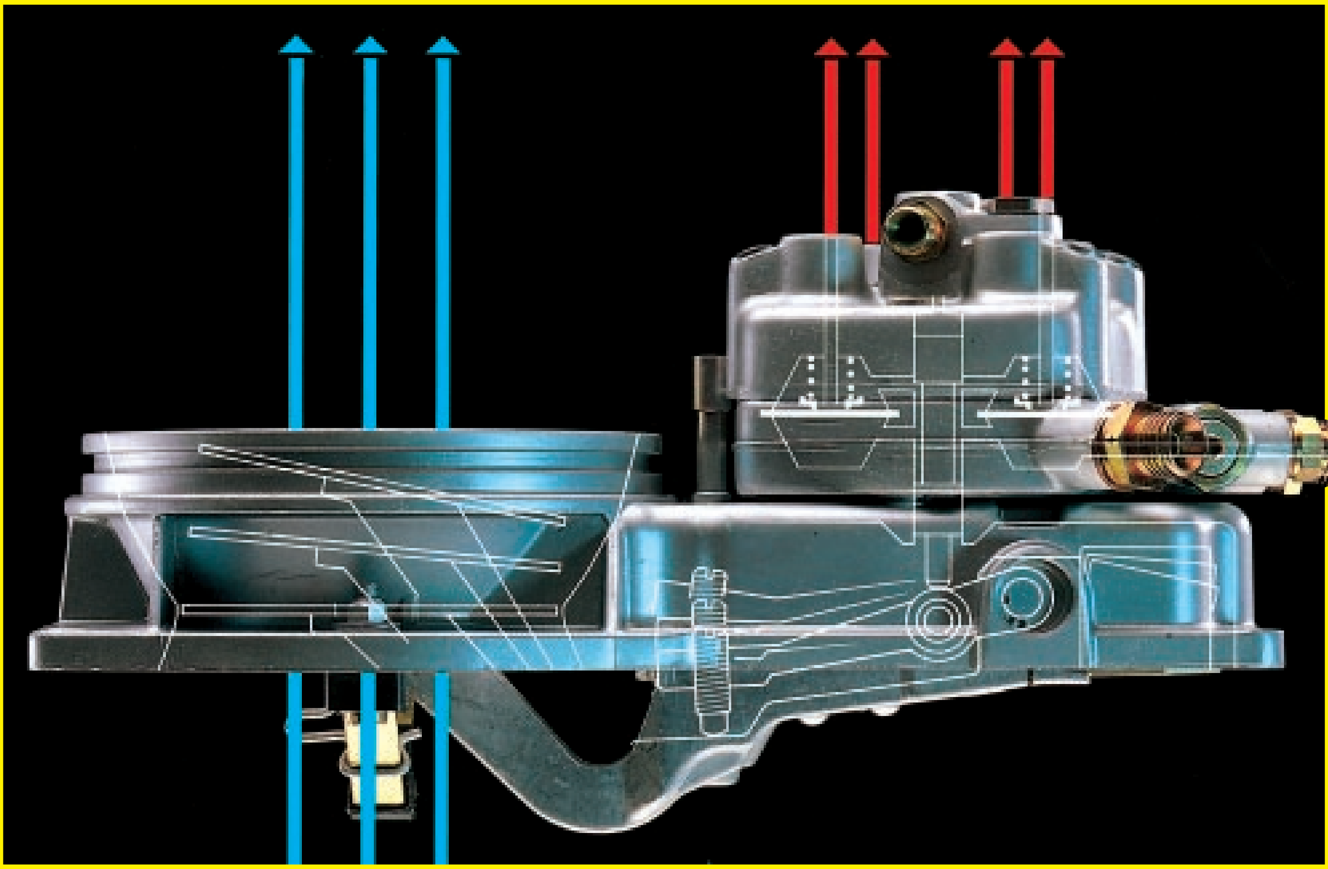
Gasoline-engine management

Gasoline Fuel-Injection System K-Jetronic



Technical Instruction

BOSCH

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K-Jetronic

Since its introduction, the K-Jetronic gasoline-injection system has proved itself in millions of vehicles.
This development was a direct result of the advantages which are inherent in the injection of gasoline with regard to demands for economy of operation, high output power, and last but not least improvements to the quality of the exhaust gases emitted by the vehicle. Whereas the call for higher engine output was the foremost consideration at the start of the development work on gasoline injection, today the target is to achieve higher fuel economy and lower toxic emissions.
Between the years 1973 and 1995, the highly reliable, mechanical multipoint injection system K-Jetronic was installed as Original Equipment in series-production vehicles. Today, it has been superseded by gasoline injection systems which thanks to electronics have been vastly improved and expanded in their functions. Since this point, the K-Jetronic has now become particularly important with regard to maintenance and repair.

This manual will describe the K-Jetronic's function and its particular features.

Combustion in the gasoline engine

Gasoline-engine management

Gasoline-injection systems

K-Jetronic

Combustion in the gasoline engine

The spark-ignition or Otto-cycle engine

Operating concept

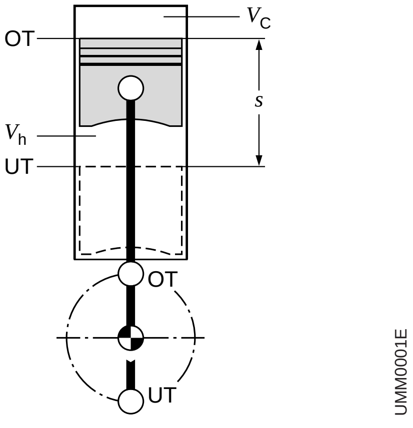
The spark-ignition or Otto-cycle[1]) powerplant is an internal-combustion (IC) engine that relies on an externally-generated ignition spark to transform the chemical energy contained in fuel into kinetic energy.

Today's standard spark-ignition engines employ manifold injection for mixture formation outside the combustion chamber. The mixture formation system produces an air/fuel mixture (based on gasoline or a gaseous fuel), which is then drawn into the engine by the suction generated as the pistons descend. The future will see increasing application of systems that inject the fuel directly into the combustion chamber as an alternate concept. As the piston rises, it compresses the mixture in preparation for the timed ignition process, in which externally-generated energy initiates combustion via the spark plug. The heat released in the combustion process pressurizes the cylinder, propelling the piston back down, exerting force against the crankshaft and performing work. After each combustion stroke the spent gases are expelled from the cylinder in preparation for ingestion of a fresh charge of air/fuel mixture. The primary design concept used to govern this gas transfer in powerplants for automotive applications is the four-stroke principle, with two crankshaft revolutions being required for each complete cycle.

Fig. 1

Reciprocating piston-engine design concept

OT = TDC (Top Dead Center); UT = BDC (Bottom Dead Center), V_h Swept volume, V_C Compressed volume, s Piston stroke.



The four-stroke principle

The four-stroke engine employs flow-control valves to govern gas transfer (charge control). These valves open and close the intake and exhaust tracts leading to and from the cylinder:

1st stroke: Induction,
2nd stroke: Compression and ignition,
3rd stroke: Combustion and work,
4th stroke: Exhaust.

Induction stroke
Intake valve: open,
Exhaust valve: closed,
Piston travel: downward,
Combustion: none.

The piston's downward motion increases the cylinder's effective volume to draw fresh air/fuel mixture through the passage exposed by the open intake valve.

Compression stroke
Intake valve: closed,
Exhaust valve: closed,
Piston travel: upward,
Combustion: initial ignition phase.

---

[1]) After Nikolaus August Otto (1832–1891), who unveiled the first four-stroke gas-compression engine at the Paris World Exhibition in 1876.

Otto cycle

As the piston travels upward it reduces the cylinder's effective volume to compress the air/fuel mixture. Just before the piston reaches top dead center (TDC) the spark plug ignites the concentrated air/fuel mixture to initiate combustion.
Stroke volume V_h
and compression volume V_C
provide the basis for calculating the compression ratio
$\varepsilon = (V_h + V_C)/V_C$.
Compression ratios ε range from 7...13, depending upon specific engine design. Raising an IC engine's compression ratio increases its thermal efficiency, allowing more efficient use of the fuel. As an example, increasing the compression ratio from 6:1 to 8:1 enhances thermal efficiency by a factor of 12 %. The latitude for increasing compression ratio is restricted by knock. This term refers to uncontrolled mixture inflammation characterized by radical pressure peaks. Combustion knock leads to engine damage. Suitable fuels and favorable combustion-chamber configurations can be applied to shift the knock threshold into higher compression ranges.

Power stroke
Intake valve: closed,
Exhaust valve: closed,
Piston travel: upward,
Combustion: combustion/post-combustion phase.

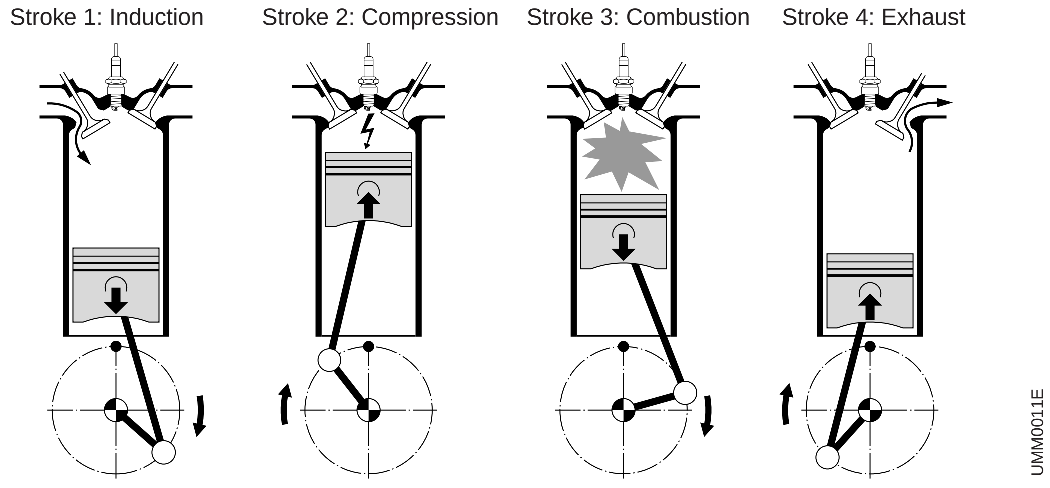
The ignition spark at the spark plug ignites the compressed air/fuel mixture, thus initiating combustion and the attendant temperature rise.
This raises pressure levels within the cylinder to propel the piston downward. The piston, in turn, exerts force against the crankshaft to perform work; this process is the source of the engine's power.
Power rises as a function of engine speed and torque ($P = M \cdot \omega$).
A transmission incorporating various conversion ratios is required to adapt the combustion engine's power and torque curves to the demands of automotive operation under real-world conditions.

Exhaust stroke
Intake valve: closed,
Exhaust valve: open,
Piston travel: upward,
Combustion: none.

As the piston travels upward it forces the spent gases (exhaust) out through the passage exposed by the open exhaust valve. The entire cycle then recommences with a new intake stroke. The intake and exhaust valves are open simultaneously during part of the cycle. This overlap exploits gas-flow and resonance patterns to promote cylinder charging and scavenging.

Fig. 2

Operating cycle of the 4-stroke spark-ignition engine



Gasoline-engine management

Technical requirements

Spark-ignition (SI) engine torque

The power P furnished by the spark-ignition engine is determined by the available net flywheel torque and the engine speed.

The net flywheel torque consists of the force generated in the combustion process minus frictional losses (internal friction within the engine), the gas-exchange losses and the torque required to drive the engine ancillaries (Figure 1).

The combustion force is generated during the power stroke and is defined by the following factors:

- The mass of the air available for combustion once the intake valves have closed,
- The mass of the simultaneously available fuel, and
- The point at which the ignition spark initiates combustion of the air/fuel mixture.

Primary engine-management functions

The engine-management system’s first and foremost task is to regulate the engine’s torque generation by controlling all of those functions and factors in the various engine-management subsystems that determine how much torque is generated.

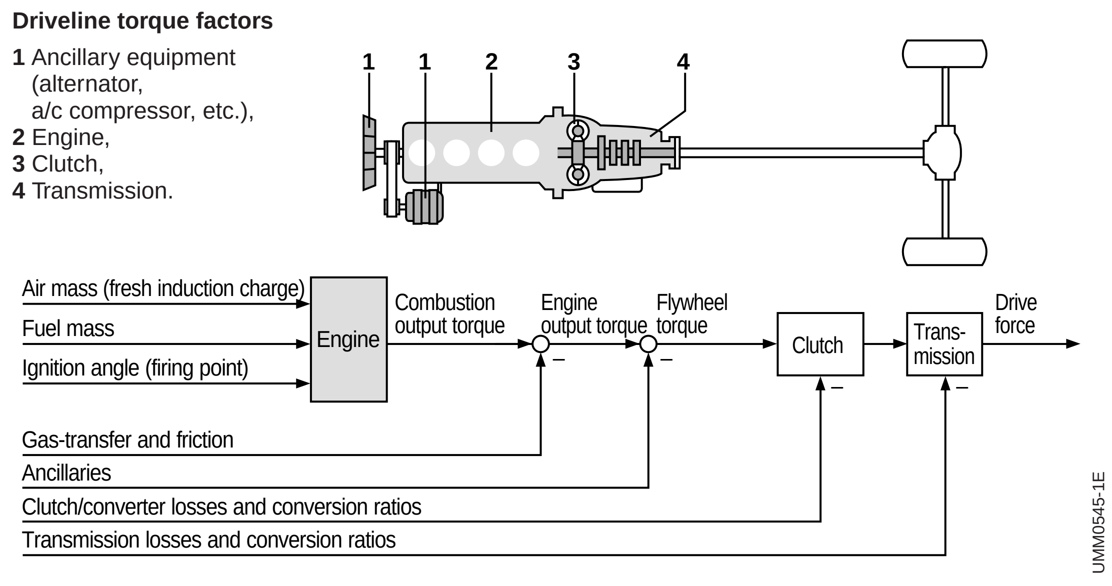
Cylinder-charge control

In Bosch engine-management systems featuring electronic throttle control (ETC), the “cylinder-charge control” subsystem determines the required induction-air mass and adjusts the throttle-valve opening accordingly. The driver exercises direct control over throttle-valve opening on conventional injection systems via the physical link with the accelerator pedal.

Mixture formation

The “mixture formation” subsystem calculates the instantaneous mass fuel requirement as the basis for determining the correct injection duration and optimal injection timing.

Fig. 1



Driveline torque factors

1 Ancillary equipment (alternator, a/c compressor, etc.),
2 Engine,
3 Clutch,
4 Transmission.

Ignition
Finally, the “ignition” subsystem determines the crankshaft angle that corresponds to precisely the ideal instant for the spark to ignite the mixture.

The purpose of this closed-loop control system is to provide the torque demanded by the driver while at the same time satisfying strict criteria in the areas of
- Exhaust emissions,
- Fuel consumption,
- Power,
- Comfort and convenience, and
- Safety.

Cylinder charge

Elements

The gas mixture found in the cylinder once the intake valve closes is referred to as the cylinder charge, and consists of the inducted fresh air-fuel mixture along with residual gases.

Fresh gas
The fresh mixture drawn into the cylinder is a combination of fresh air and the fuel entrained with it. While most of the fresh air enters through the throttle valve, supplementary fresh gas can also be drawn in through the evaporative-emissions control system (Figure 2). The air entering through the throttle-valve and remaining in the cylinder after intake-valve closure is the decisive factor defining the amount of work transferred through the piston during combustion, and thus the prime determinant for the amount of torque generated by the engine. In consequence, modifications to enhance maximum engine power and torque almost always entail increasing the maximum possible cylinder charge. The theoretical maximum charge is defined by the volumetric capacity.

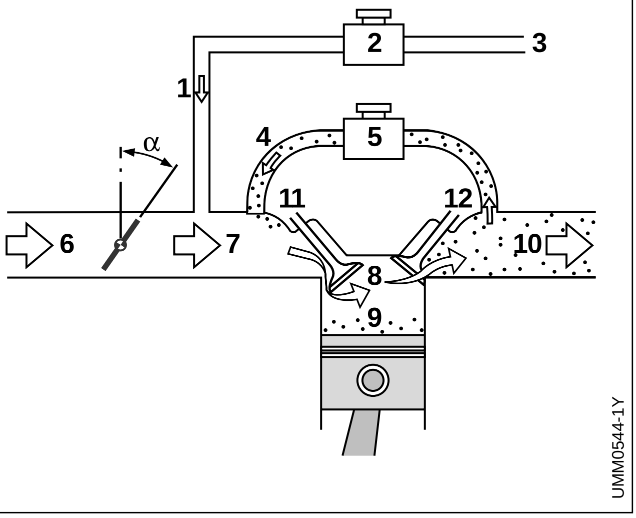
Residual gases
The portion of the charge consisting of residual gases is composed of
- The exhaust-gas mass that is not discharged while the exhaust valve is open and thus remains in the cylinder, and
- The mass of recirculated exhaust gas (on systems with exhaust-gas recirculation, Figure 2).

The proportion of residual gas is determined by the gas-exchange process.
Although the residual gas does not participate directly in combustion, it does influence ignition patterns and the actual combustion sequence. The effects of this residual-gas component may be thoroughly desirable under part-throttle operation.
Larger throttle-valve openings to compensate for reductions in fresh-gas filling

Fig. 2

Cylinder charge in the spark-ignition engine

1 Air and fuel vapor,
2 Purge valve with variable aperture,
3 Link to evaporative-emissions control system,
4 Exhaust gas,
5 EGR valve with variable aperture,
6 Mass airflow (barometric pressure p_U),
7 Mass airflow (intake-manifold pressure p_s),
8 Fresh air charge (combustion-chamber pressure p_B),
9 Residual gas charge (combustion-chamber pressure p_B),
10 Exhaust gas (back-pressure p_A),
11 Intake valve,
12 Exhaust valve,
α Throttle-valve angle.



are needed to meet higher torque demand. These higher angles reduce the engine's pumping losses, leading to lower fuel consumption. Precisely regulated injection of residual gases can also modify the combustion process to reduce emissions of nitrous oxides (NO_x) and unburned hydrocarbons (HC).

Control elements

Throttle valve

The power produced by the spark-ignition engine is directly proportional to the mass airflow entering it. Control of engine output and the corresponding torque at each engine speed is regulated by governing the amount of air being inducted via the throttle valve. Leaving the throttle valve partially closed restricts the amount of air being drawn into the engine and reduces torque generation. The extent of this throttling effect depends on the throttle valve's position and the size of the resulting aperture.

The engine produces maximum power when the throttle valve is fully open (WOT, or wide open throttle).

Figure 3 illustrates the conceptual correlation between fresh-air charge density and engine speed as a function of throttle-valve aperture.

Gas exchange

The intake and exhaust valves open and close at specific points to control the transfer of fresh and residual gases. The ramps on the camshaft lobes determine both the points and the rates at which the valves open and close (valve timing) to define the gas-exchange process, and with it the amount of fresh gas available for combustion.

Valve overlap defines the phase in which the intake and exhaust valves are open simultaneously, and is the prime factor in determining the amount of residual gas remaining in the cylinder. This process is known as "internal" exhaust-gas recirculation. The mass of residual gas can also be increased using "external" exhaust-gas recirculation, which relies on a supplementary EGR valve linking the intake and exhaust manifolds. The engine ingests a mixture of fresh air and exhaust gas when this valve is open.

Pressure charging

Because maximum possible torque is proportional to fresh-air charge density, it is possible to raise power output by compressing the air before it enters the cylinder.

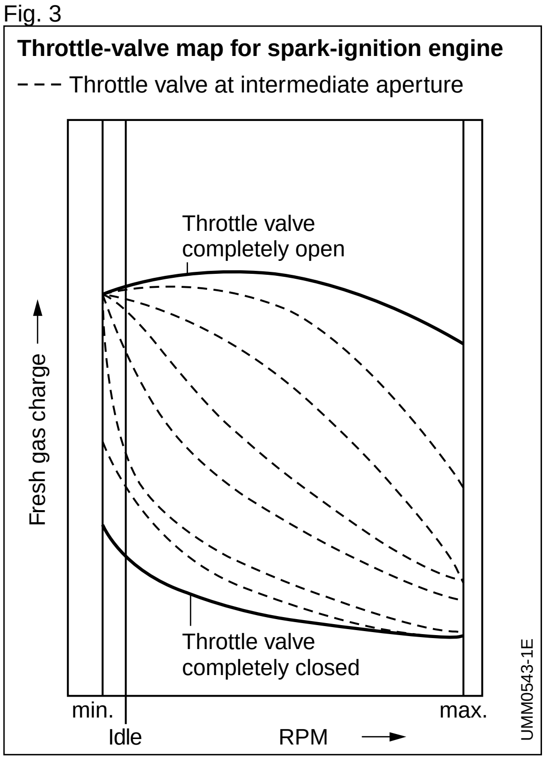
Dynamic pressure charging

A supercharging (or boost) effect can be obtained by exploiting dynamics within the intake manifold. The actual degree of boost will depend upon the manifold's configuration as well as the engine's instantaneous operating point (essentially a function of the engine's speed, but also affected by load factor). The option of varying intake-manifold geometry while the vehicle is actually being driven, makes it possible to employ dynamic precharging to increase the maximum available charge mass through a wide operational range.

Mechanical supercharging

Further increases in air mass are available through the agency of

Fig. 3



Throttle-valve map for spark-ignition engine

mechanically driven compressors powered by the engine's crankshaft, with the two elements usually rotating at an invariable relative ratio. Clutches are often used to control compressor activation.

Exhaust-gas turbochargers

Here the energy employed to power the compressor is extracted from the exhaust gas. This process uses the energy that naturally-aspirated engines cannot exploit directly owing to the inherent restrictions imposed by the gas expansion characteristics resulting from the crankshaft concept. One disadvantage is the higher back-pressure in the exhaust gas exiting the engine. This back-pressure stems from the force needed to maintain compressor output.

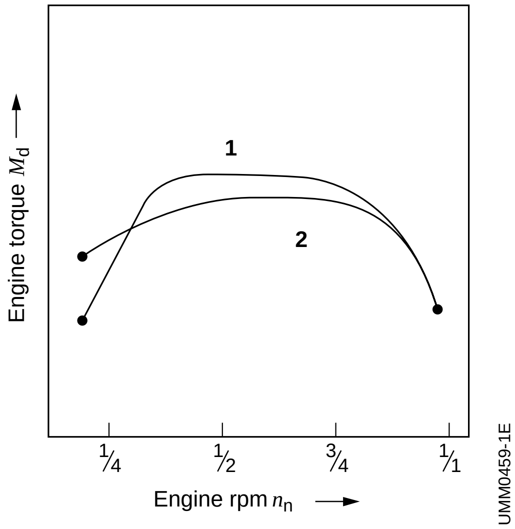
The exhaust turbine converts the exhaust-gas energy into mechanical energy, making it possible to employ an impeller to precompress the incoming fresh air. The turbocharger is thus a combination of the turbine in the exhaust-fas flow and the impeller that compresses the intake air.

Figure 4 illustrates the differences in the torque curves of a naturally-aspirated engine and a turbocharged engine.

Fig. 4

Torque curves for turbocharged and atmospheric-induction engines with equal power outputs

1 Engine with turbocharger,
2 Atmospheric-induction engine.



Mixture formation

Mixture formation

Parameters

Air-fuel mixture

Operation of the spark-ignition engine is contingent upon availability of a mixture with a specific air/fuel (A/F) ratio. The theoretical ideal for complete combustion is a mass ratio of 14.7:1, referred to as the stoichiometric ratio. In concrete terms this translates into a mass relationship of 14.7 kg of air to burn 1 kg of fuel, while the corresponding volumetric ratio is roughly 9,500 litres of air for complete combustion of 1 litre of fuel.

The air-fuel mixture is a major factor in determining the spark-ignition engine's rate of specific fuel consumption. Genuine complete combustion and absolutely minimal fuel consumption would be possible only with excess air, but here limits are imposed by such considerations as mixture flammability and the time available for combustion.

The air-fuel mixture is also vital in determining the efficiency of exhaust-gas treatment system. The current state-of-the-art features a 3-way catalytic converter, a device which relies on a stoichiometric A/F ratio to operate at maximum efficiency and reduce undesirable exhaust-gas components by more than 98 %.

Current engines therefore operate with a stoichiometric A/F ratio as soon as the engine's operating status permits

Certain engine operating conditions make mixture adjustments to non-stoichiometric ratios essential. With a cold engine for instance, where specific adjustments to the A/F ratio are required. As this implies, the mixture-formation system must be capable of responding to a range of variable requirements.

Excess-air factor

The designation l (lambda) has been selected to identify the excess-air factor (or air ratio) used to quantify the spread between the actual current mass A/F ratio and the theoretical optimum (14.7:1):

λ = Ratio of induction air mass to air requirement for stoichiometric combustion.

λ = 1: The inducted air mass corresponds to the theoretical requirement.

λ < 1: Indicates an air deficiency, producing a corresponding rich mixture. Maximum power is derived from λ = 0.85...0.95.

λ > 1: This range is characterized by excess air and lean mixture, leading to lower fuel consumption and reduced power. The potential maximum value for λ – called the “lean-burn limit (LML)” – is essentially defined by the design of the engine and of its mixture formation/induction system. Beyond the lean-burn limit the mixture ceases to be ignitable and combustion miss sets in, accompanied by substantial degeneration of operating smoothness.

In engines featuring systems to inject fuel directly into the chamber, these operate with substantially higher excess-air factors (extending to λ = 4) since combustion proceeds according to different laws.

Spark-ignition engines with manifold injection produce maximum power at air deficiencies of 5...15 % (λ = 0.95...0.85), but maximum fuel economy comes in at 10...20 % excess air (λ = 1.1...1.2).

Figures 1 and 2 illustrate the effect of the excess-air factor on power, specific fuel consumption and generation of toxic emissions. As can be seen, there is no single excess-air factor which can simultaneously generate the most favorable levels for all three factors. Air factors of λ = 0.9...1.1 produce “conditionally optimal” fuel economy with “conditionally optimal” power generation in actual practice.

Once the engine warms to its normal operating temperature, precise and consistent maintenance of λ = 1 is vital for the 3-way catalytic treatment of exhaust gases. Satisfying this requirement entails exact monitoring of induction-air mass and precise metering of fuel mass.

Optimal combustion from current engines equipped with manifold injection relies on formation of a homogenous mixture as well as precise metering of the injected fuel quantity. This makes effective atomization essential. Failure to satisfy this requirement will foster the formation of large droplets of condensed fuel on the walls of the intake tract and in the combustion chamber. These droplets will fail to combust completely and the ultimate result will be higher HC emissions.

Fig. 1

Effects of excess-air factor λ on power P and specific fuel consumption b_e.

a Rich mixture (air deficiency),
b Lean mixture (excess air).

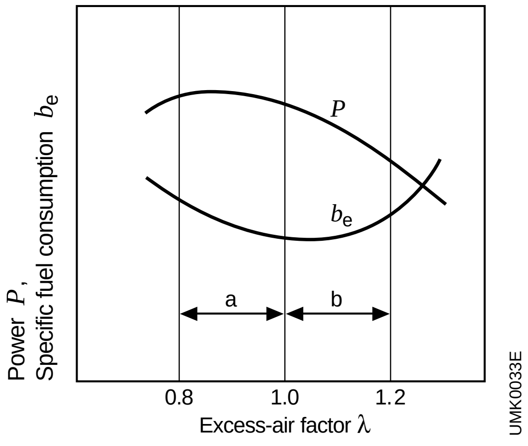
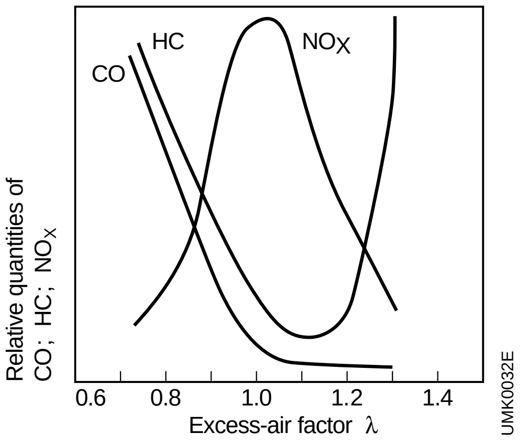


Fig. 2

Effect of excess-air factor λ on untreated exhaust emissions



Adapting to specific operating conditions

Certain operating states cause fuel requirements to deviate substantially from the steady-state requirements of an engine warmed to its normal temperature, thus necessitating corrective adaptations in the mixture-formation apparatus. The following descriptions apply to the conditions found in engines with manifold injection.

Cold starting

During cold starts the relative quantity of fuel in the inducted mixture decreases: the mixture “goes lean.” This lean-mixture phenomenon stems from inadequate blending of air and fuel, low rates of fuel vaporization, and condensation on the walls of the inlet tract, all of which are promoted by low temperatures. To compensate for these negative factors, and to facilitate cold starting, supplementary fuel must be injected into the engine.

Post-start phase

Following low-temperature starts, supplementary fuel is required for a brief period, until the combustion chamber heats up and improves the internal mixture formation. This richer mixture also increases torque to furnish a smoother transition to the desired idle speed.

Warm-up phase

The warm-up phase follows on the heels of the starting and immediate post-start phases. At this point the engine still requires an enriched mixture to offset the fuel condensation on the intake-manifold walls. Lower temperatures are synonymous with less efficient fuel processing (owing to factors such as poor mixing of air and fuel and reduced fuel vaporization). This promotes fuel precipitation within the intake manifold, with the formation of condensate fuel that will only vaporize later, once temperatures have increased. These factors make it necessary to provide progressive mixture enrichment in response to decreasing temperatures.

Idle and part-load

Idle is defined as the operating status in which the torque generated by the engine is just sufficient to compensate for friction losses. The engine does not provide power to the flywheel at idle. Part-load (or part-throttle) operation refers to the range of running conditions between idle and generation of maximum possible torque. Today’s standard concepts rely exclusively on stoichiometric mixtures for the operation of engines running at idle and part-throttle once they have warmed to their normal operating temperatures.

Full load (WOT)

At WOT (wide-open throttle) supplementary enrichment may be required. As Figure 1 indicates, this enrichment furnishes maximum torque and/or power.

Acceleration and deceleration

The fuel’s vaporization potential is strongly affected by pressure levels inside the intake manifold. Sudden variations in manifold pressure of the kind encountered in response to rapid changes in throttle-valve aperture cause fluctuations in the fuel layer on the walls of the intake tract. Spirited acceleration leads to higher manifold pressures. The fuel responds with lower vaporization rates and the fuel layer within the manifold runners expands. A portion of the injected fuel is thus lost in wall condensation, and the engine goes lean for a brief period, until the fuel layer restabilizes. In an analogous, but inverted, response pattern, sudden deceleration leads to rich mixtures. A temperature-sensitive correction function (transition compensation) adapts the mixture to maintain optimal operational response and ensure that the engine receives the consistent air/fuel mixture needed for efficient catalytic-converter performance.

Trailing throttle (overrun)

Fuel metering is interrupted during trailing throttle. Although this expedient saves fuel on downhill stretches, its primary purpose is to guard the catalytic converter against overheating stemming from poor and incomplete combustion (misfiring).

Gasoline-injection systems

Carburetors and gasoline-injection systems are designed for a single purpose: To supply the engine with the optimal air-fuel mixture for any given operating conditions. Gasoline injection systems, and electronic systems in particular, are better at maintaining air-fuel mixtures within precisely defined limits, which translates into superior performance in the areas of fuel economy, comfort and convenience, and power. Increasingly stringent mandates governing exhaust emissions have led to a total eclipse of the carburetor in favor of fuel injection.

Although current systems rely almost exclusively on mixture formation outside the combustion chamber, concepts based on internal mixture formation – with fuel being injected directly into the combustion chamber – were actually the foundation for the first gasoline-injection systems. As these systems are superb instruments for achieving further reductions in fuel consumption, they are now becoming an increasingly significant factor.

Overview

Systems with external mixture formation

The salient characteristic of this type of system is the fact that it forms the air-fuel mixture outside the combustion chamber, inside the intake manifold.

Multipoint fuel injection

Multipoint fuel injection forms the ideal basis for complying with the mixture-formation criteria described above. In this type of system each cylinder has its own injector discharging fuel into the area directly in front of the intake valve. Representative examples are the various versions of the KE and L-Jetronic systems (Figure 1).

Mechanical injection systems

The K-Jetronic system operates by injecting continually, without an external drive being necessary. Instead of being determined by the injection valve, fuel mass is regulated by the fuel distributor.

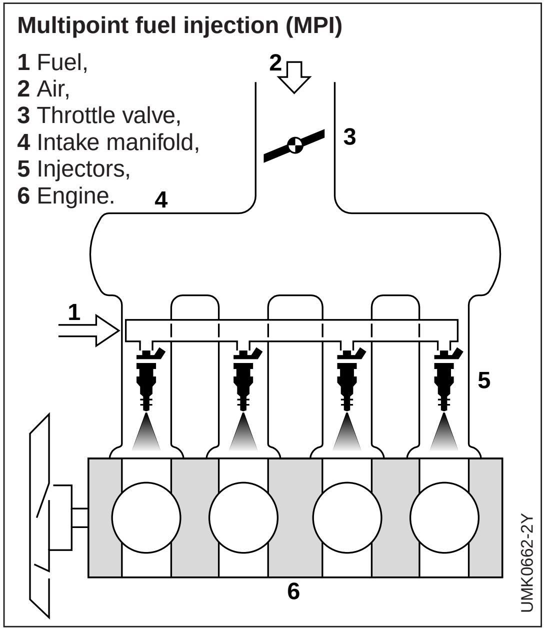
Combined mechanical-electronic fuel injection

Although the K-Jetronic layout served as the mechanical basis for the KE-Jetronic system, the latter employs expanded data-monitoring functions for more precise adaptation of injected fuel quantity to specific engine operating conditions.

Electronic injection systems

Injection systems featuring electronic control rely on solenoid-operated injection

Fig. 1



Multipoint fuel injection (MPI)

1 Fuel,
2 Air,
3 Throttle valve,
4 Intake manifold,
5 Injectors,
6 Engine.

valves for intermittent fuel discharge. The actual injected fuel quantity is regulated by controlling the injector's opening time (with the pressure-loss gradient through the valve being taken into account in calculations as a known quantity).

Examples: L-Jetronic, LH-Jetronic, and Motronic as an integrated engine-management system.

Single-point fuel injection

Single-point (throttle-body injection (TBI)) fuel injection is the concept behind this electronically-controlled injection system in which a centrally located solenoid-operated injection valve mounted upstream from the throttle valve sprays fuel intermittently into the manifold. Mono-Jetronic and Mono-Motronic are the Bosch systems in this category (Figure 2).

Systems for internal mixture formation

Direct-injection (DI) systems rely on solenoid-operated injection valves to spray fuel directly into the combustion chamber; the actual mixture-formation process takes place within the cylinders, each of which has its own injector (Figure 3). Perfect atomization of the fuel emerging from the injectors is vital for efficient combustion.

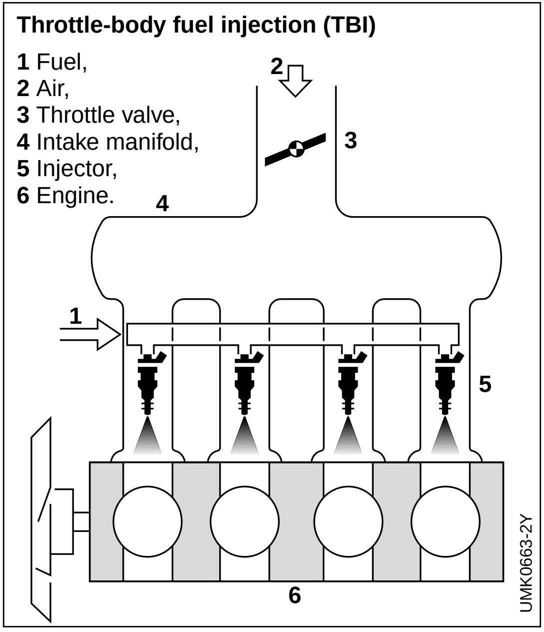
Under normal operating conditions, DI engines draw in only air instead of the combination of air and fuel common to conventional injection systems. This is one of the new system's prime advantages: It banishes all potential for fuel condensation within the runners of the intake manifold. External mixture formation usually provides a homogenous, stoichiometric air-fuel mixture throughout the entire combustion chamber. In contrast, shifting the mixture-preparation process into the combustion chamber provides for two distinctive operating modes:

With stratified-charge operation, only the mixture directly adjacent to the spark plug needs to be ignitable. The remainder of the air-fuel charge in the combustion chamber can consist solely of fresh and residual gases, without unburned fuel. This strategy furnishes an extremely lean overall mixture for idling and part-throttle operation, with commensurate reductions in fuel consumption.

Homogenous operation reflects the conditions encountered in external mixture formation by employing uniform consistency for the entire air-fuel charge throughout the combustion chamber. Under these conditions all of the fresh air within the chamber participates in the combustion process. This operational mode is employed for WOT operation.

MED-Motronic is used for closed-loop control of DI gasoline engines.

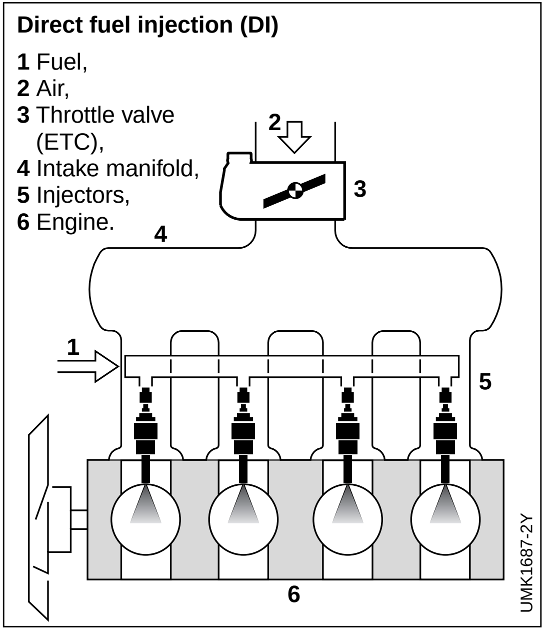
Fig. 2



Throttle-body fuel injection (TBI)

1 Fuel,
2 Air,
3 Throttle valve,
4 Intake manifold,
5 Injector,
6 Engine.

Fig. 3



Direct fuel injection (DI)

1 Fuel,
2 Air,
3 Throttle valve (ETC),
4 Intake manifold,
5 Injectors,
6 Engine.

The story of fuel injection

The story of fuel injection extends back to cover a period of almost one hundred years.

The Gasmotorenfabik Deutz was manufacturing plunger pumps for injecting fuel in a limited production series as early as 1898.

A short time later the uses of the venturi-effect for carburetor design were discovered, and fuel-injection systems based on the technology of the time ceased to be competitive.

Bosch started research on gasoline-injection pumps in 1912. The first aircraft engine featuring Bosch fuel injection, a 1,200-hp unit, entered series production in 1937; problems with carburetor icing and fire hazards had lent special impetus to fuel-injection development work for the aeronautics field. This development marks the beginning of the era of fuel injection at Bosch, but there was still a long path to travel on the way to fuel injection for passenger cars.

1951 saw a Bosch direct-injection unit being featured as standard equipment on a small car for the first time. Several years later a unit was installed in the 300 SL, the legendary production sports car from Daimler-Benz.

In the years that followed, development on mechanical injection pumps continued, and ...

In 1967 fuel injection took another giant step forward: The first electronic injection system: the intake-pressure-controlled D-Jetronic!

In 1973 the air-flow-controlled L-Jetronic appeared on the market, at the same time as the K-Jetronic, which featured mechanical-hydraulic control and was also an air-flow-controlled system.

In 1976, the K-Jetronic was the first automotive system to incorporate a Lambda closed-loop control.

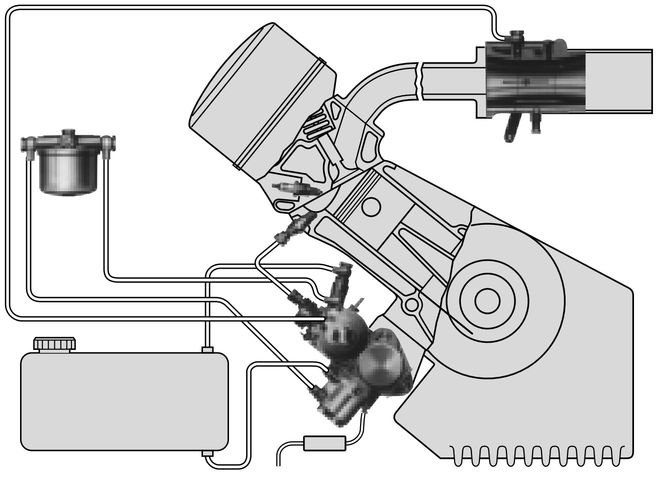
1979 marked the introduction of a new system: Motronic, featuring digital processing for numerous engine functions. This system combined L-Jetronic with electronic program-map control for the ignition. The first automotive microprocessor!

In 1982, the K-Jetronic model became available in an expanded configuration, the KE-Jetronic, including an electronic closed-loop control circuit and a Lambda oxygen sensor.

These were joined by Bosch Mono-Jetronic in 1987: This particularly cost-efficient single-point injection unit made it feasible to equip small vehicles with Jetronic, and once and for all made the carburetor absolutely superfluous.

By the end of 1997, around 64 million Bosch engine-management systems had been installed in countless types of vehicles since the introduction of the D-Jetronic in 1967. In 1997 alone, the figure was 4.2 million, comprised of 1 million throttle-body injection (TBI) systems and 3.2 million multipoint fuel-injection (MPI) systems.

Bosch gasoline fuel injection from the year 1954



K-Jetronic

System overview

The K-Jetronic is a mechanically and hydraulically controlled fuel-injection system which needs no form of drive and which meters the fuel as a function of the intake air quantity and injects it continuously onto the engine intake valves.
Specific operating conditions of the engine require corrective intervention in mixture formation and this is carried out by the K-Jetronic in order to optimize starting and driving performance, power output and exhaust composition. Owing to the direct air-flow sensing, the K-Jetronic system also allows for engine variations and permits the use of facilities for exhaust-gas aftertreatment for which precise metering of the intake air quantity is a prerequisite.
The K-Jetronic was originally designed as a purely mechanical injection system. Today, using auxiliary electronic equipment, the system also permits the use of lambda closed-loop control.
The K-Jetronic fuel-injection system covers the following functional areas:

– Fuel supply,
– Air-flow measurement and
– Fuel metering.

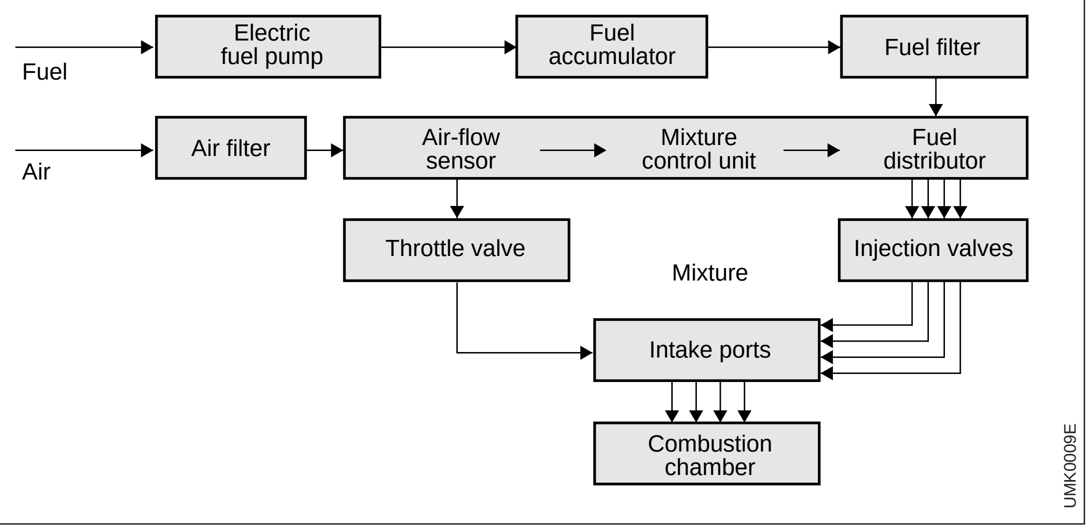
Fuel supply
An electrically driven fuel pump delivers the fuel to the fuel distributor via a fuel accumulator and a filter. The fuel distributor allocates this fuel to the injection valves of the individual cylinders.

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

Fuel metering
The amount of air, corresponding to the position of the throttle plate, drawn in by the engine serves as the criterion for metering of the fuel to the individual cylinders. The amount of air drawn in by the engine is measured by the air-flow sensor which, in turn, controls the fuel distributor. The air-flow sensor and the fuel distributor are assemblies which form part of the mixture control unit. Injection occurs continuously, i.e. without regard to the position of the intake valve. During the intake-valve closed phase, the fuel is "stored". Mixture enrichment is controlled in order to adapt to various operating conditions such as start, warm-up, idle and full load. In addition, supplementary functions such as overrun fuel cutoff, engine-speed limiting and closed-loop lambda control are possible.

Fig. 1

Functional schematic of the K-Jetronic



Fuel supply

The fuel supply system comprises
- Electric fuel pump,
- Fuel accumulator,
- Fine filter,
- Primary-pressure regulator and
- Injection valves.

An electrically driven roller-cell pump pumps the fuel from the fuel tank at a pressure of over 5 bar to a fuel accumulator and through a filter to the fuel distributor. From the fuel distributor the fuel flows to the injection valves. The injection valves inject the fuel continuously into the intake ports of the engine. Thus the system designation K (taken from the German for continuous). When the intake valves open, the mixture is drawn into the cylinder.

The fuel primary-pressure regulator maintains the supply pressure in the system constant and reroutes the excess fuel back to the fuel tank.

Owing to continual scavenging of the fuel supply system, there is always cool fuel available. This avoids the formation of fuel-vapor bubbles and achieves good hot starting behavior.

Electric fuel pump

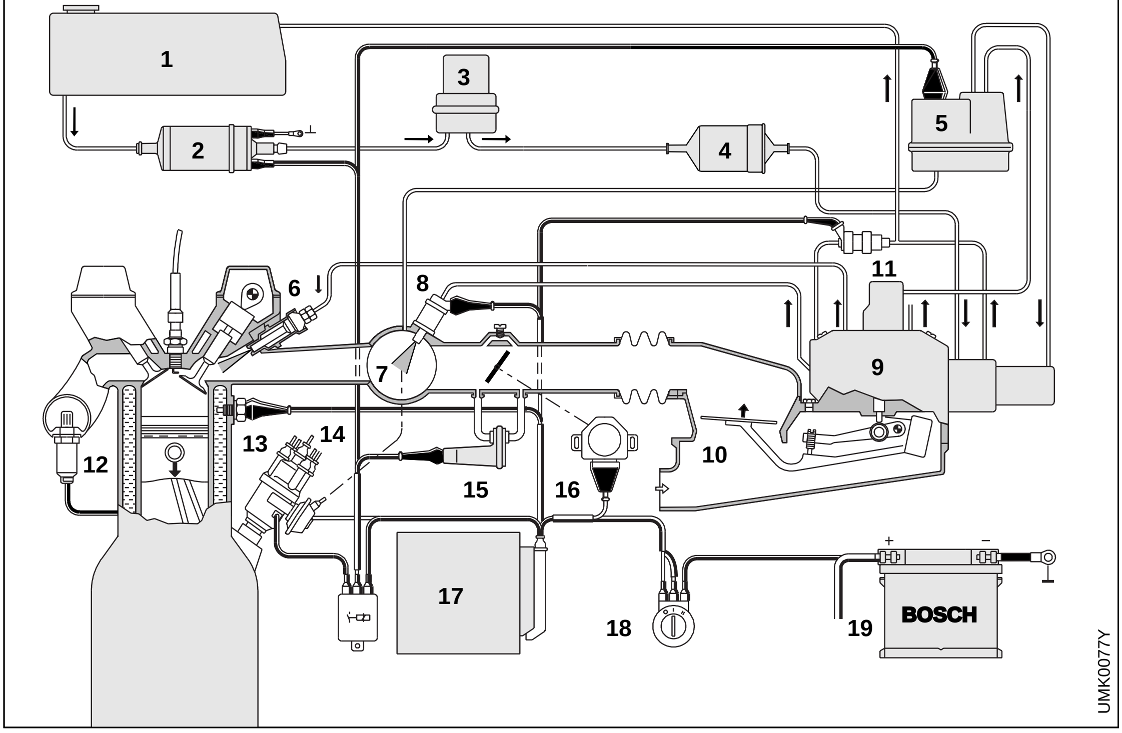
The electric fuel pump is a roller-cell pump driven by a permanent-magnet electric motor.

The rotor plate which is eccentrically mounted in the pump housing is fitted with metal rollers in notches around its circumference which are pressed against the pump housing by centrifugal force and act as rolling seals. The fuel is carried in the cavities which form between the rollers. The pumping action takes place when the rollers, after having closed the inlet bore, force the trapped fuel in front of them until it can escape from the pump through the outlet bore (Figure 4). The fuel flows directly around the electric motor. There is no danger of explosion, however, because there is never an ignitable mixture in the pump housing.

Fig. 2

Schematic diagram of the K-Jetronic system with closed-loop lambda control

1 Fuel tank, **2** Electric fuel pump, **3** Fuel accumulator, **4** Fuel filter, **5** Warm-up regulator, **6** Injection valve, **7** Intake manifold, **8** Cold-start valve, **9** Fuel distributor, **10** Air-flow sensor, **11** Timing valve, **12** Lambda sensor, **13** Thermo-time switch, **14** Ignition distributor, **15** Auxiliary-air device, **16** Throttle-valve switch, **17** ECU, **18** Ignition and starting switch, **19** Battery.



The electric fuel pump delivers more fuel than the maximum requirement of the engine so that compression in the fuel system can be maintained under all operating conditions. A check valve in the pump decouples the fuel system from the fuel tank by preventing reverse flow of fuel to the fuel tank.

The electric fuel pump starts to operate immediately when the ignition and starting switches are operated and remains switched on continuously after the engine has started. A safety circuit is incorporated to stop the pump running and, thus, to prevent fuel being delivered if the ignition is switched on but the engine has stopped turning (for instance in the case of an accident).

The fuel pump is located in the immediate vicinity of the fuel tank and requires no maintenance.

Fuel accumulator

The fuel accumulator maintains the pressure in the fuel system for a certain time after the engine has been switched off in order to facilitate restarting, particularly when the engine is hot. The special design of the accumulator housing (Figure 5) 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 whilst the other represents the compensation volume and is connected to the atmosphere or to the fuel tank by means of a vent fitting. 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.

Electric fuel pump

1 Suction side, **2** Pressure limiter, **3** Roller-cell pump, **4** Motor armature, **5** Check valve, **6** Pressure side.

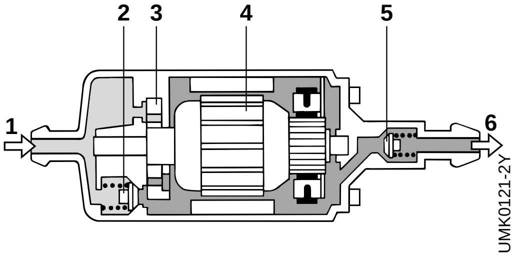


Fig. 3

Fig. 4

Operation of roller-cell pump

1 Suction side, **2** Rotor plate, **3** Roller, **4** Roller race plate, **5** Pressure side.

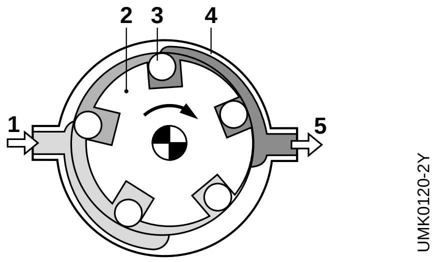
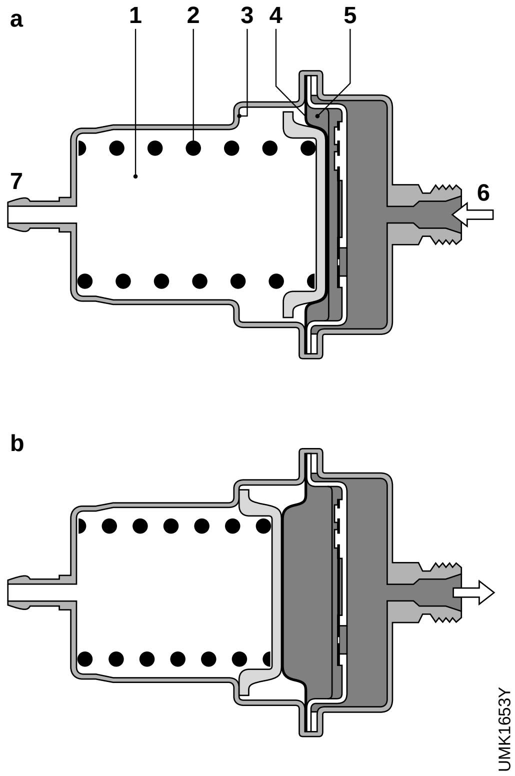


Fig. 5

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 filter

The fuel filter retains particles of dirt which are present in the fuel and which would otherwise have an adverse effect on the functioning of the injection system. The fuel filter contains a paper element with a mean pore size of 10 µm backed up by a fluff trap. This combination ensures a high degree of cleaning.

The filter is held in place in the housing by means of a support plate. It is fitted in the fuel line downstream from the fuel accumulator and its service life depends upon the amount of dirt in the fuel. It is imperative that the arrow on the filter housing showing the direction of fuel flow through the filter is observed when the filter is replaced.

Fuel filter

1 Paper element,
2 Strainer,
3 Support plate.

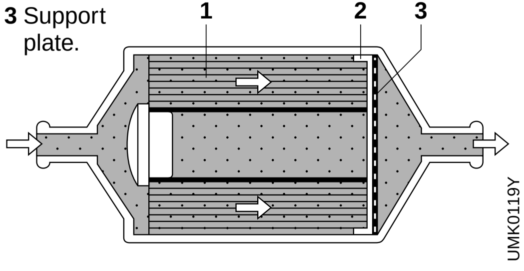


Fig. 6

Primary-pressure regulator

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

It is incorporated in the fuel distributor and holds the delivery pressure (system pressure) at about 5 bar. The fuel pump always delivers more fuel than is required by the vehicle engine, and this causes a plunger to shift in the pressure regulator and open a port through which excess fuel can return to the tank.

The pressure in the fuel system and the force exerted by the spring on the pressure-regulator plunger balance each other out. If, for instance, fuel-pump delivery drops slightly, the plunger is shifted by the spring to a corresponding new position and in doing so closes off the port slightly through which the excess fuel returns to the tank. This means that less fuel is diverted off at this point and the system pressure is controlled to its specified level.

When the engine is switched off, the fuel pump also switches off and the primary pressure drops below the opening pressure of the injection valves. The pressure regulator then closes the return-flow port and thus prevents the pressure in the fuel system from sinking any further (Fig. 8).

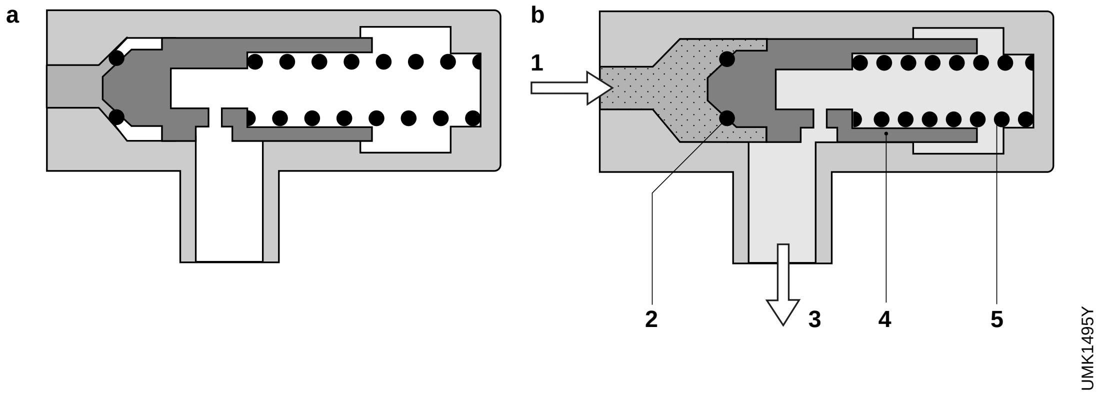
Fuel-injection valves

The injection valves open at a given pressure and atomize the fuel through oscillation of the valve needle. The injection valves inject the fuel metered to them into the intake passages and onto the intake valves. They are secured in special

Fig. 7

Primary-pressure regulator fitted to fuel distributor

a In rest position, **b** In actuated position.
1 System-pressure entry, **2** Seal, **3** Return to fuel tank, **4** Plunger, **5** Spring.



holders to insulate them against the heat radiated from the engine. The injection valves have no metering function themselves, and open of their own accord when the opening pressure of e.g. 3.5 bar is exceeded. They are fitted with a valve needle (Fig. 9) which oscillates (“chatters”) audibly at high frequency when fuel is injected. This results in excellent atomization of the fuel even with the smallest of injection quantities. When the engine is switched off, the injection valves close tightly when the pressure in the fuel-supply system drops below their opening pressure. This means that no more fuel can enter the intake passages once the engine has stopped.

Air-shrouded fuel-injection valves

Air-shrouded injection valves improve the mixture formation particularly at idle. Using the pressure drop across the throttle valve, a portion of the air inducted by the engine is drawn into the cylinder through the injection valve (Fig. 20): The result is excellent atomization of the fuel at the point of exit (Fig. 10). Air-shrouded injection valves reduce fuel consumption and toxic emission constituents.

Pressure curve after engine switchoff

Firstly pressure falls from the normal system pressure (**1**) to the pressure-regulator closing pressure (**2**). The fuel accumulator then causes it to increase to the level (**3**) which is below the opening pressure (**4**) of the injection valves.

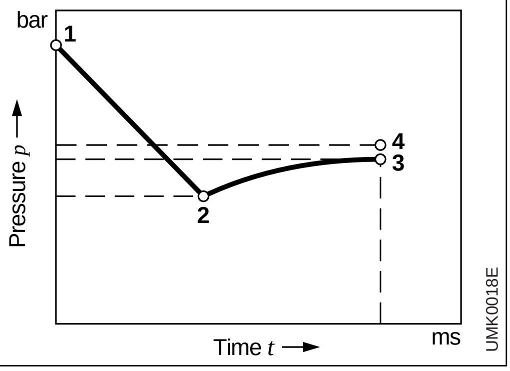


Fig. 8

Fig. 9

Fuel-injection valve

a In rest position,
b In actuated position.
1 Valve housing,
2 Filter,
3 Valve needle,
4 Valve seat.

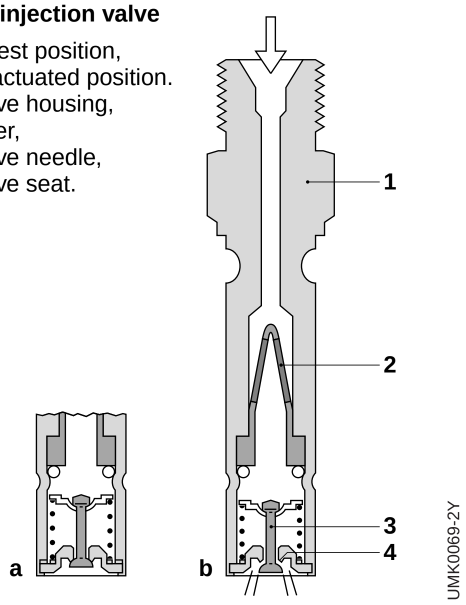
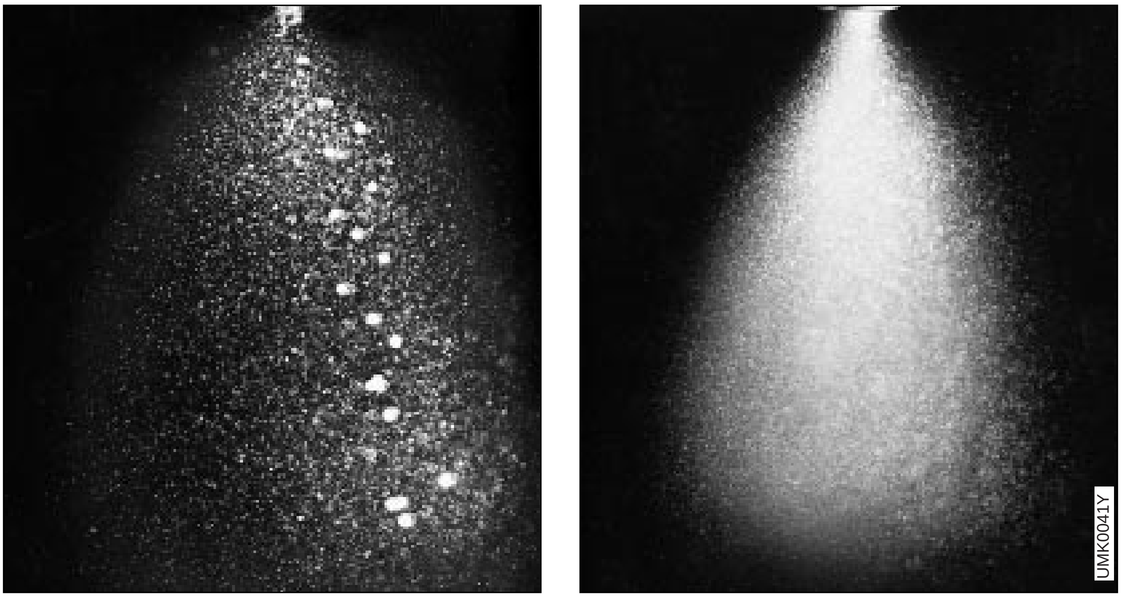


Fig. 10
Spray pattern of an injection valve without air-shrouding (left) and with air-shrouding (right).



Fuel metering

The task of the fuel-management system is to meter a quantity of fuel corresponding to the intake air quantity.

Basically, fuel metering is carried out by the mixture control unit. This comprises 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 mixture formation system (see section "Adaptation to operating conditions").

Air-flow sensor

The quantity of air drawn in by the engine is a precise measure of 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.

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.

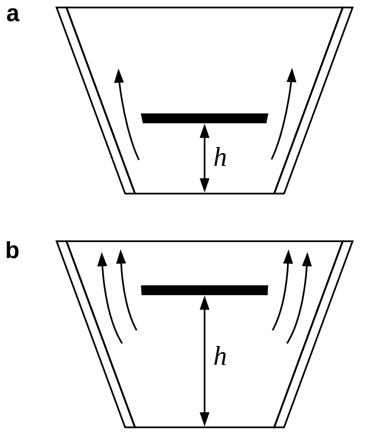


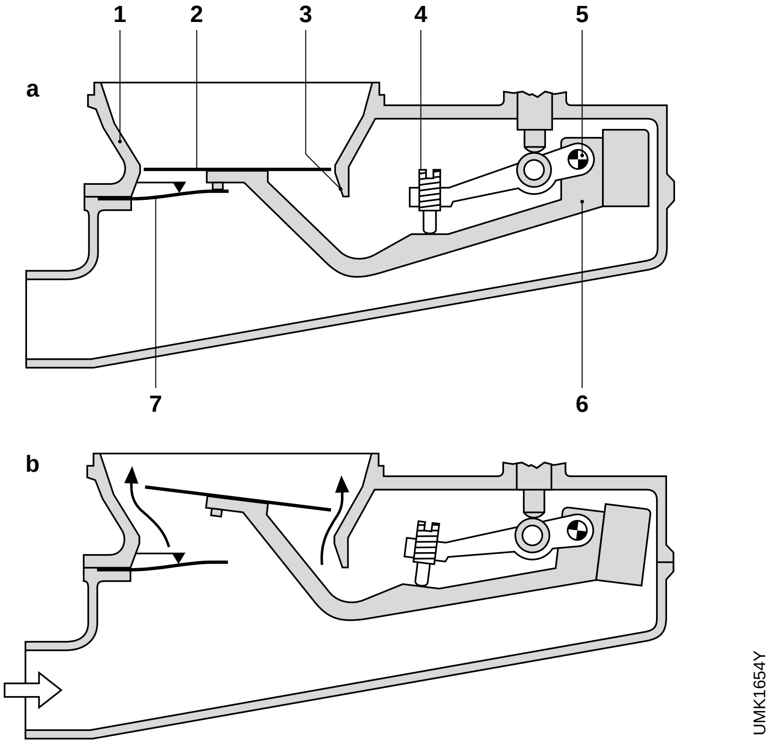
Fig. 11

Fig. 12

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 Pivot,
6 Lever,
7 Leaf spring.



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 plate (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 the event of misfire, and past its zero position to open a relief cross-section in the funnel. A rubber buffer limits the downward stroke (the upwards stroke on the downdraft air-flow sensor). A counterweight compensates for the weight of the sensor plate and lever system (this is carried out by an extension spring on the downdraft air-flow sensor). A leaf spring ensures the correct zero position in the switched-off phase.

Barrel with metering slits

1 Intake air, **2** Control pressure, **3** Fuel inlet,
4 Metered quantity of fuel, **5** Control plunger,
6 Barrel with metering slits, **7** Fuel distributor.

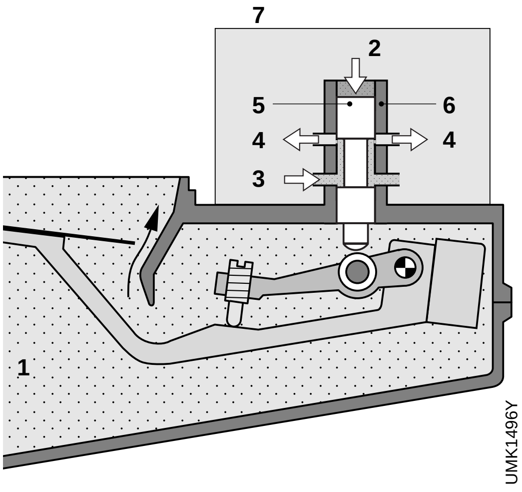


Fig. 13

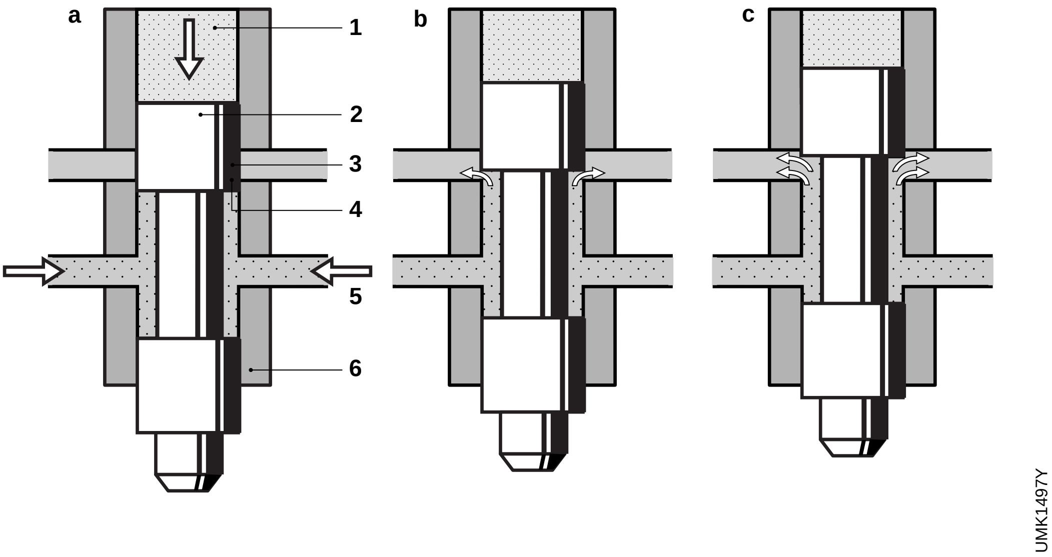
Fuel distributor

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

Fig. 14

Barrel with metering slits and control plunger

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



Depending upon its position in the barrel with metering slits, the control plunger opens or closes the slits to a greater or lesser extent. The fuel flows through the open section of the slits to the differential pressure valves and then to the fuel injection valves. If sensor-plate travel is only small, then the control plunger is lifted only slightly and, as a result, only a small section of the slit is opened for the passage of fuel. With larger plunger travel, the plunger opens a larger section of the slits and more fuel can flow. There is a linear relationship between sensor-plate travel and the slit section in the barrel which is opened for fuel flow.

A hydraulic force generated by the so-called control pressure is applied to the control plunger. It opposes the movement resulting from sensor-plate deflection. One of its functions is to ensure that the control plunger follows the sensor-plate movement immediately and does not, for instance, stick in the upper end position when the sensor plate moves down again. Further functions of the control pressure are discussed in the sections “Warm-up enrichment” and “Full-load enrichment”.

Control pressure

The control pressure is tapped from the primary pressure through a restriction bore (Figure 16). This restriction bore serves to decouple the control-pressure circuit and the primary-pressure circuit from one another. A connection line joins the fuel distributor and the warm-up regulator (control-pressure regulator).

When starting the cold engine, the control pressure is about 0.5 bar. As the engine warms up, the warm-up regulator increases the control pressure to about 3.7 bar (Figure 26).

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

Barrel with metering slits

The slits are shown enlarged (the actual slit is about 0.2 mm wide).

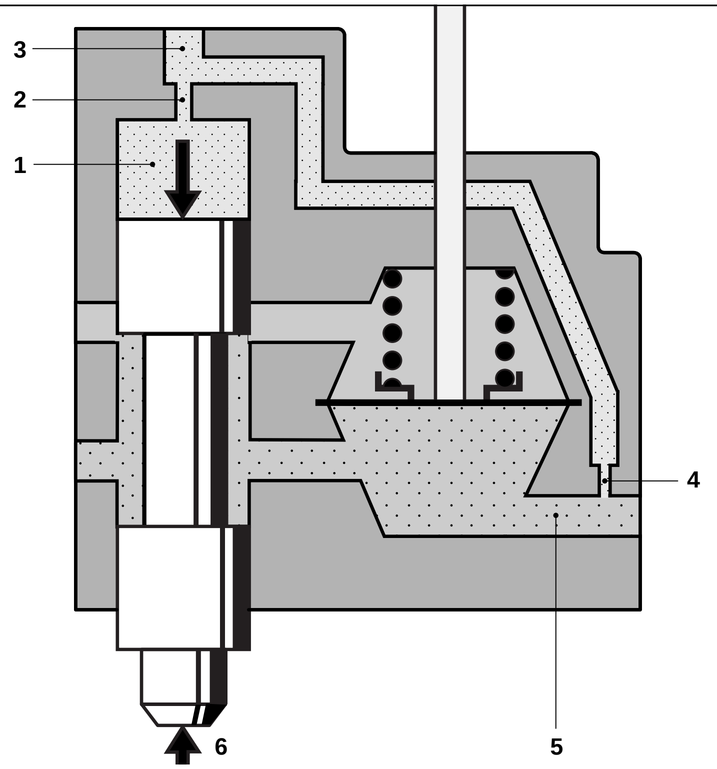
Fig. 15

The control pressure influences the fuel distribution. If the control pressure is low, the air drawn in by the engine can deflect the sensor plate further. This results in the control plunger opening the metering slits further and the engine being allocated more fuel. On the other hand, if the control pressure is high, the air drawn in by the engine cannot deflect the sensor plate so far and, as a result, the engine receives less fuel. In order to fully seal off the control-pressure circuit with absolute certainty when the engine has been switched off, and at the same time to maintain the pressure in the fuel circuit, the return line of the warm-up regulator is fitted with a check valve. This (push-up) valve is attached to the primary-pressure regulator and is held open during operation by the pressure-regulator plunger. When the engine is switched off and the plunger of the primary-pressure regulator returns to its zero position, the check valve is closed by a spring (Figure 17).

Differential-pressure valves

The differential-pressure valves in the fuel distributor result in a specific 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-

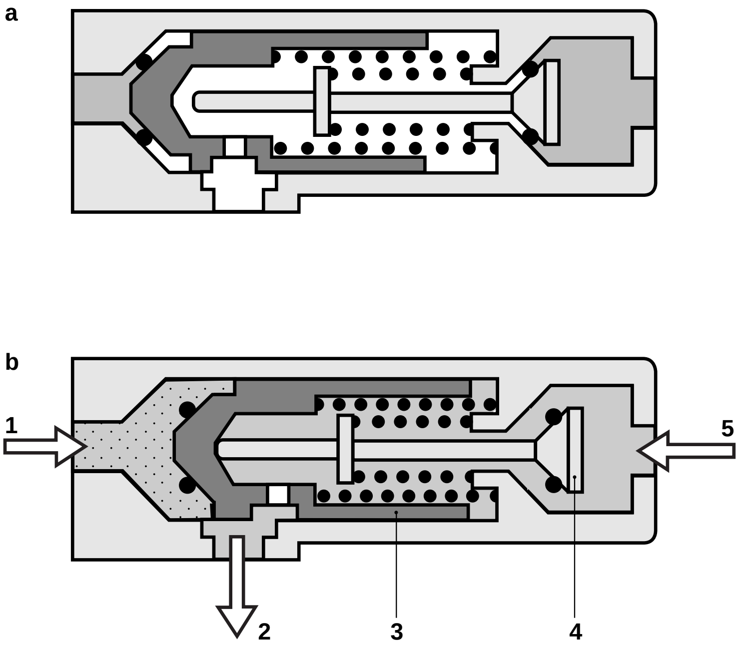


Primary pressure and control pressure

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

Fig. 16

Fig. 17



Primary-pressure regulator with push-up valve in the control-pressure circuit

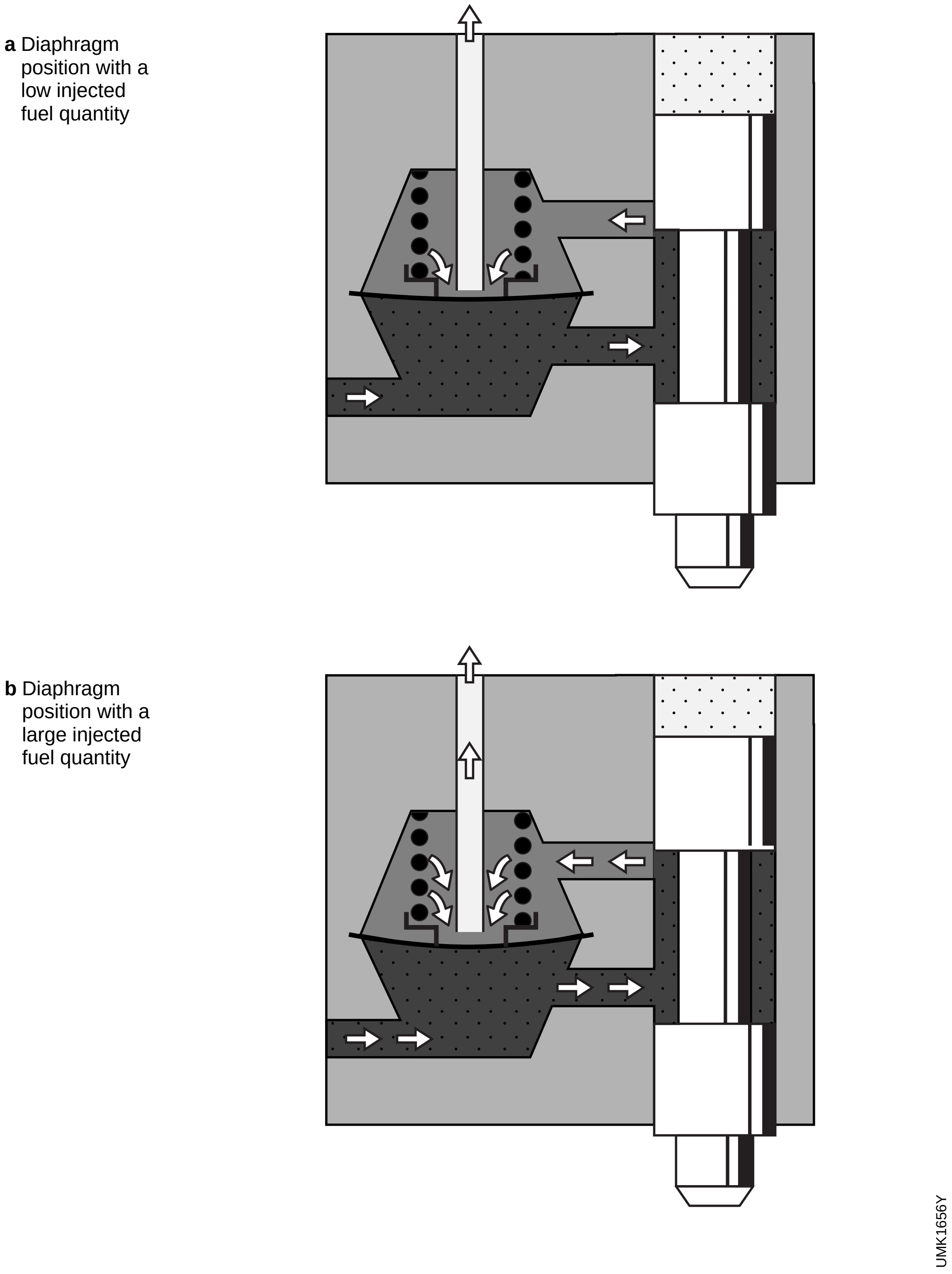
a In zero (inoperated) position,
b In operating position.
1 Primary pressure intake,
2 Return (to fuel tank),
3 Plunger of the primary-pressure regulator,
4 Push-up valve,
5 Control-pressure intake (from warm-up regulator).

plate travel is also doubled. If this travel is to result in a change of delivered fuel in the same relationship, in this case double the travel equals double the quantity, then a constant drop in pressure must be guaranteed at the metering slits (Figure 14), regardless of the amount of fuel flowing through them.

The differential-pressure valves maintain the differential pressure between the upper and lower chamber constant regardless of fuel throughflow. The differential pressure is 0.1 bar.

The differential-pressure valves achieve a high metering accuracy and are of the flat-seat type. They are fitted in the fuel

Differential-pressure valve



a Diaphragm position with a low injected fuel quantity

b Diaphragm position with a large injected fuel quantity

Fig. 18

distributor and one such valve is allocated to each metering slit. A diaphragm separates the upper and lower chambers of the valve (Figures 18 and 19). The lower chambers of all the valves are connected with one another by a ring main and are subjected to the primary pressure (delivery pressure). The valve seat is located in the upper chamber. Each upper chamber is connected to a metering slit and its corresponding connection to the fuel-injection line. The upper chambers are completely sealed off from each other. The diaphragms are spring-loaded and it is this helical spring that produces the pressure differential.

Fuel distributor with differential-pressure valves

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

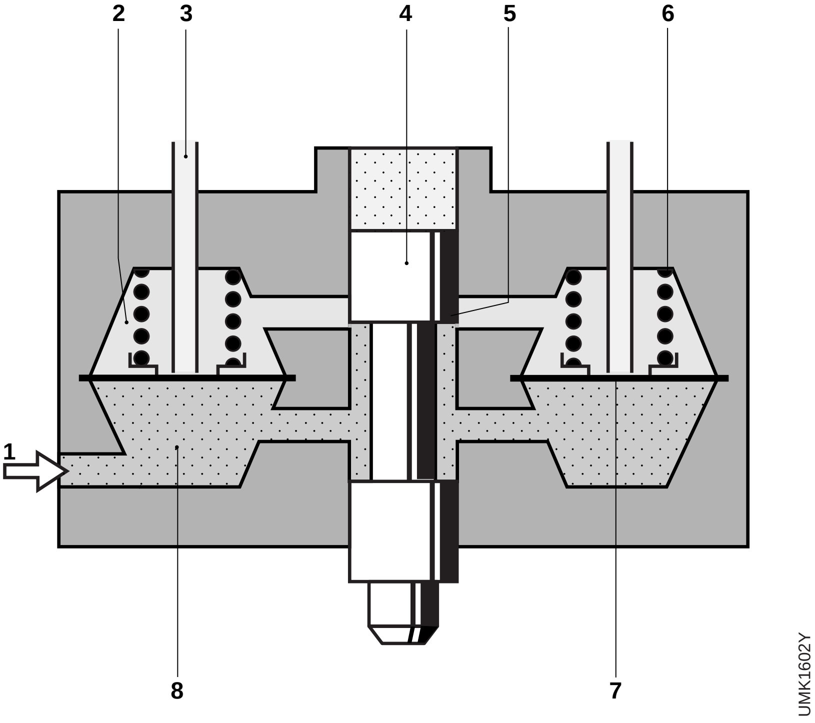


Fig. 19

If a large basic fuel quantity flows into the upper chamber through the metering slit, the diaphragm is bent downwards and enlarges the valve cross-section at the outlet leading to the injection valve until the set differential pressure once again prevails.

If the fuel quantity drops, the valve cross-section is reduced owing to the equilibrium of forces at the diaphragm until the differential pressure of 0.1 bar is again present.

This causes an equilibrium of forces to prevail at the diaphragm which can be maintained for every basic fuel quantity by controlling the valve cross-section.

Mixture formation

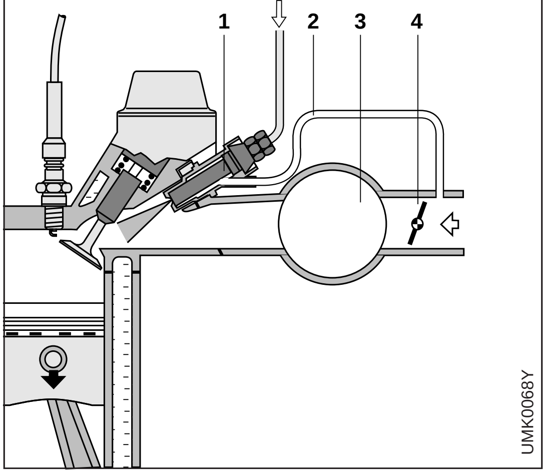
The formation of the air-fuel mixture takes place in the intake ports and cylinders of the engine.

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

Fig. 20

Mixture formation with air-shrouded fuel-injection valve

1 Fuel-injection valve, **2** Air-supply line,
3 Intake manifold, **4** Throttle valve.



Air-shrouded fuel-injection valves favor mixture formation since they atomize the fuel very well at the outlet point (Figures 10, 20).

Adaptation to operating conditions

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

Basic mixture adaptation

The basic adaptation of the air-fuel mixture to the operating modes of idle, part load and full load is by appropriately shaping the air funnel in the air-flow sensor (Figures 21 and 22).

If the funnel had a purely conical shape, the result would be a mixture with a constant air-fuel ratio throughout the whole of the sensor plate range of travel (metering range). However, it is necessary to meter to the engine an air-fuel mixture which is optimal for particular operating modes such as idle, part load and full load. In practice, this means a richer mixture at idle and full load, and a leaner mixture in the part-load range. This adaptation is achieved by designing the air funnel so that it becomes wider in stages.

If the cone shape of the funnel is flatter than the basic cone shape (which was specified for a particular mixture, e.g. for $\lambda = 1$), this results in a leaner mixture. If the funnel walls are steeper than in the basic model, the sensor plate is lifted further for the same air throughput, more fuel is therefore metered by the control plunger and the mixture is richer. Consequently, this means that the air funnel can be shaped so that it is poss-ible to meter mixtures to the engine which have different air-fuel ratios depending upon the sensor-plate position in the funnel (which in turn corresponds to the particular engine operating mode i.e. idle, part load and full load). This results in a richer mixture for idle and full load (idle and full-load enrichment) and, by contrast, a leaner mixture for part load.

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.
A Annular area opened by the sensor plate (identical in a, b and c).

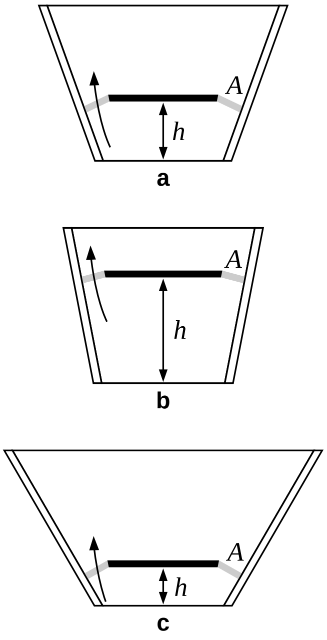
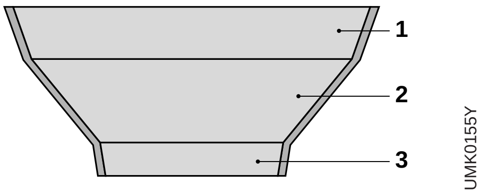


Fig. 21

Fig. 22

Adaptation of the air-funnel shape

1 For maximum power, **2** For part load, **3** For idle.



Cold-start enrichment

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

In order to compensate for the condensation losses due to condensation on the cold cylinder walls, and in order to facilitate starting the cold engine during cold starting, extra fuel must be injected at the instant of start-up. This extra fuel is injected by the cold-start valve into the intake manifold. The injection period of the cold-start valve is limited by a thermo-time switch depending upon the engine temperature.

This process is known as cold-start enrichment and results in a "richer" air-fuel

Cold-start valve in operated state

1 Electrical connection, **2** Fuel supply with strainer, **3** Valve (electromagnet armature), **4** Solenoid winding, **5** Swirl nozzle, **6** Valve seat.

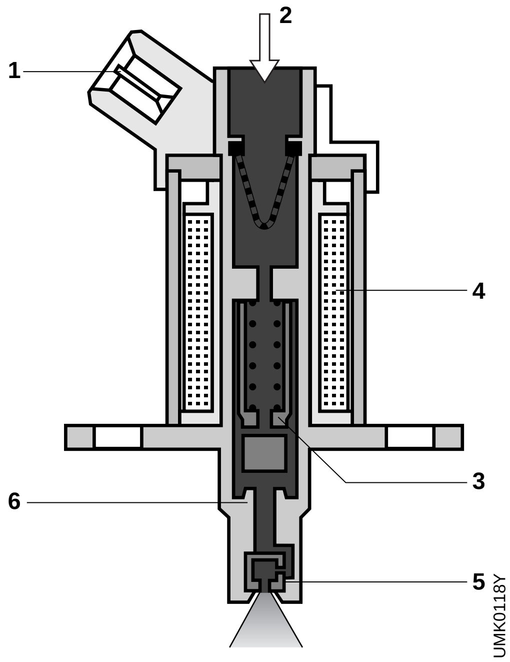


Fig. 23

mixture, i.e. the excess-air factor λ is temporarily less than 1.

Cold-start valve

The cold-start valve (Figure 23) is a solenoid-operated valve. An electromagnetic winding is fitted inside the valve. When unoperated, the movable electromagnet armature is forced against a seal by means of a spring and thus closes the valve. When the electromagnet is energized, the armature which consequently has lifted from the valve seat opens the passage for the flow of fuel through the valve. From here, the fuel enters a special nozzle at a tangent and is caused to rotate or swirl.

The result is that the fuel is atomized very finely and enriches the mixture in the manifold downstream of the throttle valve. The cold-start valve is so positioned in the intake manifold that good distribution of the mixture to all cylinders is ensured.

Thermo-time switch

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

Thermo-time switch

1 Electrical connection, **2** Housing, **3** Bimetal, **4** Heating filament, **5** Electrical contact.

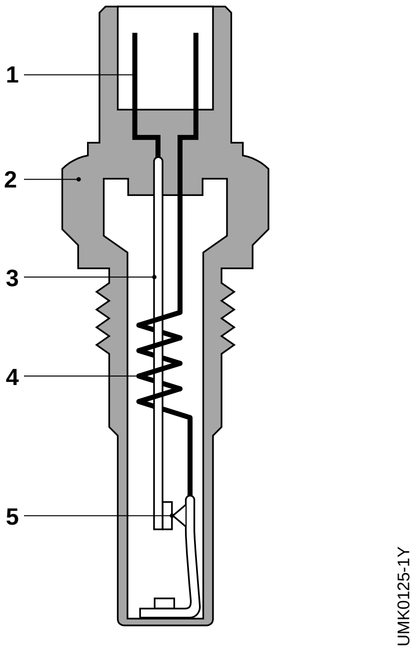


Fig. 24

The thermo-time switch (Figure 24) 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 position 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 seconds). 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.

Warm-up regulator

a With the engine cold,
b With the engine at operating temperature.
1 Valve diaphragm,
2 Return,
3 Control pressure (from the mixture-control unit),
4 Valve spring,
5 Bimetal spring,
6 Electrical heating.

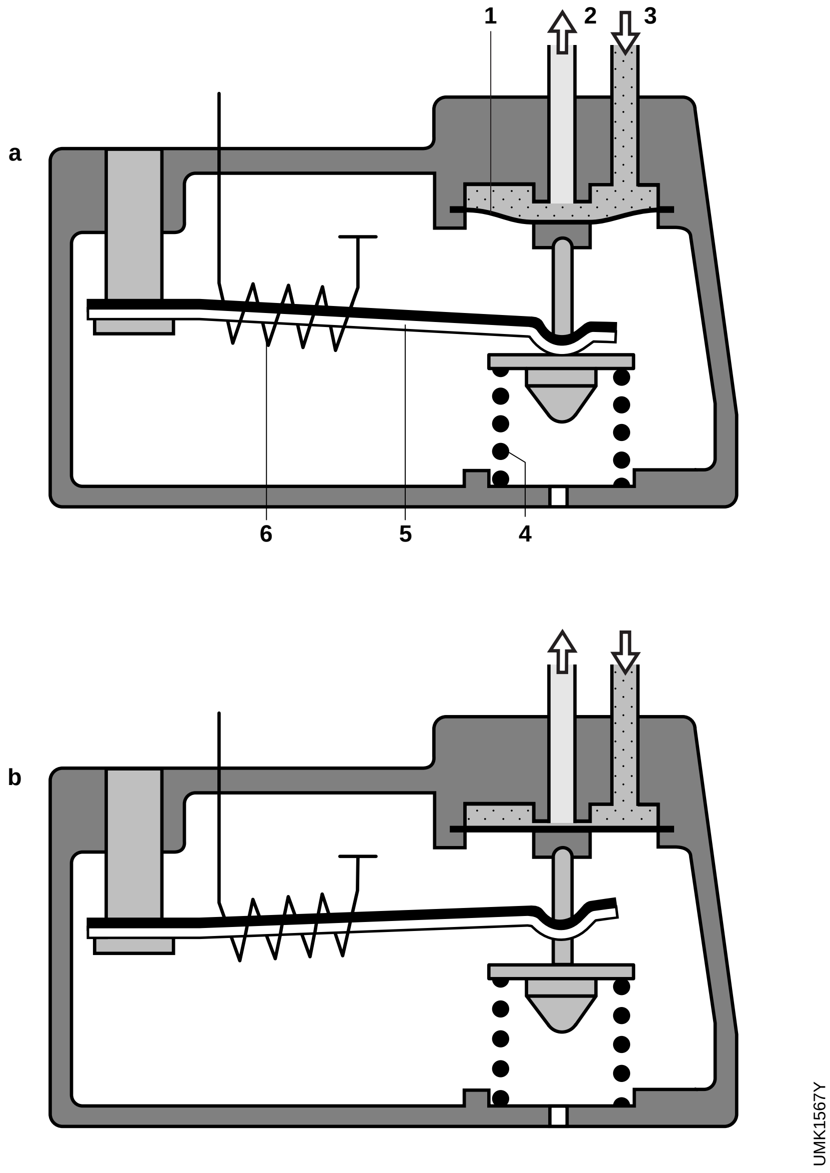


Fig. 25

Warm-up enrichment

Warm-up enrichment is controlled by the warm-up regulator. When the engine is cold, the warm-up regulator reduces the control pressure to a degree dependent upon engine temperature and thus causes the metering slits to open further (Figure 25).

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

Warm-up regulator

The change of the control pressure is effected by the warm-up regulator which is fitted to the engine in such a way that it ultimately adopts the engine temperature. An additional electrical heating system enables the regulator to be matched precisely to the engine characteristic.

The warm-up regulator comprises a spring-controlled flat seat (diaphragm-type) valve and an electrically heated bimetal spring (Figure 25).

In cold condition, the bimetal spring exerts an opposing force to that of the valve spring and, as a result, reduces the effective pressure applied to the underside of the valve diaphragm. This means that the valve outlet cross-section is slightly increased at this point and more fuel is diverted out of the control-pressure circuit in order to achieve a low control pressure. Both the electrical heating system and the engine heat the bimetal spring as soon as the engine is cranked. The spring bends, and in doing so reduces the force opposing the valve spring which, as a result, pushes up the diaphragm of the flat-seat valve. The valve outlet cross-section is reduced and the pressure in the control-pressure circuit rises.

Warm-up enrichment is completed when the bimetal spring has lifted fully from the valve spring. The control pressure is now solely controlled by the valve spring and maintained at its normal level. The control pressure is about 0.5 bar at cold start and about 3.7 bar with the engine at operating temperature (Figure 26).

Idle stabilization

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

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

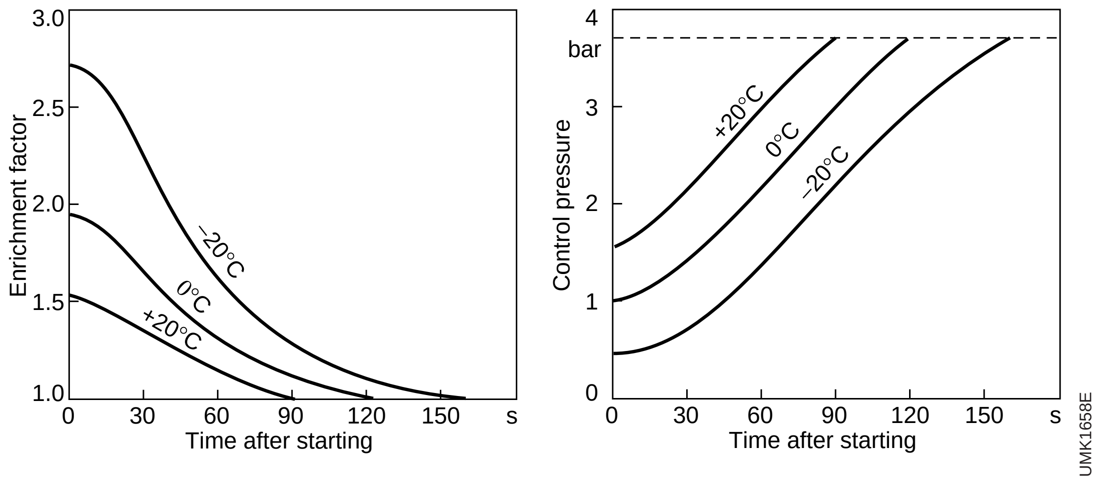
Auxiliary-air device

In the auxiliary-air device, a perforated plate is pivoted by means of a bimetal spring and changes the open cross-section of a bypass line. This perforated plate thus opens a correspondingly large cross-section of the bypass line, as a function of the temperature, and this cross-section is reduced with increasing engine temperature and is ultimately closed. The bimetal spring also has an electrical heating system which permits the opening time to be restricted dependent upon the engine type. The in-

Fig. 26

Warm-up regulator characteristics at various operating temperatures

Enrichment factor 1.0 corresponds to fuel metering with the engine at operating temperature.



stallation location of the auxiliary-air device is selected such that it assumes the engine temperature. This guarantees that the auxiliary-air device only functions when the engine is cold (Figure 27).

Full-load enrichment

Engines operated in the part-load range with a very lean mixture require an enrichment during full-load operation, in addition to the mixture adaptation resulting from the shape of the air funnel.

This extra enrichment is carried out by a specially designed warm-up regulator. This regulates the control pressure depending upon the manifold pressure (Figures 28 and 30).

This model of the warm-up regulator uses two valve springs instead of one. The outer of the two springs is supported on the housing as in the case with the normal-model warm-up regulator. The inner spring however is supported on a diaphragm which divides the regulator into an upper and a lower chamber. The manifold pressure which is tapped via a hose connection from the intake manifold downstream of the throttle valve acts in the upper chamber. Depending upon the model, the lower chamber is subjected to atmospheric pressure either directly or by means of a second hose leading to the air filter.

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

The inner spring is relieved of tension and the control pressure reduced by the specified amount as a result. This results in mixture enrichment.

Auxiliary-air device

1 Electrical connection, **2** Electrical heating,
3 Bimetal spring, **4** Perforated plate.

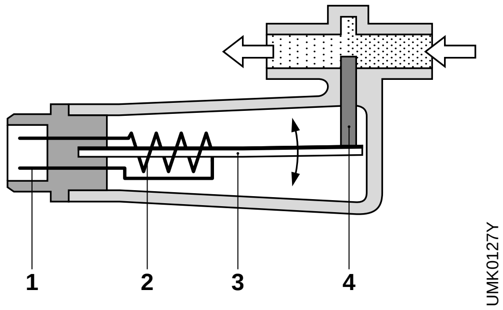


Fig. 29

Fig. 28

Dependence of the control pressure on engine load

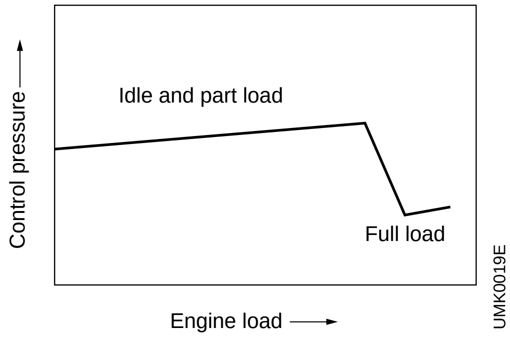
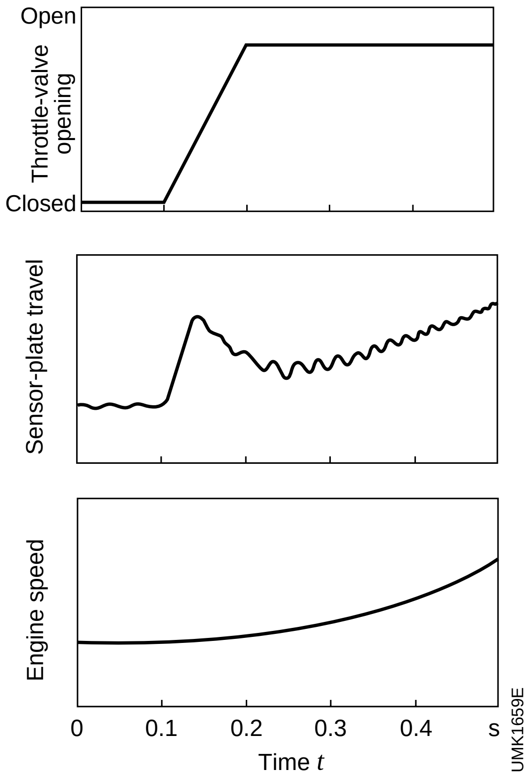


Fig. 29

Acceleration response

Behavior of the K-Jetronic when the throttle valve is suddenly opened.



Acceleration response

The good acceleration response is a result of “overswing” of the air-flow sensor plate (Figure 29).

Transitions from one operating condition to another produce changes in the mixture ratio which are utilized to improve driveability.

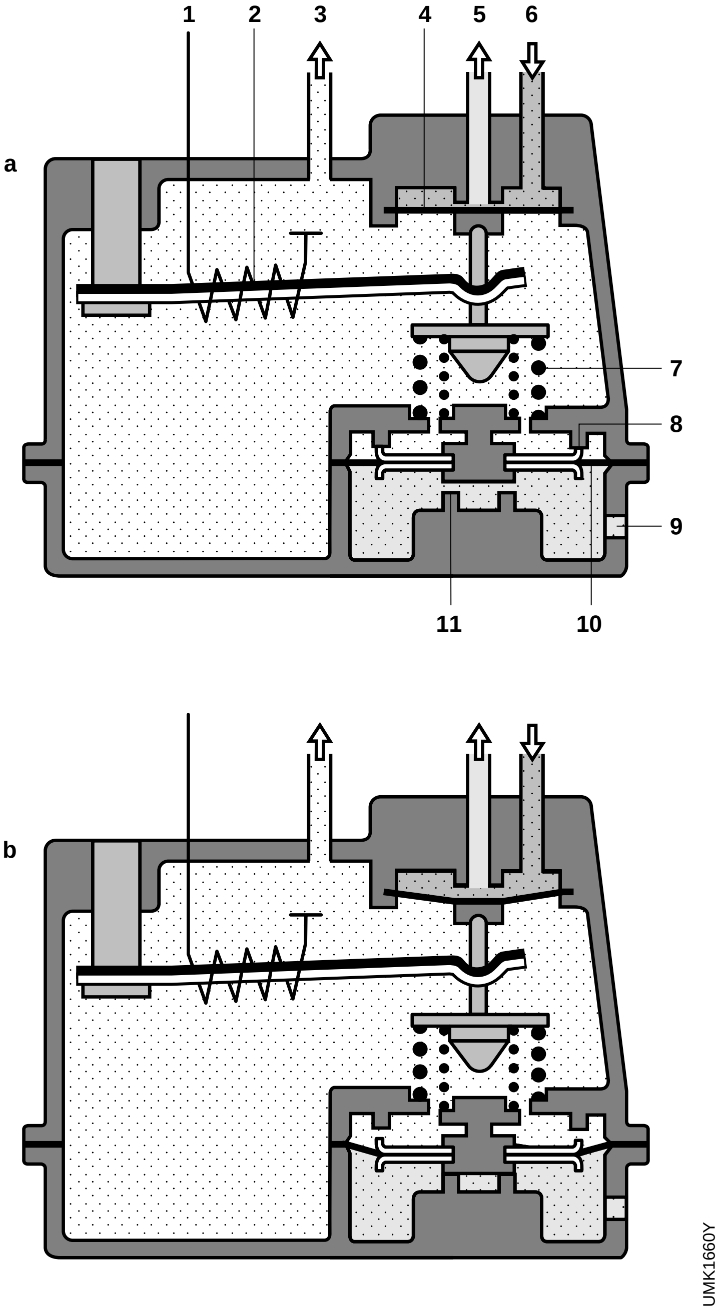
If, at constant engine speed, the throttle valve is suddenly opened, the amount of air which enters the combustion chamber, plus the amount of air which is needed to bring the manifold pressure up to the new level, flow through the airflow sensor. This causes the sensor plate to briefly “overswing” past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

Fig. 30

Warm-up regulator with full-load diaphragm

a During idle and part load,
b During full load.

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



Supplementary functions

Overrun fuel cutoff

Smooth fuel cutoff effective during overrun responds as a function of the engine speed. The engine-speed information is provided by the ignition system. Intervention is via an air bypass around the sensor plate. A solenoid valve controlled by an electronic speed switch opens the bypass at a specific engine speed. The sensor plate then reverts to zero position and interrupts fuel metering. Cutoff of the fuel supply during overrun operation permits the fuel consumption to be reduced considerably not only when driving downhill but also in town traffic.

Engine speed limiting

The fuel supply can be cut off to limit the maximum permissible engine speed.

Lambda closed-loop control

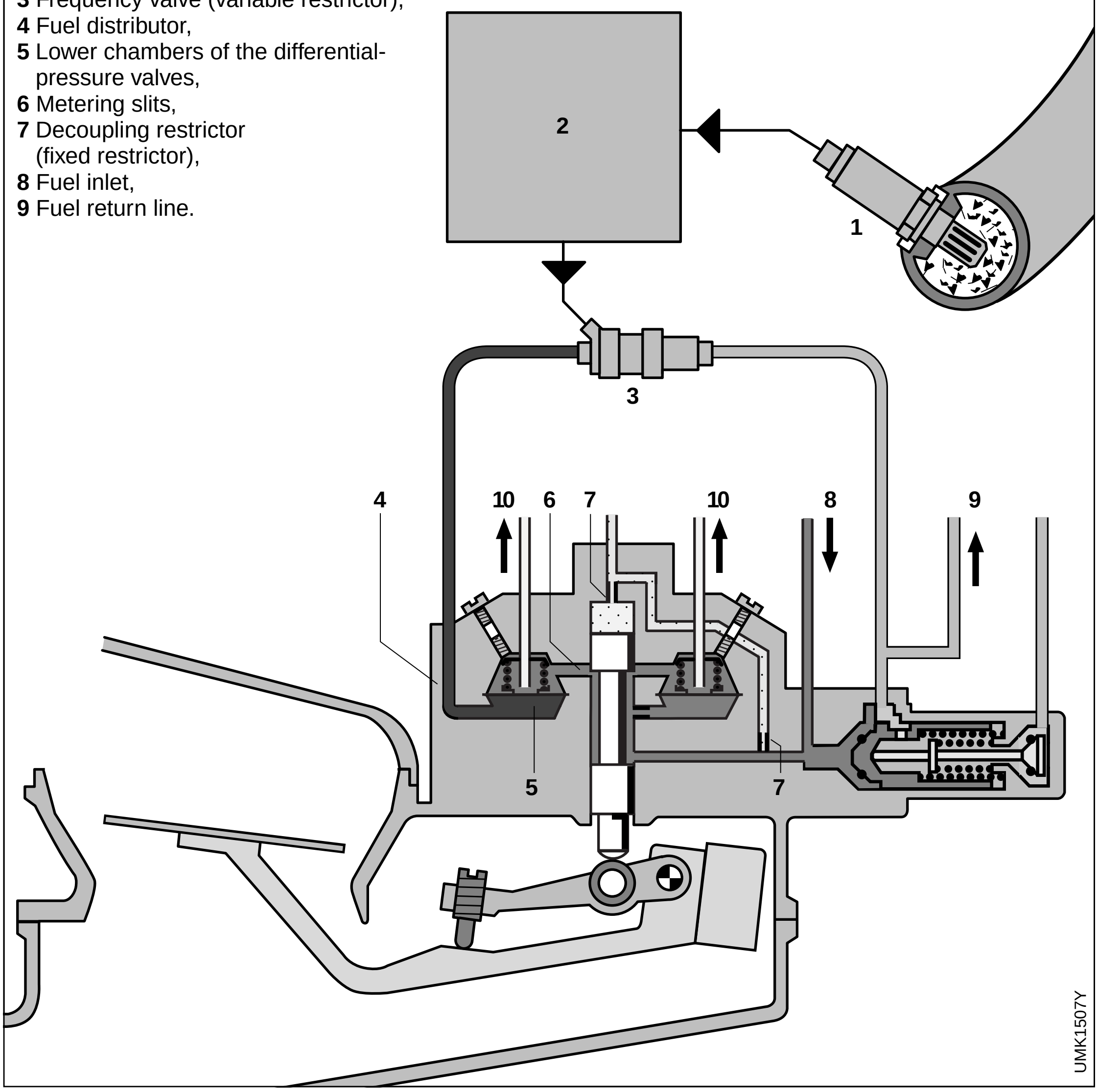
Open-loop control of the air-fuel ratio is not adequate for observing extremely low exhaust-gas limit values. The lambda closed-loop control system required for operation of a three-way catalytic converter necessitates the use of an electronic control unit on the K-Jetronic. The important input variable for this control unit is the signal supplied by the lambda sensor.

In order to adapt the injected fuel quantity to the required air-fuel ratio with $\lambda = 1$, the

Fig. 31

Additional components for lambda closed-loop control

1 Lambda sensor,
2 Lambda closed-loop controller,
3 Frequency valve (variable restrictor),
4 Fuel distributor,
5 Lower chambers of the differential-pressure valves,
6 Metering slits,
7 Decoupling restrictor (fixed restrictor),
8 Fuel inlet,
9 Fuel return line.



pressure in the lower chambers of the fuel distributor is varied. If, for instance, the pressure in the lower chambers is reduced, the differential pressure at the metering slits increases, whereby the injected fuel quantity is increased. In order to permit the pressure in the lower chambers to be varied, these chambers are decoupled from the primary pressure via a fixed restrictor, by comparison with the standard K-Jetronic fuel distributor. A further restrictor connects the lower chambers and the fuel return line.

This restrictor is variable: if it is open, the pressure in the lower chambers can drop. If it is closed, the primary pressure builds up in the lower chambers. If this restrictor is opened and closed in a fast rhythmic succession, the pressure in the lower chambers can be varied dependent upon the ratio of closing time to opening time. An electromagnetic valve, the frequency valve, is used as the variable restrictor. It is controlled by electrical pulses from the lambda closed-loop controller.

Fig. 32

Components of the K-Jetronic system

1 Fuel accumulator, **2** Electric fuel pump, **3** Fuel filter, **4** Warm-up regulator, **5** Mixture-control unit with air-flow sensor and fuel distributor, **6** Cold-start valve, **7** Thermo-time switch, **8** Injection valves, **9** Auxiliary-air device, **10** Electronic control relay.

Exhaust-gas treatment

Lambda sensor

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

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

Operation

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

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

Construction

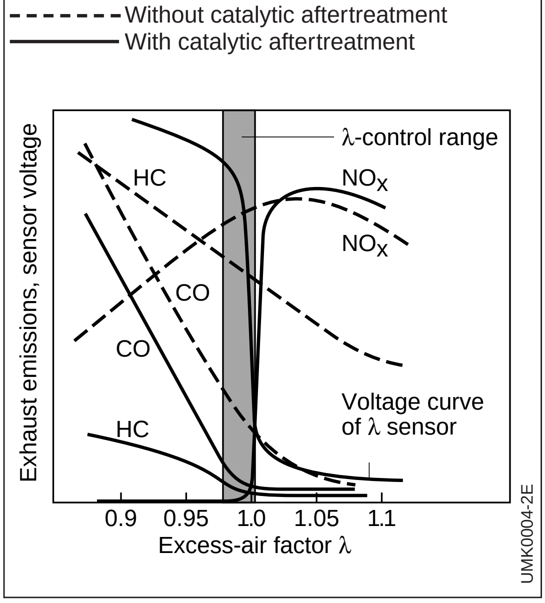
The ceramic sensor body is held in a threaded mounting and provided with a protective tube and electrical connections. The surface of the sensor ceramic body has a microporous platinum layer which on the one side decisively influences the sensor characteristic while on the other serving as an electrical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

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

The voltage output of the λ sensor, and its internal resistance, are dependent upon temperature. Reliable functioning of the sensor is only possible with exhaust-gas temperatures above 360 °C (unheated version), and above 200 °C (heated version).

Fig. 33

Control range of the lambda sensor and reduction of pollutant concentrations in exhaust



Heated Lambda oxygen sensor

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

The active sensor ceramic is heated internally by a ceramic heating element with the result that the temperature of the ceramic body always remains above the function limit of 350 °C.

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

Lambda closed-loop control circuit

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

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

In case of a deviation from this λ = 1.00 figure, the voltage of the sensor output signal changes abruptly. This pronounced change is evaluated by the ECU which is provided with a closed-loop control circuit for this purpose. The injection of fuel to the engine is controlled by the fuel-management system in accordance with the information on the composition of the air-fuel mixture received from the Lambda sensor. This control is such that an airfuel ratio of λ = 1 is achieved. The sensor voltage is a measure for the correction of the fuel quantity in the air-fuel mixture.

Fig. 34

Positioning of the lambda sensor in a dual exhaust system

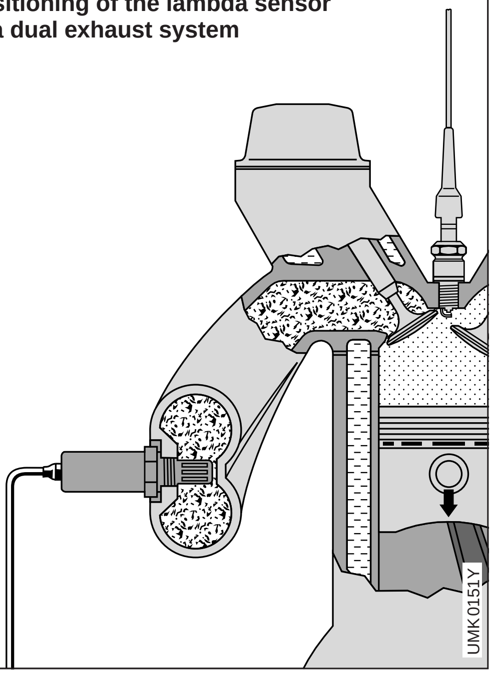
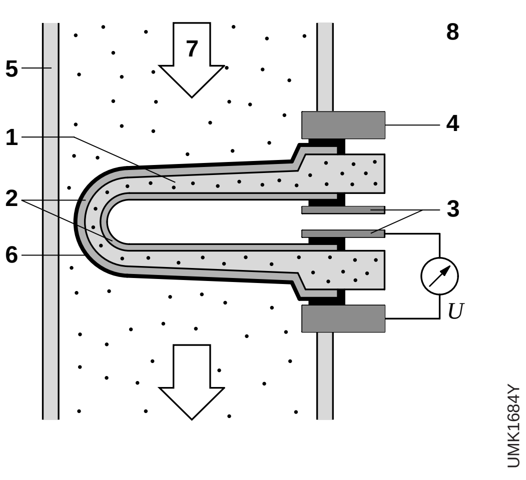


Fig. 35

Location of the lambda sensor in the exhaust pipe (schematic)

1 Sensor ceramic, **2** Electrodes, **3** Contact, **4** Electrical contacting to the housing, **5** Exhaust pipe, **6** Protective ceramic coating (porous), **7** Exhaust gas, **8** Air. U voltage.



The signal which is processed in the closed-loop control circuit is used to control the actuators of the Jetronic installation. In the fuel-management system of the K-Jetronic (or carburetor system), the closed-loop control of the mixture takes place by means of an additional control unit and an electromechanical actuator (frequency valve). In this manner, the fuel can be metered so precisely that depending upon load and engine speed, the air-fuel ratio is an optimum in all operating modes. Tolerances and the ageing of the engine have no effect whatsoever. At values above λ = 1.00, more fuel is metered to the engine, and at values below λ = 1.00, less. This continuous, almost lag-free adjustment of the air-fuel mixture to λ = 1.00, is one of the prerequisites for the efficient after-treatment of the exhaust gases by the downstream catalytic converter.

Control functions at various operating modes

Start

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

Acceleration and full load (WOT)

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

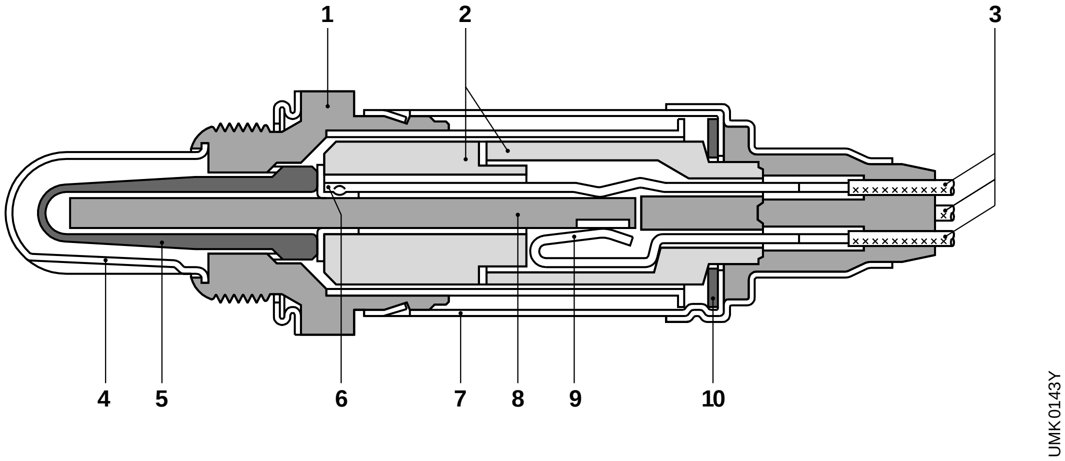
Deviations in air-fuel mixture

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

Fig. 36

Heated lambda sensor

1 Sensor housing, **2** Protective ceramic tube, **3** Connection cable, **4** Protective tube with slots, **5** Active sensor ceramic, **6** Contact element, **7** Protective sleeve, **8** Heater, **9** Clamp terminals for heater.



Lambda closed control-loop

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

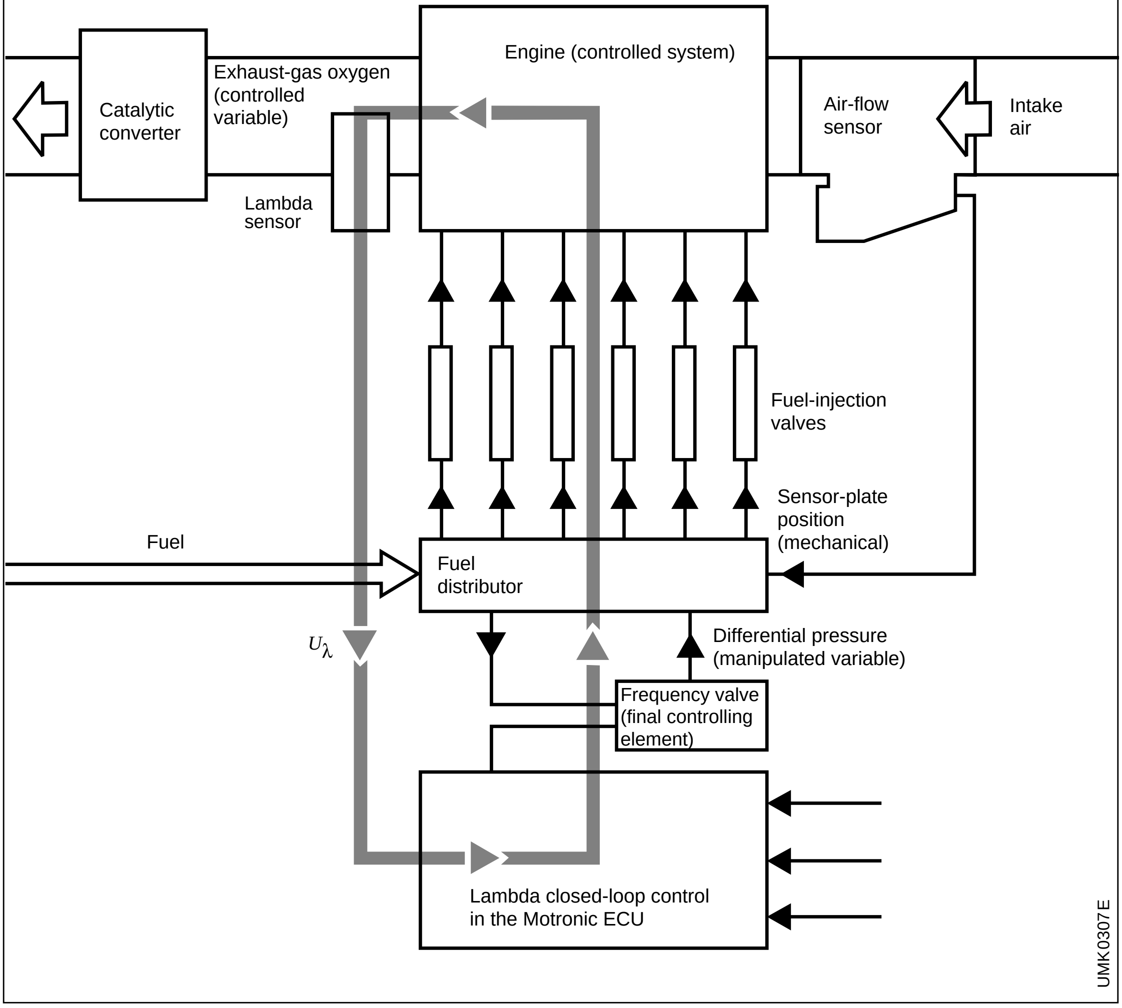


Fig. 37

Fig. 38

View of the unheated (front) and heated lambda sensors

Electrical circuitry

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

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

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

Function

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

If the temperature of the engine is above approximately +35 °C when the starting process is commenced, the thermo-time switch will have already open-circuited the connection to the start valve which,

Fig. 39

Circuit without voltage applied

1 Ignition and starting switch,
2 Cold-start valve,
3 Thermo-time switch,
4 Control relay,
5 Electric fuel pump,
6 Warm-up regulator,
7 Auxiliary-air device.

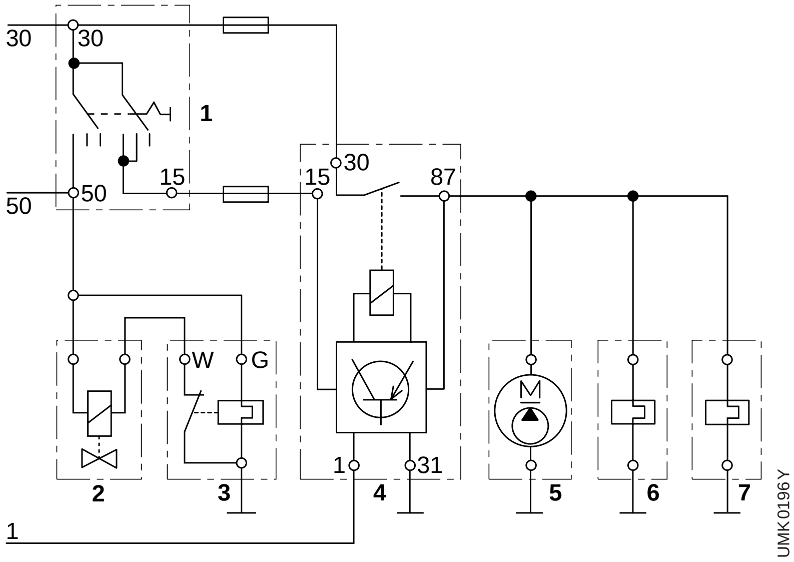
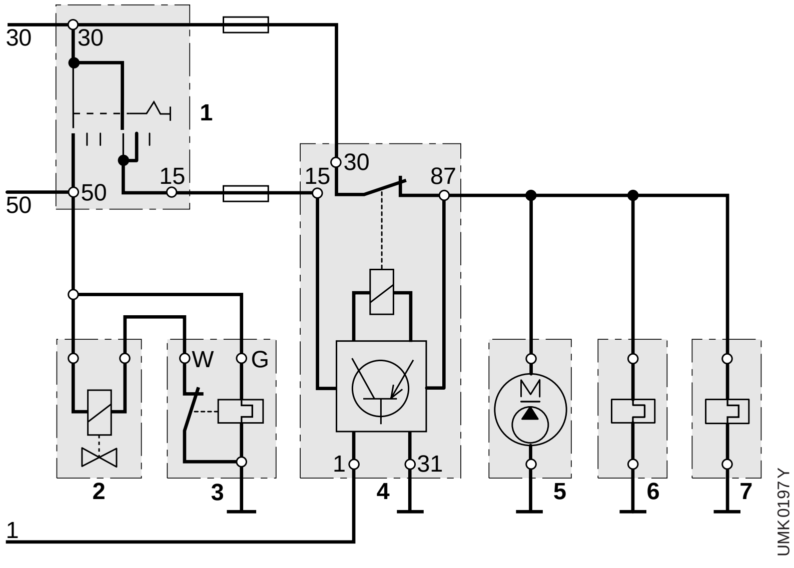


Fig. 40

Starting (with the engine cold)

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



consequently, does not inject extra fuel. In this case, the thermo-time switch functions as a temperature switch.

Voltage from the ignition and starting switch is still present at the control relay which switches on as soon as the engine runs. The engine speed reached when the starting motor cranks the engine is high enough to generate the “engine running” signal which is taken from the ignition pulses coming from terminal 1 of the ignition coil. An electronic circuit in the control relay evaluates these pulses. After the first pulse, the control relay is switched on and applies voltage to the electric fuel pump, the auxiliary-air device and the warm-up regulator. The control relay remains switched on as long as the ignition is switched on and the ignition is running. If the pulses from terminal 1 of the ignition coil stop because the engine has stopped turning, for instance in the case of an accident, the control relay switches off approximately 1 second after the last pulse is received.

This safety circuit prevents the fuel pump from pumping fuel when the ignition is switched on but the engine is not turning.

Fig. 41

Operation

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

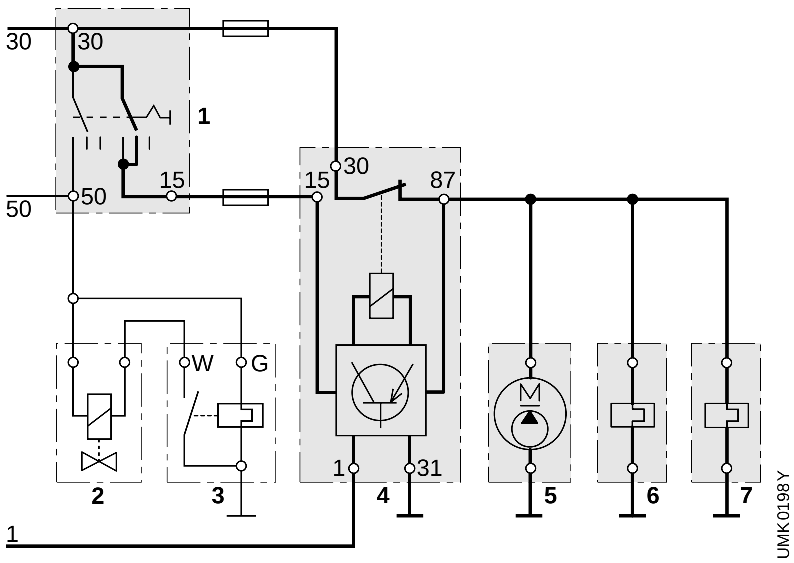
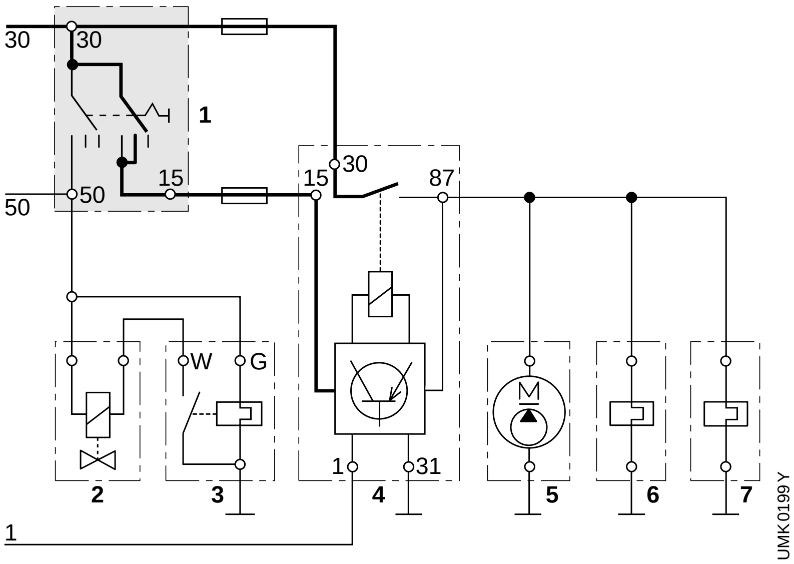


Fig. 42

Ignition on but engine stopped

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



Workshop testing techniques

Bosch customer service

Customer service quality is also a measure for product quality. The car driver has more than 10,000 Bosch Service Agents at his disposal in 125 countries all over the world. These workshops are neutral and not tied to any particular make of vehicle. Even in sparsely populated and remote areas of Africa and South America the driver can rely on getting help very quickly. Help which is based upon the same quality standards as in Germany, and which is backed of course by the identical guarantees which apply to customer-service work all over the world. The data and performance specs for the Bosch systems and assemblies of equipment are precisely matched to the engine and the vehicle. In order that these can be checked in the workshop, Bosch developed the appropriate measurement techniques, test equipment, and special tools and equipped all its Service Agents accordingly.

Testing techniques for K-Jetronic

Apart from the regular replacement of the fuel filter as stipulated by the particular vehicle's manufacturer, the K-Jetronic gasoline-injection system requires no special maintenance work.

In case of malfunctions, the workshop expert has the following test equipment, together with the appropriate test specs, at his disposal:

- Injector tester
- Injected-quantity comparison tester
- Pressure-measuring device, and
- Lambda closed-loop control tester (only needed if Lambda control is fitted).

Together with the relevant Test Instructions and Test Specifications in a variety of different languages, this uniform testing technology is available throughout the world at the Bosch Service Agent workshops and at the majority of the workshops belonging to the vehicle manufacturers. Purposeful trouble-shooting and technically correct repairs cannot be performed at a reasonabe price without this equipment. It is therefore inadvisable for the vehicle owner to attempt to carry out his own repairs.

Fig. 43

Injector tester

Injector tester

The injector tester (Fig. 43) was developed specifically for testing the K- and KE-Jetronic injectors when removed from the engine. The tester checks all the functions of the injector which are essential for correct engine running:

- Opening pressure,
- Leakage integrity,
- Spray shape,
- Chatter.

Those injectors whose opening pressure is outside tolerance are replaced. For the leak test, the pressure is slowly increased up to 0.5 bar below the opening pressure and held at this point. Within 60 secs, no droplet of fuel is to form at the injector. During the chatter test, the injector must generate a "chattering" noise without a fuel droplet being formed. Serviceable injectors generate a fully atomized spray pattern. "Pencil" jets and "bundled" jets are not to form.

Injected-quantity comparison tester

Without removing the fuel distributor from the vehicle, a comparitive measurement is made to determine the differences in the delivered quantities from the various fuel-distributor outlets (this applies to all engines of up to maximum eight cylinders.

Fig. 44). And since the test is performed using the original injectors it is possible to ascertain at the same time whether any scatter in the figures results from the fuel distributor itself or from the injectors.

The tester’s small measuring tubes serve for idle measurement and its larger measuring tubes for part-load or full-load measurement.

Connection to the fuel distributor is by means of eight hoses. The injectors are pulled out of their mountings on the engine and inserted in the automatic couplings at the ends of the hoses. Each automatic coupling incorporates a push-up valve which prevents fuel escaping on hoses which are not connected (e.g. on 6-cylinder systems. Fig. 44). A further hose returns the fuel to the tank.

Pressure-measuring device

This is used to measure all the pressures which are important for correct K-Jetronic operation:

– Primary (system) pressure: Provides information on the performance of the fuel-supply pump, on fuel-filter flow resistance, and on the condition of the primary-pressure regulator.
– Control pressure: Important for assessment of all operating conditions (for instance: Cold/warm engine; part load/full load; fuel-enrichment functions, occasionally pressure at high altitudes).
– Leakage integrity of the complete system. This is particularly important with regard to the cold-start and hot-start behavior. Automatic couplings in the hoses prevent the escape of fuel.

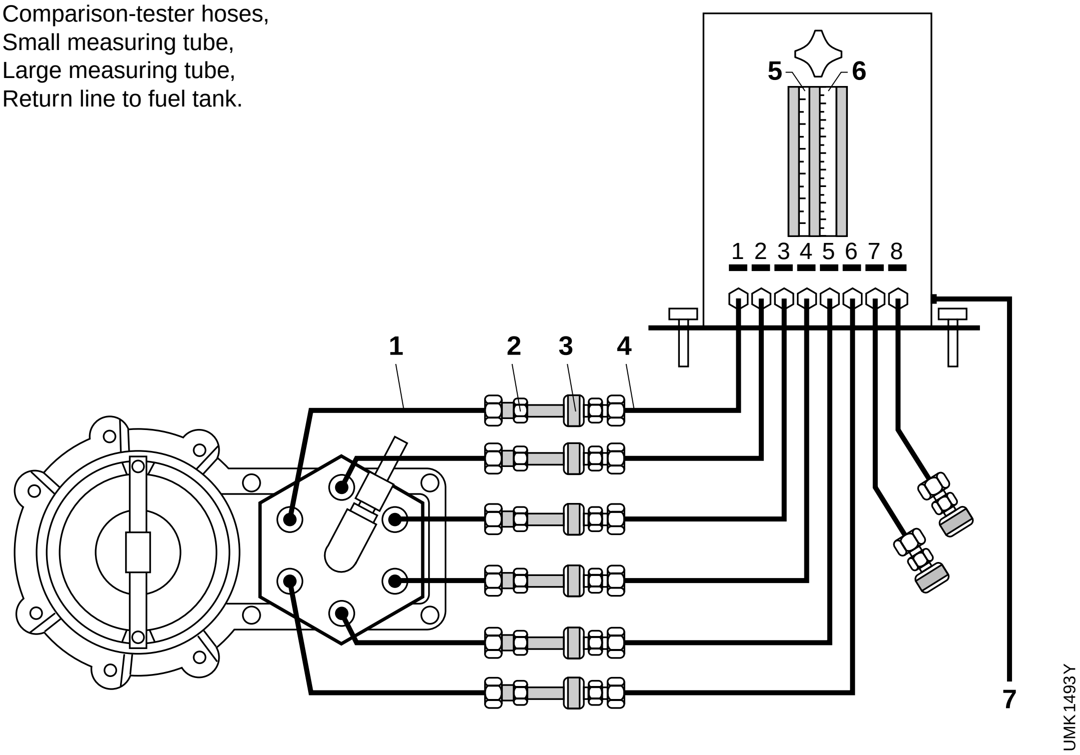
Lambda closed-loop-control tester

On K-Jetronic systems with Lambda closed-loop control, this tester serves to check the duty factor of the Lambda-sensor signal (using simulation of the “rich”/ “lean” signal), and the “open-loop/closed-loop control function”. Special adapter lines are available for connection to the Lambda-sensor cable of the various vehicle models. Measured values are shown on an analog display.

Fig. 44

Injected-quantity comparison tester (connected to a 6-cylinder installation)

1 Fuel-distributor injection lines,
2 Injectors,
3 Automatic couplings,
4 Comparison-tester hoses,
5 Small measuring tube,
6 Large measuring tube,
7 Return line to fuel tank.



The Program

	Order Number
Gasoline-engine management	
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