the maximum permissible engine speed is reached. Today, for reasons of exhaust-gas emissions and fuel economy, this method is no longer entirely satisfactory. An obvious method is to apply electronics to engine-speed limiting by switching off the fuel injection. When the current through the electro-hydraulic actuator is reversed, the baffle plate is pulled away from the nozzle (Fig. 44), the pressure drop approaches zero and the diaphragms in the differential pressure valves stop the flow of fuel to the injection valves. The same process takes place as with the overrun fuel cut-off facility (refer to Page 20).
In the ECU, the actual engine speed is compared with the programmed maximum speed n_0. If the maximum speed is exceeded, the ECU suppresses the injection pulses. This function operates within a bandwidth of 80 min^{-1} above and below the permissible maximum speed (Fig. 47). This electronic engine-speed limiting facility prevents the engine from "overrevving", but without the adverse effects inherent in the mechanical system mentioned above.

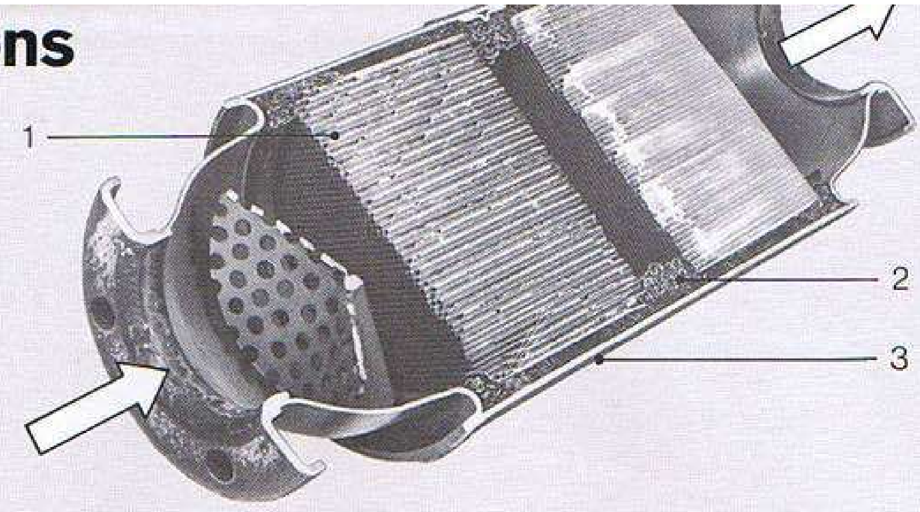
Adaptation of the air-fuel mixture at high altitudes

The low density of the air at high altitudes necessitates a leaner air-fuel mixture.

At high altitudes, due to the lower air density, the volumetric flow measured by the air-flow sensor corresponds to a lower air-mass flow. Depending upon the facilities incorporated in the particular KE-Jetronic, this error can be compensated for by correcting the injection time. Over-enrichment is avoided and, therefore, excessive fuel consumption at high altitudes.
The altitude compensation is provided by a sensor which measures the air pressure. In accordance with the prevailing air pressure, the sensor inputs a signal to the ECU which changes the pressure-actuator current accordingly. This alters the lower-chamber pressure, and therefore the pressure difference at the metering slits, and this results in a change in the injected fuel quantity.
It is also possible to incorporate continuous adaptation of the injected fuel quantity according to the changing air pressure.

Text to Fig. 45
At considerable heights above sea level, there is a significant difference between the measured air quantity and its actual mass. This is due to air density decreasing at high altitudes. A barometric altitude sensor measures the air pressure and reports this to the ECU which adjusts the injected fuel quantity accordingly by means of the electrohydraulic pressure actuator.

Clean emissions



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 driveability, 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.

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 (Fig. 48) 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 (NO_x) to nitrogen (N).

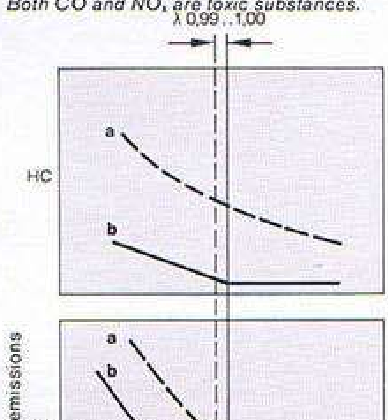
It is therefore perfectly clear that the catalytic aftertreatment of the exhaust gas is considerably more effective than for instance the purely thermal afterburning of the exhaust gases in a thermal reactor.

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. The converter shell contains a ceramic "honeycomb" which is coated with a noble metal, preferably platinum. When the exhaust gas flows through this honeycomb, the platinum accelerates the chemical conversion of the toxic substances. Only lead-free gasoline may be used with such converters because the lead otherwise destroys the catalytic property of the noble-metal catalyst. At present, lead-free gasoline is only available in Japan and in the USA, and to a limited extent in the Federal Republic of Germany. For this reason, catalytic converters can only be used in these countries.
The prerequisite for catalytic conversion is that the engine burns an optimum air-fuel mixture. This optimum, or stoichiometric, mixture (see Page 4) is arrived at when precisely that amount of fuel is injected for the inducted air quantity in order to ensure that, theoretically, perfect combustion can take place. Such an air-fuel mixture is characterized by the excess-air factor $\lambda = 1.00$. With this excess-air factor, the catalytic converter operates with high efficiency.
This means therefore, that the actual difficulty encountered when using "catalytic aftertreatment" lies in maintaining λ at precisely 1.00 for all operating modes, because even a deviation of only 1% has considerable adverse effects on 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 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. 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 fuel quantity. This is referred to as a closed control loop. The Lambda oxygen sensor facility incorporated in the KE-Jetronic system converts what would otherwise be an open-loop control into a closed-loop control. This form of control is particularly effective on fuel-injection engines because they do not have the additional delay times caused by the long intake paths found on carburetor engines.

48) Catalytic converter.
When exhaust gases flow through the catalytic converter, the platinum accelerates the chemical decomposition of the toxic substances.
1 Ceramic material coated with catalytically active material (platinum), 2 Steel wool for locating purposes, 3 Converter shell.

49) Effectiveness of the catalytic aftertreatment of exhaust gas using the Lambda closed-loop control.
Range for optimum air-fuel mixture: $\lambda = 0.99 \dots 1.00$. Toxic content: a = without aftertreatment, b = with aftertreatment, HC hydrocarbons, CO carbon monoxide, NO_x oxides of nitrogen. The diagram below demonstrates the considerable extent to which exhaust-gas emissions can be reduced by the application of catalytic aftertreatment and by the air-fuel mixture. The absolute necessity for a high degree of control accuracy is shown by the pronounced increase in carbon monoxide (CO) just below the $\lambda = 1.00$ point, as well as by the sudden jump in the oxides of nitrogen (NO_x) content just above the $\lambda = 1.00$ point. Both CO and NO_x are toxic substances.



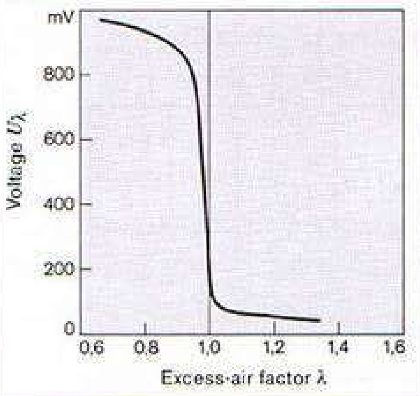
Lambda closed-loop control

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.

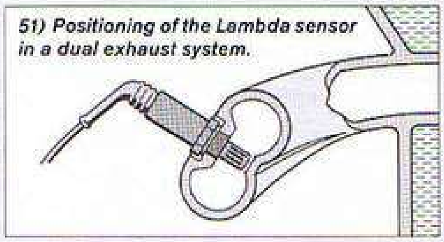
Operation

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.

50) Voltage signal from the Lambda sensor.



51) Positioning of the Lambda sensor in a dual exhaust system.



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 (Fig. 50).

Construction

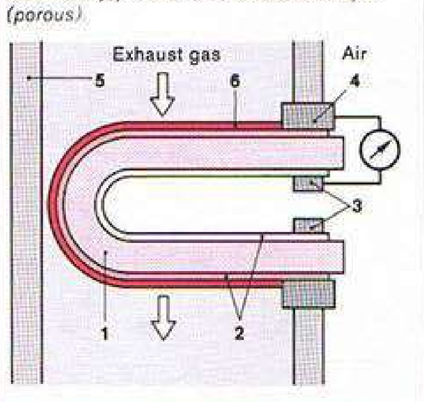
The ceramic sensor body is held in a threaded mounting and provided with a protective tube and electrical connections. The surface of the sensor ceramic body has a microporous platinum layer which on the one side decisively influences the sensor characteristic while on the other serving as an electrical 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 combustion 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.

Lambda closed-loop control

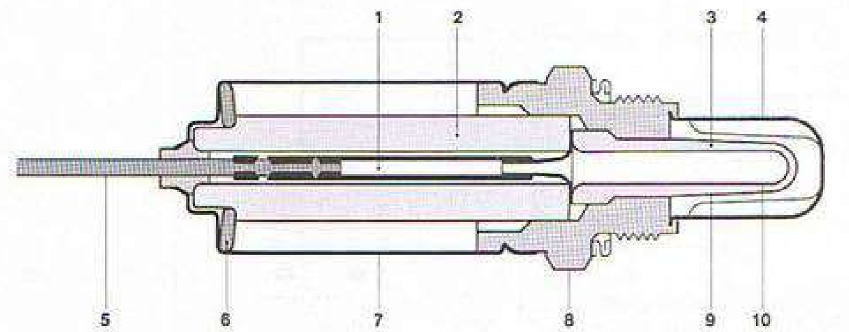
By means of the Lambda closed-loop control, the air-fuel ratio can be maintained very accurately at λ = 1.00

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. This influences the correction of the injected-fuel quantity which has been worked out electronically by the KE-Jetronic. Using this concept, it is possible to control the fuel metering so accurately that the air-fuel ratio is optimum in all operating ranges independent of load and engine speed. Tolerances and the effects of engine ageing are of no importance. If, for instance, λ = 1.03 (slightly lean mixture), the Lambda control circuit compensates for this excess air by increasing the amount of fuel injected.
The process is reversed if the mixture is slightly rich (e.g. λ = 0.97). This continuing adjustment of the mixture to the λ = 1.00 figure is the prerequisite for ensuring that the upstream catalytic converter can carry out the aftertreatment of the exhaust gas with maximum efficiency.

52) Function of the Lambda sensor.
1 Sensor ceramic, 2 Electrodes, 3 Contacts, 4 Electrical contacting to the housing, 5 Exhaust pipe, 6 Protective ceramic layer (porous).



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

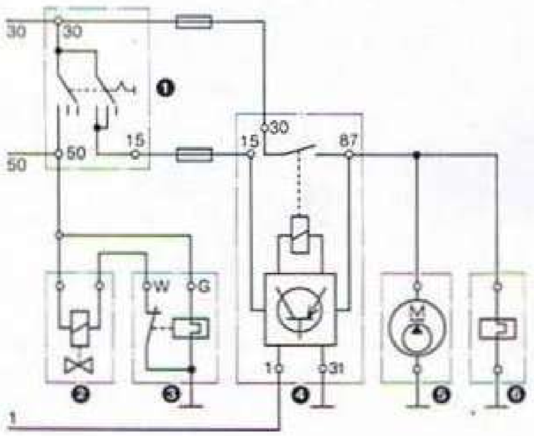


Electrical circuitry

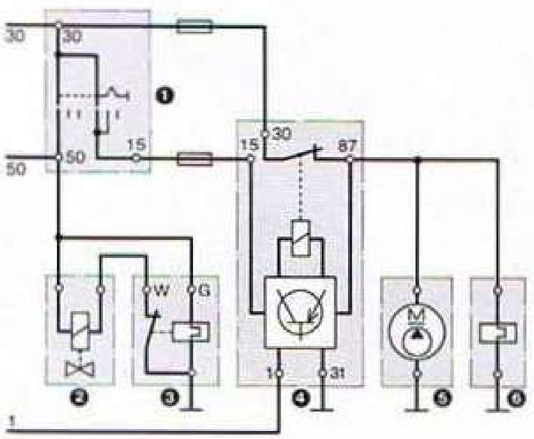
<u>The control relay switches the electric fuel pump, the auxiliary-air device, the cold-start valve, and the thermo-time switch.</u>

During cranking, the ignition and starting switch applies voltage to the control relay (Fig. 55) which switches on as soon as the engine turns. Here, the engine speed reached by the engine when it is cranked by the starter suffices for the relay to be switched on. Engine start is signalled by the pulses from Terminal 1 of the ignition coil which are evaluated by the electronic circuitry in the control relay. Upon receipt of the first pulse, the control relay switches on and applies voltage to the electric fuel pump and the auxiliary-air device. If the pulses from the ignition coil are interrupted (for instance due to an accident) the control relay switches off about 1 second after the last pulse is received. This safety circuit thus prevents the fuel pump from continuing to deliver fuel when the engine is stationary and the ignition is switched on.

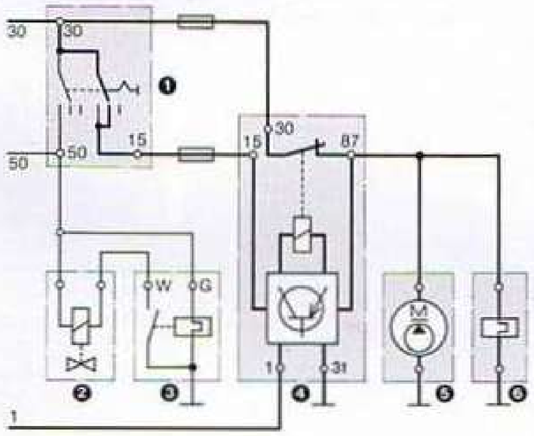
54) Circuitry with the engine stationary (without ECU).
1 Ignition and starting switch, 2 Cold-start valve, 3 Thermo-time switch, 4 Control relay, 5 Electric fuel pump, 6 Auxiliary-air device.



55) Circuitry during cranking (engine cold).
The cold-start valve and the thermo-time switch are switched on.
The engine turns (pulses from terminal 1 of the ignition coil).
The control relay, electric fuel pump, and auxiliary-air device are switched on.



56) Engine running.
Ignition switched on, engine running.
The control relay, electric fuel pump, and auxiliary-air device are switched on.



57) Ignition switched on, engine stationary.
No pulses coming from ignition coil terminal 1.
The control relay, electric fuel pump, and auxiliary-air device are switched off.