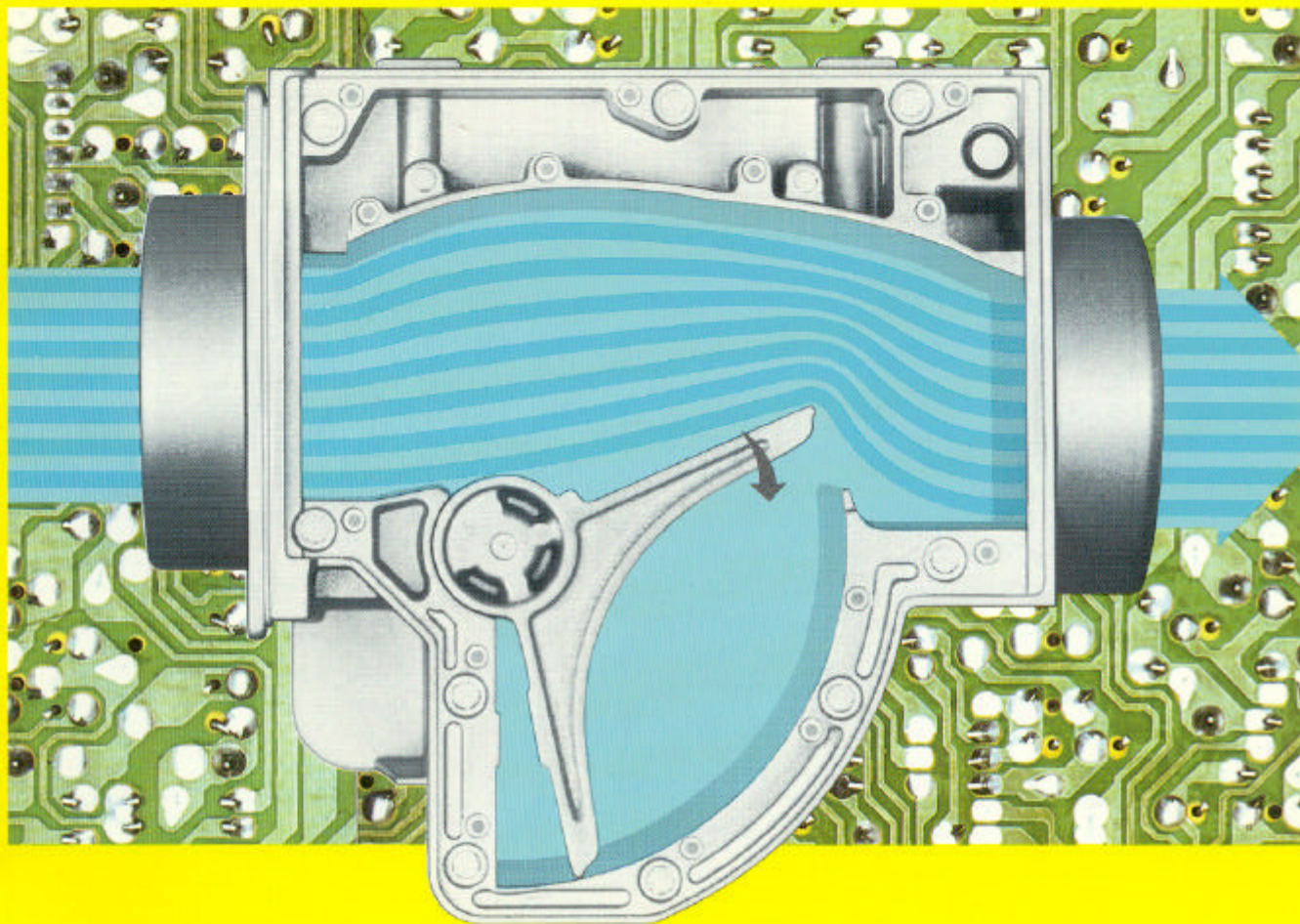


Engine management for spark-ignition engines

Gasoline Fuel-Injection System L-Jetronic

Edition 95/96



Technical Instruction



BOSCH

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L-Jetronic

Since their introduction, Jetronic fuel-injection systems have proved themselves millions of times over under the harsh conditions of everyday driving.

The on-going development of the control unit and the sensors has led from the D-Jetronic to the L-Jetronic, and resulted in this fuel-injection system becoming even more precise and reliable.

New circuitry for the evaluation of the sensor signals has led to more economical and more sophisticated engine operating characteristics. Thanks to the employment of the Lambda sensor, and the integration of the Lambda closed-loop control unit, the L-Jetronic can already comply today with the exhaust-gas legislation of tomorrow. This booklet tells you all you want to know about the latest developments in the L-Jetronic.

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Combustion in the spark-ignition engine

The spark-ignition or Otto-cycle engine

Principles

The spark-ignition or Otto-cycle¹⁾ engine is a combustion engine with externally supplied ignition which converts the energy contained in the fuel into kinetic energy.

The spark-ignition engine employs a mixture-formation apparatus located outside the combustion chamber to form an air-fuel mixture (based on gasoline or a gas). As the piston descends, the mixture is drawn into the combustion chamber, where it is then compressed as the piston moves upward. An external ignition source, triggered at specific intervals, uses a spark plug to initiate combustion in the mixture. The heat released in the combustion process raises the pressure within the cylinder, and the piston pushes down against the crankshaft, providing

the actual work energy (power). After each combustion stroke the spent gases are expelled from the cylinder and a fresh air-fuel mixture is drawn in. In automotive engines this exchange of gases is generally regulated according to the four-stroke principle, with two crankshaft revolutions being required for each complete cycle.

The four-stroke principle

The four-stroke spark-ignition engine employs gas-exchange valves to control the gas flow. These valves open and close the cylinder's intake and exhaust tracts:

- 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.

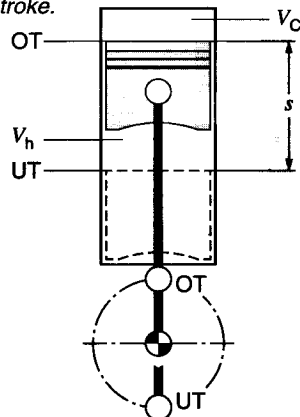
The piston's downward motion increases the cylinder's effective volume and pulls in fresh air-fuel mixture through the open intake valve.

Compression stroke

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

Fig. 1: Design concept of the reciprocating piston engine

TDC Top Dead Center, BDC Bottom Dead Center,
 V_h Stroke volume, V_c Compression volume,
 s Piston stroke.



¹⁾ After Nikolaus August Otto (1832 – 1891), who unveiled the first four-stroke gas-compression engine at the Paris World Exhibition in 1878.

As the piston travels upward, it reduces the cylinder's effective volume and compresses the air-fuel mixture. Just before the piston reaches top dead center (TDC), the spark plug ignites the compressed air-fuel mixture to initiate combustion.

The compression ratio is calculated with the stroke volume V_h and compression volume V_C :

$$\epsilon = (V_h + V_C) / V_C$$

Compression ratios ϵ range between 7 and 13 to one, depending upon engine design. Increasing the compression ratio in a combustion engine enhances its thermal efficiency and provides more effective use of the fuel. For instance, raising the compression ratio from 6:1 to 8:1 produces a 12% improvement in thermal efficiency. The latitude for such increases is restricted by the knock (or preignition) limit. Knock refers to uncontrolled mixture combustion characterized by a radical increase in pressure. Combustion knock leads to engine damage. Appropriate fuels and combustion-chamber configurations can be employed to shift the knock limit toward higher compression ratios.

Power stroke

Intake valve: closed,
Exhaust valve: closed,
Piston travel: upward,
Combustion: combustion completed.

When the spark at the spark plug ignites the air-fuel mixture, the gas mixture combusts and the temperature increases.

The pressure level in the cylinder also increases, pushing the piston downward. The force from the moving piston is transferred through the connecting rod and to the crankshaft in the form of work; this is the actual source of the engine's power.

Output rises as a function of increased engine speed and higher torque ($P = M \cdot \omega$).

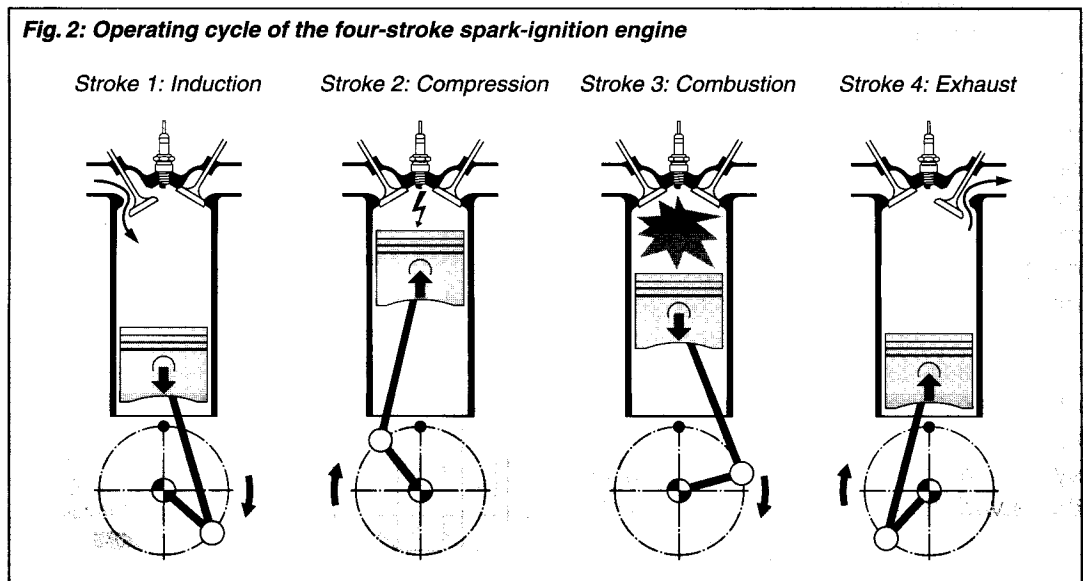
A transmission incorporating various conversion ratios is required to adapt the combustion engine's power and torque curves to the demands of actual vehicular operation.

Exhaust stroke

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

As the piston travels upward, it pushes the spent gases (exhaust gases) out through the open exhaust valve. The cycle is then repeated. The periods when the valves are open overlap by a certain degree; this improves the gas-flow and oscillation patterns for enhanced cylinder filling and scavenging.

The spark-ignition or Otto-cycle engine



Mixture formation

Overview

Parameters

Air-fuel mixture

The spark-ignition engine requires a specific air/fuel ratio (A/F ratio) in order to operate. The theoretical ideal for complete combustion is 14.7:1, and is referred to as the stoichiometric ratio. Mixture corrections are required to satisfy the special engine demands encountered under particular operating conditions.

The specific fuel consumption of the spark-ignition engine is largely a function of the A/F ratio. In theory, excess air is required to achieve the minimum fuel consumption that would result from complete combustion. In practice, however, latitude is restricted by factors such as mixture flammability and limits on the time available for combustion.

On contemporary engines, minimum fuel consumption is encountered at an A/F ratio corresponding to approximately 15...18 kg air for each kg of fuel. In other words, about 10,000 litres of air are required to support combustion in one litre of fuel (Figure 1).

Because automotive powerplants spend most of their time operating at part-throttle, engines are designed for minimum fuel consumption in this range. Mixtures containing a higher proportion of fuel provide better performance under other conditions such as idle and full-throttle operation. The mixture-formation system must be capable of satisfying these variegated requirements.

Excess-air factor

The excess-air factor (or air ratio) λ has been chosen to indicate how far the actual air-fuel mixture deviates from the theoretical optimum (14.7:1).

λ = Induction air mass/air requirement for stoichiometric combustion

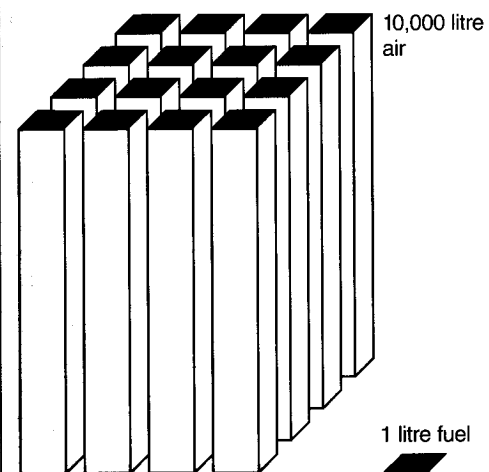
$\lambda = 1$: The induction air mass corresponds to the theoretical requirement.

$\lambda < 1$: Air deficiency, rich mixture. Increased output is available at $\lambda = 0.85 \dots 0.95$.

$\lambda > 1$: Excess air (lean mixture) in the range $\lambda = 1.05 \dots 1.3$. Excess-air factors in this range result in lower fuel consumption accompanied by reduced performance.

$\lambda > 1.3$: The mixture ceases to be ignitable. Ignition miss occurs, accompanied by pronounced loss of operating smoothness.

Fig. 1: A/F ratio for combustion with minimum specific fuel consumption



Spark-ignition engines achieve their maximum output at air-deficiency levels of 5...15% ($\lambda = 0.95...0.85$), while minimum fuel consumption is achieved with an air excess of 10...20% ($\lambda = 1.1...1.2$). $\lambda = 1$ provides optimum idling characteristics.

Figures 2 and 3 illustrate the effect of the excess-air factor λ on output, specific fuel consumption and exhaust emissions. It will be noted that no single excess-air factor can simultaneously generate optimal response in all areas. Air factors ranging from λ 0.9...1.1 provide the best results in actual practice.

Once the engine has reached its normal operating temperature, it is essential that $\lambda = 1$ be maintained to support subsequent exhaust treatment with a three-way catalytic converter. The preconditions for satisfying this requirement are precise determination of the induction-air quantity accompanied by an arrangement capable of providing exact fuel metering.

To ensure a satisfactory combustion process, precise fuel metering must be accompanied by homogeneous mixture formation. The fuel must be thoroughly atomized. If this condition is not satisfied, large fuel droplets will form along the walls of the inlet tract, leading to higher HC emissions.

Adapting to specific operating conditions

Certain operating states will cause the fuel requirement to deviate considerably from that required by a stationary engine at normal operating temperature; the mixture must be corrected accordingly.

Cold starts

During cold starts, the relative amount of fuel in the mixture decreases; the mixture "goes lean." Inadequate blending of fuel and air in the intake mixture, low fuel vaporization and condensation on the walls of the intake tract due to the low temperatures, all contribute to this phenomenon. To compensate, and to assist the cold engine in "getting started," supplementary fuel must be made available for starting.

Post-start phase

After starts at low temperatures, supplementary fuel must be provided to enrich the mixture until the combustion chamber heats up and the mixture formation within the cylinder improves. The richer mixture also increases torque to provide a smoother transition to the desired idle speed.

Fig. 2: Effect of excess-air factor λ on output P and specific fuel consumption b_e
a) Rich mixture (air deficiency)
b) Lean mixture (excess air).

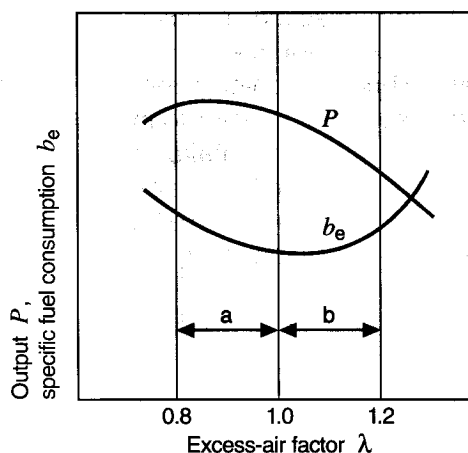
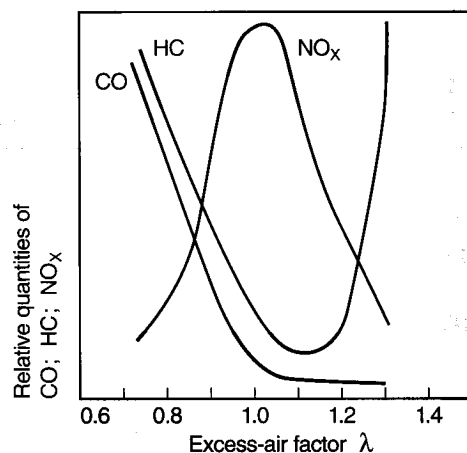


Fig. 3: Effect of excess-air factor λ on exhaust emissions



Warm-up phase

The starting and post-start phases are followed by the engine's warm-up phase. In this phase the engine still requires a richer mixture, as the cylinder walls are still cool, and a portion of the fuel continues to condense on them. Since the quality of mixture formation drops along with falling temperatures (due to less effective mixing of air and fuel, and large fuel droplets), condensation forms in the intake manifold, where it remains until it is vaporized as temperatures increase. These factors make it necessary to provide progressive mixture enrichment in response to decreasing temperatures.

Part-throttle operation

During part-throttle operation priority is assigned to adjusting the mixture for minimum fuel consumption. The three-way catalytic converters required to meet stringent emissions limits are making it increasingly important to control the systems for $\lambda = 1$.

Full-throttle operation

When the throttle valve has opened to its maximum aperture, the engine should respond by providing its maximum torque/output. As Figure 2 indicates, this necessitates enriching the air-fuel mixture to $\lambda = 0.85 \dots 0.90$.

Acceleration

When the throttle valve opens suddenly, the air-fuel mixture responds by leaning out briefly. This is due to the fuel's restricted vaporization potential at higher manifold vacuum levels (increased tendency to form fuel layers on intake-tract walls).

To obtain good transition response, the mixture must be enriched by an amount which varies according to engine temperature. This enrichment provides good acceleration response.

Trailing-throttle (overrun) operation

The fuel-metering process can be interrupted on trailing throttle to reduce fuel consumption during descents and under braking. Another advantage is the fact

that no harmful exhaust emissions are generated in this operating mode.

High-altitude adjustment

Increases in altitude (as encountered during alpine operation) are accompanied by a reduction in air density. This means that the intake air being drawn into the engine at high altitudes displays a lower mass per unit of volume. A system which fails to adjust the mixture accordingly will supply an excessively rich mixture, and the ultimate result will be higher fuel consumption and increased exhaust emissions.

Mixture-formation systems

The function of the carburetor or fuel-injection system is to supply the engine with the optimum air-fuel mixture for instantaneous operating conditions. For some years now, fuel injection has represented the preferred method, a development accelerated by the advantages that injecting the fuel provides in the areas of economy, performance, driveability and low exhaust emissions. Fuel injection can be applied for extremely precise metering, supplying exactly the correct amount of fuel for given operating and load conditions while simultaneously ensuring minimum levels of exhaust emissions. The composition of the mixture is controlled to maintain low emissions.

Multipoint fuel injection

Multipoint injection supplies the ideal starting point for meeting these objectives. The multipoint injection system uses a separate injector to inject the fuel directly through the intake valve at each individual cylinder. Examples of this type of design are the KE- and L-Jetronic in their various individual configurations (Figure 4).

Mechanical injection system

K-Jetronic is a mechanical injection system in widespread use. This driveless system injects the fuel in a continuous process.

Combined mechanical and electronic injection system

KE-Jetronic is an expanded version of the basic K-Jetronic system. It monitors an extended range of operating data for electronic open-loop control of auxiliary functions to provide more precise fuel metering under varying engine operating conditions.

Electronic injection systems

Electronically-controlled injection systems use electro-magnetic injectors to inject the fuel intermittently.

Examples:

L-Jetronic, LH-Jetronic, and the Motronic integrated fuel-injection and ignition system.

Single-point (throttle-body, central) fuel injection

Single-point fuel injection describes an electronically-controlled injection unit featuring an electromagnetic injector located directly above the throttle valve. This injector sprays fuel into the intake manifold in an intermittent pattern.

Mono-Jetronic is the brand name of the Bosch single-point injection system (Figure 5).

Advantages of fuel injection

Reduced fuel consumption

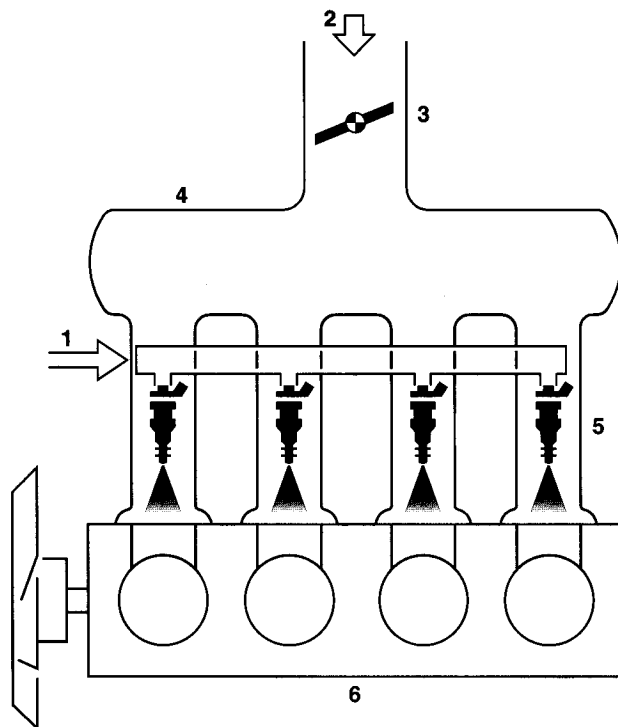
This system monitors all essential engine operating data (e.g., engine speed, load, temperature, throttle-valve aperture) for precise adaptation to stationary and dynamic operating conditions, thereby ensuring that the engine receives only the amount of fuel that it actually requires under any given circumstances.

Improved performance

K- and L-Jetronic allow greater latitude in intake-tract design for better cylinder-

Fig. 4: Multipoint fuel injection

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



filling (volumetric efficiency) and higher torque. The results are enhanced specific output and an improved torque curve. Mono-Jetronic also conforms with standard practice in incorporating separate arrangements for measuring air and metering fuel; the reduction in the length of the throttled section of the intake tract also provides higher outputs (compared with the carburetor).

Immediate acceleration response

All Jetronic units adapt to changes in load state with virtually no delay. This applies to both the single-point and multipoint injection systems: The multipoint systems spray the fuel directly toward the intake valves, effectively banishing virtually all problems associated with intake-tract condensation. With single-point injection, the extended mixture-transport paths make it necessary to compensate for the creation and depletion of condensate layers during transitions. This is achieved by incorporating special design features in the systems used to meter and mix the fuel.

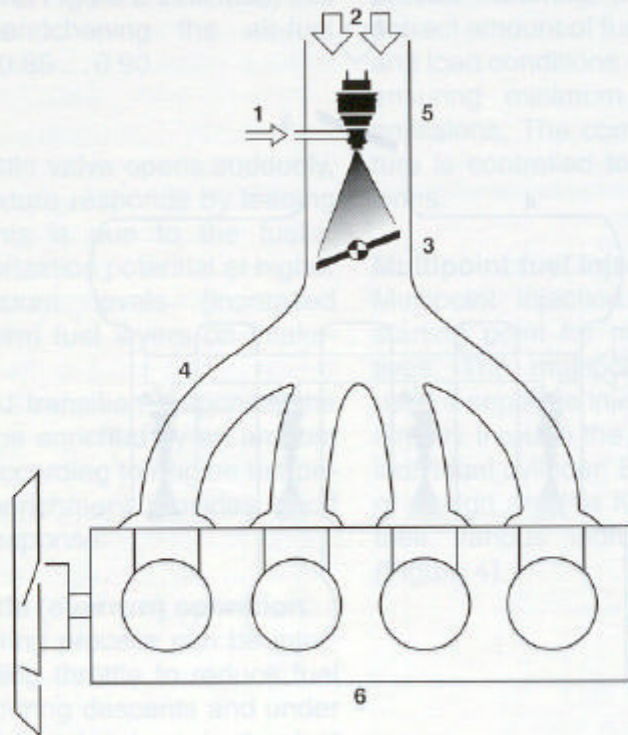
Improved cold starting and warm-up behavior

The fuel is precisely metered according to the engine temperature and starter speed to ensure rapid starts and a rapid climb to a steady idle. In the warm-up phase, the system supplies exactly the correct fuel quantity for combining smooth running and immediate throttle response with the lowest possible fuel consumption.

Low exhaust emissions

The air-fuel mixture exercises a direct influence on the concentration of harmful emissions in the exhaust gases. If the engine is to be operated with a minimal level of exhaust emissions, then the mixture-formation system must be capable of maintaining a specific air/fuel ratio. The operating accuracy of the Jetronic units allow them to maintain the required levels of precise mixture formation.

Fig. 5: Single-point fuel injection (TBI)
1 Fuel, 2 Air, 3 Throttle valve, 4 Intake manifold, 5 Injector, 6 Engine.



The story of fuel injection

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

The Gasmotorenfabrik 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 1200-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 as well as an air-flow sensor.

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!

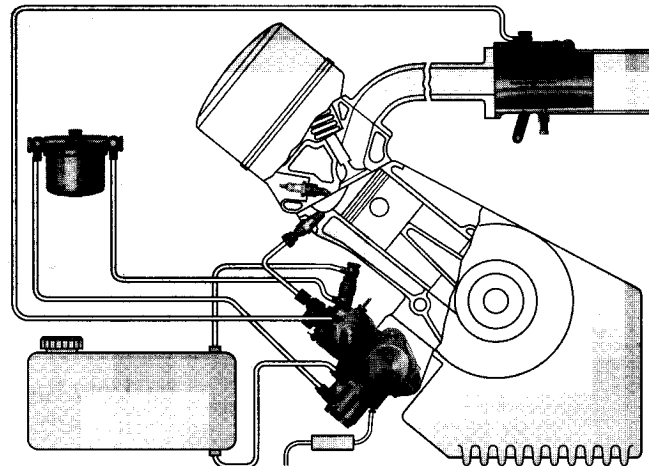
In 1982, the K-Jetronic model became available in an expanded configuration including an electronic closed-loop control circuit and a Lambda oxygen sensor the KE-Jetronic.

These were joined by Bosch Mono-Jetronic in 1983: This particularly cost-efficient single-point injection unit made it feasible to equip small vehicles with Jetronic.

1991 saw Bosch fuel-injection units performing in more than 37 million vehicles throughout the world.

5.6 million engine-management systems were delivered in 1992. Of this number, 2.5 million were Mono-Jetronic and Mono-Motronic systems, with 2 million Motronic systems being supplied within the same period. Today fuel-injection systems have become an essential automotive component.

*Bosch gasoline fuel injection
from the year 1954*



L-Jetronic

Outline of system

The L-Jetronic is an electronically controlled fuel-injection system which injects fuel intermittently into the intake ports. It does not require any form of drive. It combines the advantages of direct air-flow sensing and the special capabilities afforded by electronics.

As is the case with the K-Jetronic system, this system detects all changes resulting from the engine (wear, deposits in the combustion chamber and changes in valve settings), thus guaranteeing a uniformly good exhaust gas quality.

The task of the gasoline injection system is to supply to each cylinder precisely the correct amount of fuel as is necessary for the operation of the engine at that particular moment. A prerequisite for this, however, is the processing of as many influencing factors as possible relevant to the supply of fuel. Since, however, the operating condition of the engine often changes quite rapidly, a speedy adaptation of the fuel delivery to the driving situation at any given moment is of prime importance. Electronically controlled gasoline injection is particularly suitable here. It enables a variety of operational data at any particular location of the vehicle to

be registered and converted into electrical signals by sensors. These signals are then passed on to the control unit of the fuel-injection system which processes them and calculates the exact amount of fuel to be injected. This is influenced via the duration of injection.

Function

A pump supplies the fuel to the engine and creates the pressure necessary for injection. Injection valves inject the fuel into the individual intake ports and onto the intake valves. An electronic control unit controls the injection valves.

The L-Jetronic consists principally of the following function blocks:

- fuel supply system,
- operating-data sensing system and
- fuel-metering system.

Fuel-supply system

The fuel system supplies fuel from the fuel tank to the injection valves, creates the pressure necessary for injection and maintains it at a constant level.

Operating-data sensing system

The sensors register the measured variables which characterize the operating mode of the engine.

The most important measured variable is the amount of air drawn in by the engine and registered by the air-flow sensor. Other sensors register the position of the throttle, the engine speed, the air temperature and the engine temperature.

Fuel-metering system

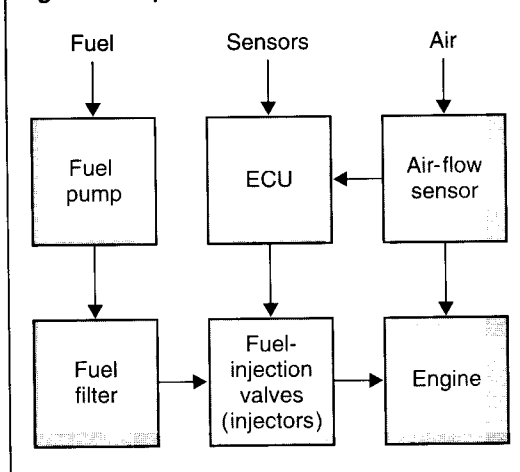
The signals delivered by the sensors are evaluated in the electronic control unit (ECU) where they are used to generate the appropriate control pulses for the injection valves.

Advantages of the L-Jetronic system

Low fuel consumption

In carburetor systems, due to segregation processes in the intake manifold, the individual cylinders of the engine do

Fig. 1: Principle of the L-Jetronic (simplified)



not all receive the same amount of air-fuel mixture. Optimum fuel distribution cannot be achieved if a mixture is created which is suitable for supplying sufficient fuel even to the worst-fed cylinder. This would result in high fuel consumption and unequal stressing of the cylinders.

In L-Jetronic systems, each cylinder has its own injection valve. The injection valves are controlled centrally; this ensures that each cylinder receives precisely the same amount of fuel, the optimum amount, at any particular moment and under any particular load.

Adaptation to operating conditions

The L-Jetronic system adapts to changing load conditions virtually immediately since the required quantity of fuel is computed by the control unit (ECU) within milliseconds and injected by the injection valves onto the engine intake valves.

Low-pollution exhaust gas

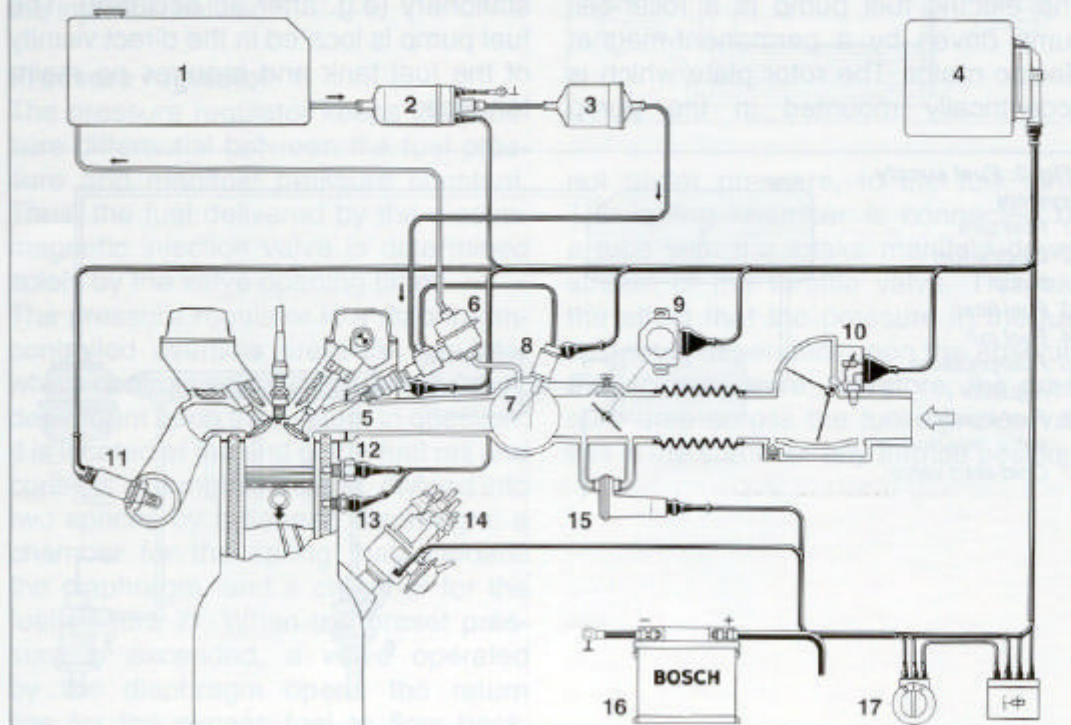
The concentration of pollutants in the exhaust gas is directly related to the air-fuel ratio. If the engine is to be operated with the least pollutant emission, then a fuel-management system is necessary which is capable of maintaining a given air-fuel ratio. The L-Jetronic works so precisely that the precise mixture formation necessary for observing the present-day exhaust regulations is guaranteed.

Higher power output per litre

The fact that there is no carburetor enables the intake passages to be designed aerodynamically in order to achieve optimum air distribution and cylinder charge and, thus, greater torque. Since the fuel is injected directly onto the intake valves, the engine receives only air through the intake manifold. This results in a higher power output per litre and a torque curve appropriate to practice.

Fig. 2: Schematic diagram of an L-Jetronic system with lambda closed-loop control

- 1 Fuel tank, 2 Electric fuel pump, 3 Fuel filter, 4 ECU, 5 Fuel-injection valve (injector),
6 Fuel rail and fuel-pressure regulator, 7 Intake manifold, 8 Cold-start valve, 9 Throttle-valve switch,
10 Air-flow sensor, 11 Lambda sensor, 12 Thermo-time switch, 13 Engine-temperature sensor,
14 Ignition distributor, 15 Auxiliary-air device, 16 Battery, 17 Ignition and starting switch.



Fuel supply system

The fuel supply system comprises the following components:

- electric fuel pump,
- fine filter,
- fuel rail,
- pressure regulator and
- fuel-injection valves.

An electrically driven roller-cell pump pumps the fuel from the fuel tank at a pressure of approximately 2.5 bar through a filter into the fuel rail. From the fuel rail, fuel lines diverge to the injection valves. At the end of the fuel rail is a pressure regulator which maintains the injection pressure at a constant level (Figure 3). More fuel circulates in the fuel system than is needed by the engine even under the most extreme conditions. The excess fuel is returned to the fuel tank by the pressure regulator but not under pressure. The constant flushing through of the fuel system enables it to be continually supplied with cool fuel. This helps to avoid the formation of fuel vapour bubbles and guarantees good hot-starting characteristics.

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

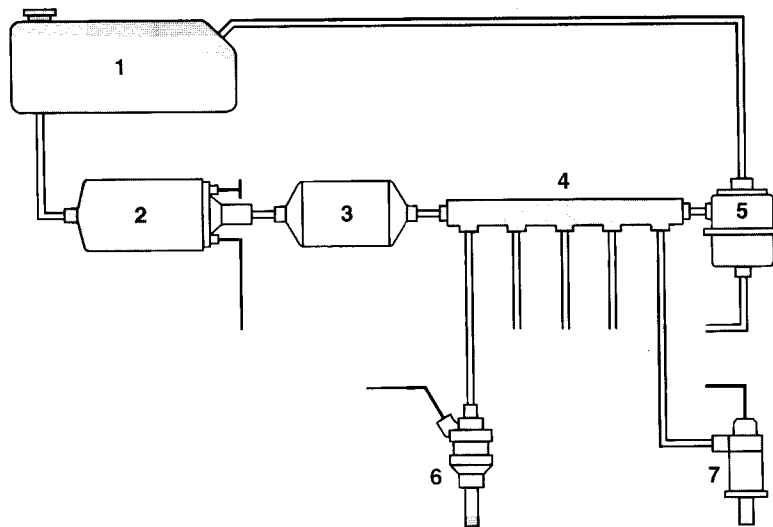
housing is fitted with metal rollers in notches around its circumference which are pressed against the pump housing by centrifugal force and act as seals. The fuel is carried in the cavities which form between the rollers. The pumping action takes place when the rollers, after having closed the inlet port, force the trapped fuel around in front of them until it can escape from the pump through the outlet port (Figure 5). The fuel flows directly around the electric motor. There is no danger of explosion, however, because there is never an ignitable mixture in the pump housing.

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

The electric fuel pump starts immediately when the ignition and starting switch is operated and remains switched on continuously after the engine has started. A safety circuit prevents fuel from being delivered when the ignition is switched on, but when the engine is stationary (e.g. after an accident). The fuel pump is located in the direct vicinity of the fuel tank and requires no maintenance.

Fig. 3: Fuel supply system

- 1 Fuel tank
- 2 Electric fuel pump
- 3 Fuel filter
- 4 Fuel rail
- 5 Fuel-pressure regulator
- 6 Fuel-injection valve (injector)
- 7 Cold-start valve



Fuel filter

The fuel filter filters off impurities in the fuel which could impair the function of the injection system. The filter contains a paper element with an average pore size of $10\ \mu\text{m}$, which is backed up by a fluff strainer (Figure 6). This combination ensures a high degree of filtration. A support plate secures the filter in its metal housing. The filter is installed in the fuel line downstream of the fuel accumulator.

When the filter is changed, it is imperative that the throughflow direction as indicated by the arrow on the housing be observed.

Fuel rail

The fuel rail supplies all injection valves with an equal quantity of fuel and ensures the same fuel pressure at all injection valves.

The fuel rail has a storage function. Its volume, compared with the amount of fuel injected during each working cycle of the engine, is large enough to prevent variations in pressure. The injection valves connected to the fuel rail are therefore subjected to the same fuel pressure.

The fuel rail also facilitates easy fitting of the injection valves.

Pressure regulator

The pressure regulator keeps the pressure differential between the fuel pressure and manifold pressure constant. Thus, the fuel delivered by the electromagnetic injection valve is determined solely by the valve opening time.

The pressure regulator is a diaphragm-controlled overflow pressure regulator which controls pressure at 2.5 or 3 bar, dependent upon the system in question. It is located at the end of the fuel rail and consists of a metal housing, divided into two spaces by a flanged diaphragm: a chamber for the spring that preloads the diaphragm, and a chamber for the fuel (Figure 7). When the preset pressure is exceeded, a valve operated by the diaphragm opens the return line for the excess fuel to flow back,

Fig. 4: Electric fuel pump

1 Intake, 2 Pressure limiter, 3 Roller-cell pump, 4 Motor armature, 5 Check valve, 6 Outlet port.

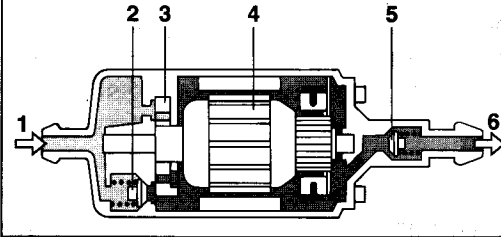


Fig. 5: Pumping action roller-cell pump

1 Intake, 2 Rotor plate, 3 Roller, 4 Roller race plate, 5 Outlet port.

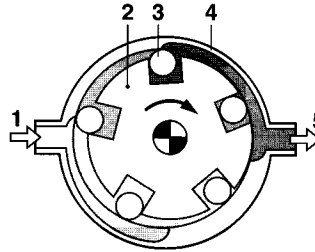
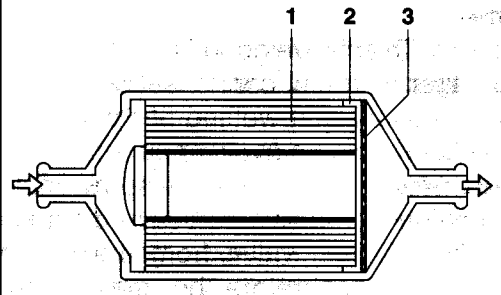


Fig. 6: Fuel filter

1 Paper filter, 2 Strainer, 3 Support plate



not under pressure, to the fuel tank. The spring chamber is connected by a tube with the intake manifold downstream of the throttle valve. This has the effect that the pressure in the fuel system is dependent upon the absolute manifold pressure; therefore, the pressure drop across the fuel-injection valves is the same for any throttle position.

Fuel-injection valves

The electronically controlled fuel-injection valves inject precisely metered fuel into the intake ports and onto the intake valves.

Each engine cylinder has its own fuel-injection valve. The valves are solenoid-operated and are opened and closed by means of electric pulses from the electronic control unit. The fuel-injection valve consists of a valve body and the needle valve with fitted solenoid armature. The valve body contains the solenoid winding and the guide for the needle valve. When there is no current flowing in the solenoid winding, the needle valve is pressed against its seat on the valve outlet by a helical spring. When a current is passed through the solenoid winding, the needle valve is lifted by approximately 0.1 mm from its seat and the fuel can be injected through the precision annular orifice. The front end of the needle valve has a specially ground pintle for atomizing the fuel (Figure 8). The pickup and release times of the valve lie in the range of 1 to 1.5 ms. To achieve good fuel distribution together with low condensation loss, it is necessary that wetting of the intake-manifold walls be avoided.

The means that a particular spray angle in conjunction with a particular distance of the injection valve from the intake valve must therefore be maintained, specific to the engine concerned. The fuel-injection valves are fitted with the help of special holders and are mounted in rubber mouldings in these holders. The insulation from the heat of the engine thereby achieved prevents the formation of fuel-vapour bubbles and guarantees good hot-starting characteristics. The rubber mouldings also ensure that the fuel-injection valves are not subjected to excessive vibration.

Fig. 7: Fuel-pressure regulator

1 Intake-manifold connection, 2 Spring, 3 Valve holder, 4 Diaphragm, 5 Valve, 6 Fuel inlet, 7 Fuel return.

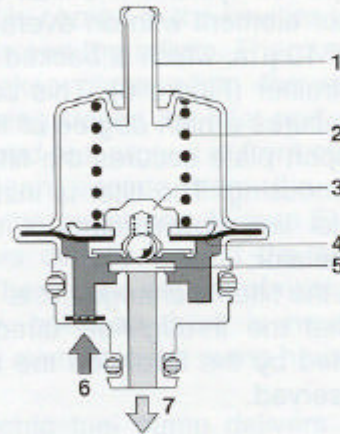
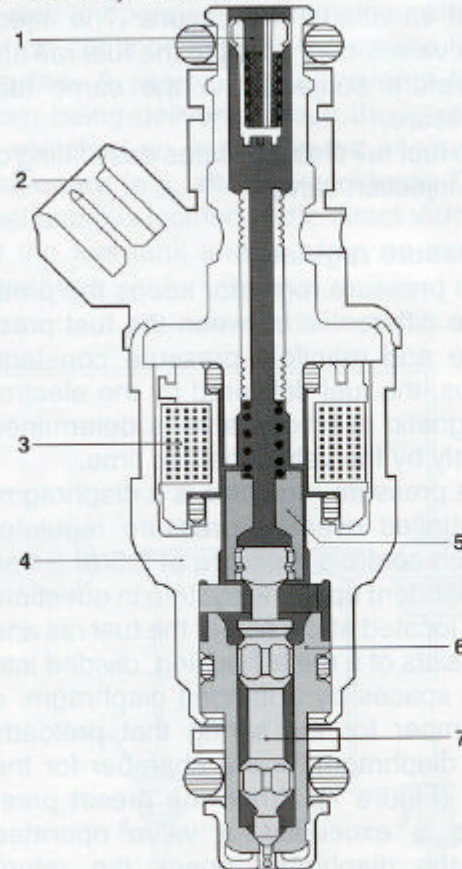


Fig. 8: Solenoid-operated fuel-injection valve (injector)

1 Filter in fuel inlet, 2 Electrical connection, 3 Solenoid winding, 4 Valve housing, 5 Armature, 6 Valve body, 7 Valve needle.



Operating-data sensing system

Sensors detect the operating mode of the engine and signal this condition electrically to the control unit. The sensors and ECU form the control system. The sensors are described in conjunction with the relevant main function or compensation function.

Measured variables

The measured variables characterizing the operating mode of the engine are as follows:

- main measured variables
- measured variables for compensation
- measured variables for precise compensation.

The ECU evaluates all measured variables together so that the engine is always supplied with exactly the amount of fuel required for the instantaneous operating mode. This achieves optimum driveability.

Main measured variables

The main measured variables are the engine speed and the amount of air drawn in by the engine. These determine the amount of air per stroke which then serves as a direct measure for the loading condition of the engine.

Measured variables for compensation

For operating conditions such as cold start and warm-up and the various load conditions which deviate from normal operation, the mixture must be adapted to the modified conditions. Starting and warm-up conditions are detected by sensors which transmit the engine temperature to the control unit. For compensating various load conditions, the load range (idle, part-load, full-load) is transmitted to the control unit via the throttle-valve switch.

Measured variables for precision compensation

In order to achieve optimum driving behavior, further operating ranges and in-

fluences can be considered: the sensors mentioned above detect the data for transition response when accelerating, for maximum engine-speed limitation and during overrun. The sensor signals have a particular relationship to each other in these operating ranges. The control unit recognizes these relationships and influences the control signals of the injection valves accordingly.

Calculating engine speed

Information on engine speed and the start of injection is passed on to the L-Jetronic ECU in breaker-triggered ignition systems by the contact-breaker points in the ignition distributor, and, in breakerless ignition systems, by terminal 1 of the ignition coil.

Measuring the air flow

The amount of air drawn in by the engine is a measure of its loading condition. The air-flow measurement system allows for all changes which may take place in the engine during the service life of the vehicle, e.g. wear, combustion-chamber deposits and changes to the valve setting.

Since the quantity of air drawn in must first pass through the air-flow sensor before entering the engine, this means that, during acceleration, the signal leaves the sensor before the air is actually drawn into the cylinder. This

Fig. 9: Calculating engine speed with a breaker-triggered ignition system
1 Ignition distributor, 2 ECU.
n Engine speed.

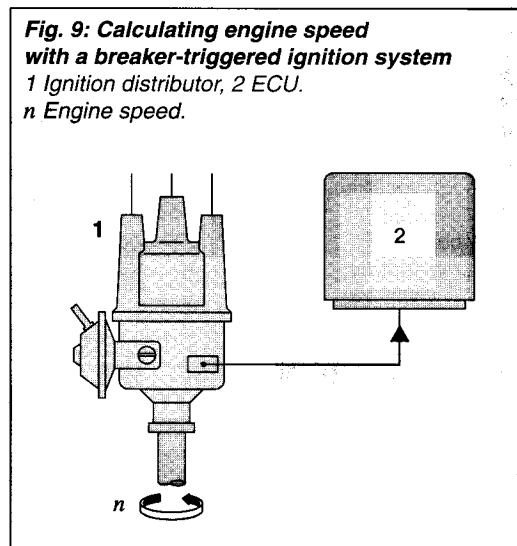


Fig. 10: Air-flow sensor in the intake system

- 1 Throttle valve
 - 2 Air-flow sensor
 - 3 Intake air temperature signal to the ECU
 - 4 ECU
 - 5 Air-flow sensor signal to the ECU
 - 6 Air filter
- Q_L Intake-air quantity
 α Deflection angle

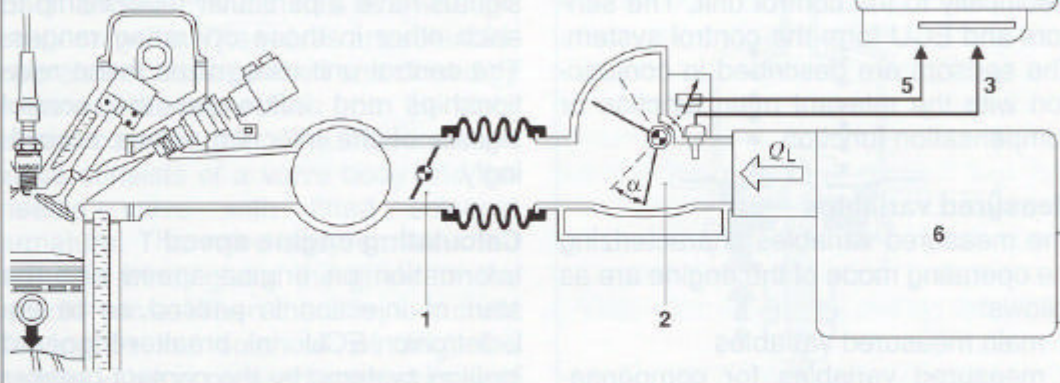


Fig. 11: Air-flow sensor (air side)

- 1 Compensation flap
- 2 Damping volume
- 3 Bypass
- 4 Sensor flap
- 5 Idle-mixture adjusting screw (bypass)

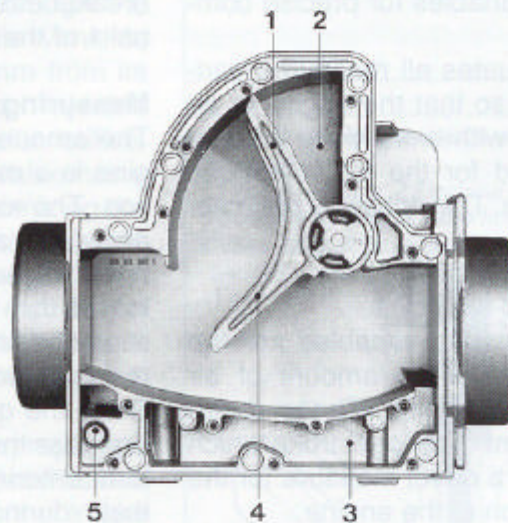
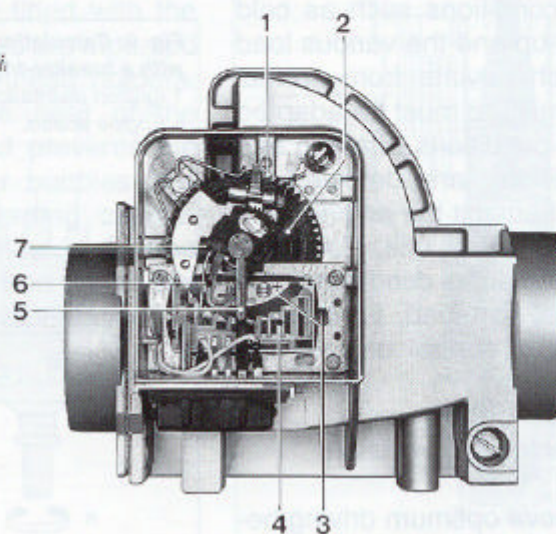


Fig. 12: Air-flow sensor (electrical-connection side)

- 1 Ring gear for spring preload
- 2 Return spring
- 3 Wiper track
- 4 Ceramic substrate with resistors and conductor straps
- 5 Wiper tap
- 6 Wiper
- 7 Pump contact



permits correct mixture adaptation at any time during load changes.

The sensor flap in the air-flow sensor measures the entire air quantity inducted by the engine, thereby serving as the main controlled variable for determining the load signal and basic injection quantity.

Air-flow sensor

The principle is based on the measurement of the force emanating from the stream of air drawn in by the engine. This force has to counteract the opposing force of a return spring acting upon the air-flow sensor flap. The flap is deflected in such a manner that, together with the profile of the measurement channel, the free cross-section increases along with the rise in the quantity of air passing through it (Figs. 10, 11 and 12).

The change in the free air-flow sensor cross-section, depending on the position of the sensor flap, was selected so that a logarithmic relationship results between flap angle and air throughput. The result is that, at low air throughput, where measurement precision must be particularly high, the sensitivity of the air-flow sensor is also high. In order to prevent the oscillations in the intake system caused by the engine intake strokes from having more than a minimum effect upon the sensor-flap position, a compensation flap is attached rigidly to the sensor flap. The pressure oscillations have the same effects upon both flaps and the moments of force therefore cancel each other out so that the measurement is not affected. The angular position of the sensor flap is transformed by a potentiometer into a voltage. The potentiometer is calibrated such that the relationship between air throughput and voltage output is inversely proportional. In order that aging and the temperature characteristic of the potentiometer have no effect upon the accuracy, only resistance values are evaluated in the ECU. In order to set the air-fuel ratio at idle, an adjustable bypass channel is provided.

Fuel metering

As the central unit of the system, the ECU evaluates the data delivered by the sensors on the operating mode of the engine. From this data, control pulses for the injection valves are generated, whereby the quantity to be injected is determined by the length of time the injection valves are opened.

Electronic control unit (ECU)

Configuration

The L-Jetronic ECU is in a splash-proof sheet-metal housing which is fitted where it is not affected by the heat radiated from the engine. The electronic components in the ECU are arranged on printed-circuit boards; the output-stage power components are mounted on the metal frame of the ECU thus assuring good heat dissipation. By using integrated circuits and hybrid modules, it has been possible to reduce the number of parts to a minimum. The reliability of the ECU was increased by combining functional groups into integrated circuits (e.g. pulse shaper, pulse divider and division control multivibrator) and by combining components into hybrid modules.

A multiple plug is used to connect the ECU to the injection valves, the sensors and the vehicle electrical system. The input circuit in the ECU is designed so that the latter cannot be connected with the wrong polarity and cannot be short-circuited. Special Bosch testers are available for carrying out measurements on the ECU and on the sensors. The testers can be connected between the wiring harness and the ECU with multiple plugs.

Operating data processing

Engine speed and inducted air quantity determine the basic duration of injection.

The timing frequency of the injection pulses is determined on the basis of the engine speed.

The pulses delivered by the ignition

system for this purpose are processed by the ECU. First of all, they pass through a pulse-shaping circuit which generates square-wave pulses from the signal "delivered" in the form of damped oscillations, and feeds these to a frequency divider.

The frequency divider divides the pulse frequency given by the ignition sequence in such a manner that two pulses occur for each working cycle regardless of the number of cylinders. The start of the pulse is, at the same time, the start of injection for the injection valves. For each turn of the crankshaft, each injection valve injects once, regardless of the position of the intake valves. When the intake valve is closed, the fuel is stored and the next time it opens the fuel is drawn into the combustion chamber together with the air. The duration of injection depends on the amount of air measured by the air-flow sensor and the engine speed.

The ECU also evaluates the signal supplied by the potentiometer. Fig. 14 shows the interrelationships between intake air quantity, flap angle, potentiometer voltage and injected quantity. Assuming a specific intake-air quantity Q_L flowing through the air-flow sensor (point Q), we thus obtain the theoret-

ically required injection quantity Q_K (point D). In addition, a specific flap angle (point A) is established as a function of the air intake quantity. The potentiometer actuated by the air-flow sensor flap supplies a voltage signal U_S to the ECU (point B) which controls the injection valves, whereby point C represents the injected fuel quantity V_E . It can be seen that the fuel quantity injected in practice and the theoretically required injection quantity are identical (line C-D).

Fig. 14: Interrelationships between intake-air quantity, sensor-flap angle, voltage at the potentiometer and injected fuel quantity

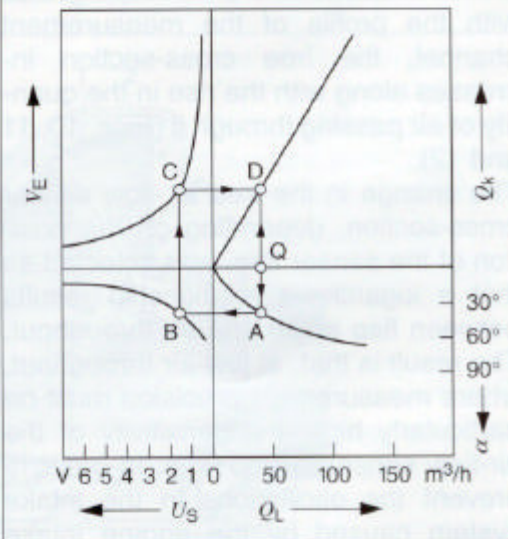
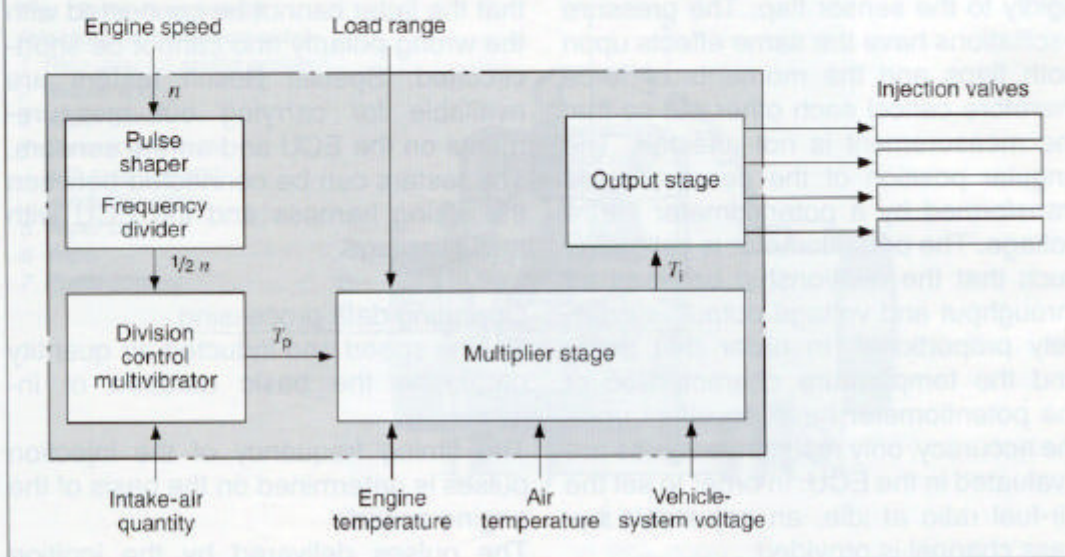


Fig. 13: Block diagram of the ECU

T_i Injection pulses, corrected, T_p Basic injection duration, n Engine speed.



Generation of injection pulses (Fig. 15)

The generation of the basic injection duration is carried out in a special circuit group in the ECU, the division control multivibrator.

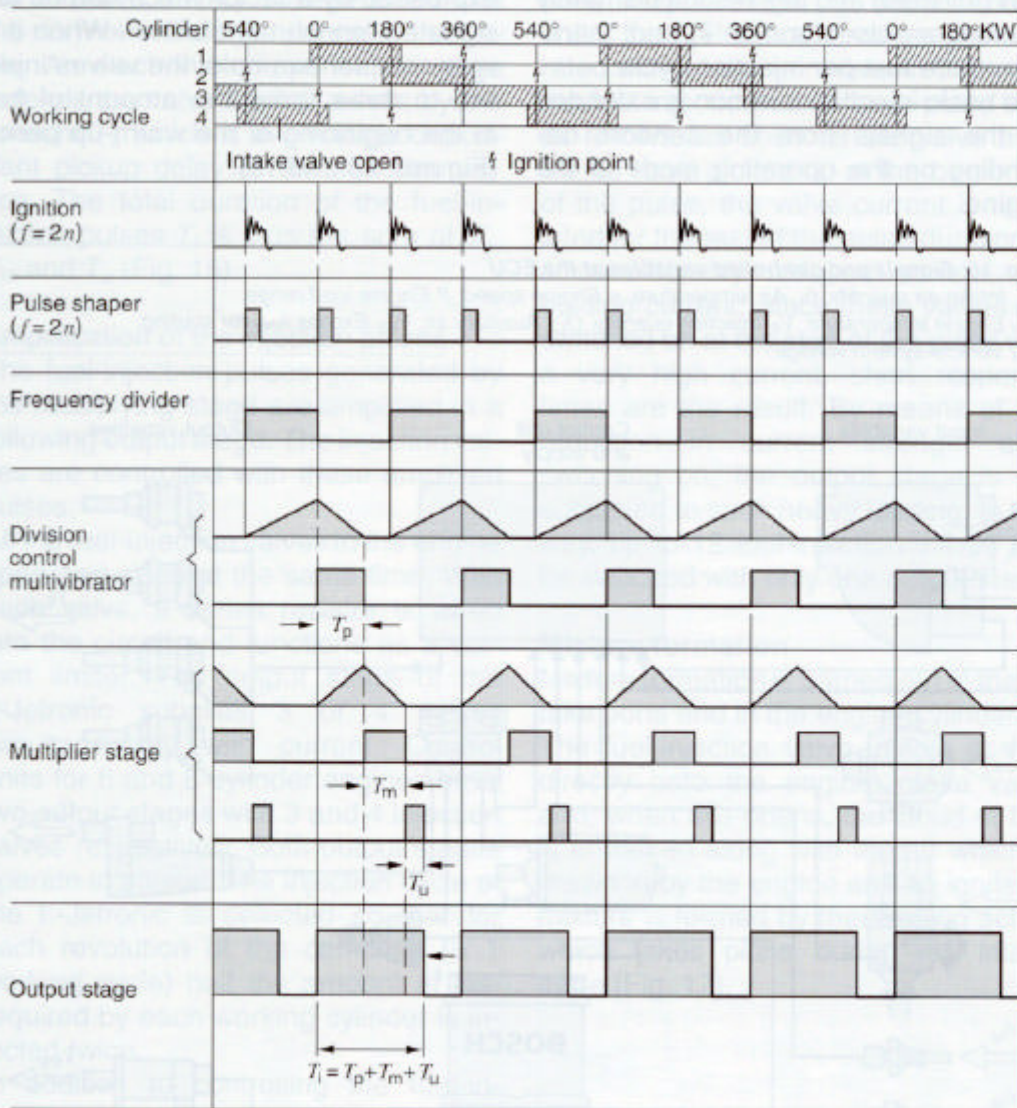
The division control multivibrator (DSM) receives the information on speed n from the frequency divider and evaluates it together with the air-quantity signal U_S . For the purpose of intermittent fuel injection, the DSM converts the voltage U_S into square-wave control

pulses. The duration T_p of this pulse determines the basic injection quantity, i.e. the quantity of fuel to be injected per intake stroke without considering any corrections. T_p is therefore regarded as the "basic injection duration". The greater the quantity of air drawn in with each intake stroke, the longer the basic injection duration.

Two border cases are possible here: if the engine speed n increases at a constant air throughput Q , then the abso-

Fig. 15: Complete schematic pulse-timing diagram of the L-Jetronic for 4-cylinder engines

f Ignition pulse frequency or sparking rate
 n Engine speed
 T_p Basic duration of injection
 T_m Pulse duration extension resulting from corrections
 T_u Pulse duration extension resulting from voltage compensation
 T_i Pulse control time. The actual injection duration per cycle differs from the pulse control time since both a response delay and a release delay change the injection duration.



*KW = Crankshaft

Time →

Mixture formation

lute pressure sinks downstream of the throttle valve and the cylinders draw in less air per stroke, i.e. the cylinder charge is reduced. As a result, less fuel is needed for combustion and the duration of the pulse T_p is correspondingly shorter. If the engine output and thereby the amount of air drawn in per minute increase and providing the speed remains constant, then the cylinder charge will improve and more fuel will be required: the pulse duration T_p of the DSM is longer (Figs. 15 and 16).

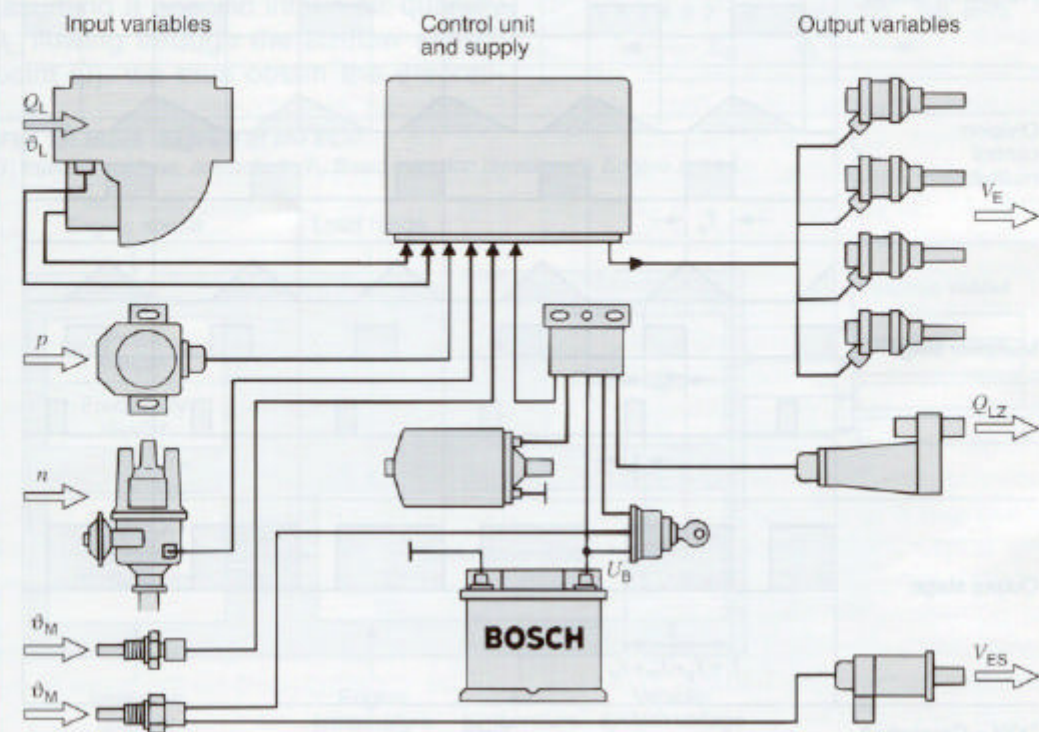
During normal driving, engine speed and output usually change at the same time, whereby the DSM continually calculates the basic injection duration T_p . At a high speed, the engine output is normally high (full load) and this results ultimately in a longer pulse duration T_p and, therefore, more fuel per injection cycle.

The basic injection duration is extended by the signals from the sensors depending on the operating mode of the engine.

Adaptation of the basic injection duration to the various operating conditions is carried out by the multiplying stage in the ECU. This stage is controlled by the DSM with the pulses of duration T_p . In addition, the multiplying stage gathers information on various operating modes of the engine, such as cold start, warm-up, full-load operation etc. From this information, the correction factor k is calculated. This is multiplied by the basic injection duration T_p calculated by the division control multivibrator. The resulting time is designated T_m . T_m is added to the basic injection duration T_p , i.e. the injection duration is extended and the air-fuel mixture becomes richer. T_m is therefore a measure of fuel enrichment, expressed by a factor which can be designated "enrichment factor". When it is very cold, for example, the valves inject two to three times the amount of fuel at the beginning of the warm-up period (Figures 13 and 15).

Fig. 16: Signals and controlled variables at the ECU

Q_L Intake air quantity, ϑ_L Air temperature, n Engine speed, P Engine load range, ϑ_M Engine temperature, V_E Injection quantity, Q_{LZ} Auxiliary air, V_{ES} Excess fuel for starting, U_B Vehicle-system voltage.



Voltage correction

The pickup time of the fuel-injection valves depends very much on the battery voltage. Without electronic voltage correction, the response delay which results from a low-voltage battery would cause the injection duration to be too short and, as a result, insufficient fuel would be injected. The lower the battery voltage, the less fuel the engine would receive. For this reason, a low battery voltage, i.e. after starting with a heavily discharged battery, must be compensated for with an appropriate extension T_u of the pre-calculated pulse time in order that the engine receives the correct fuel quantity. This is known as "voltage compensation". For voltage compensation, the effective battery voltage is fed into the control unit as the controlled variable. An electronic compensation stage extends the valve control pulses by the amount T_u which is the voltage-dependent pickup delay of the injection valves. The total duration of the fuel-injection pulses T_i is thus the sum of T_p , T_m and T_u (Fig. 15).

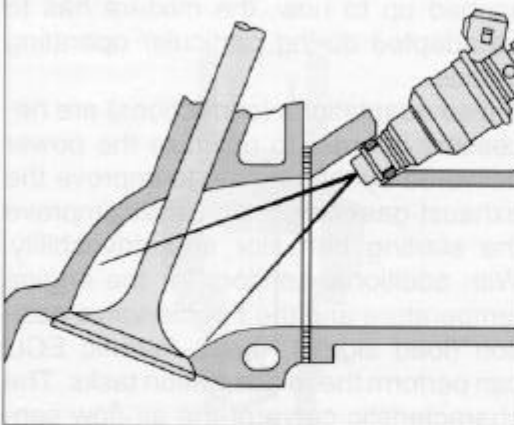
Amplification of the injection pulses

The fuel-injection pulses generated by the multiplying stage are amplified in a following output stage. The injection valves are controlled with these amplified pulses.

All the fuel-injection valves in the engine open and close at the same time. With each valve, a series resistor is wired into the circuit and functions as a current limiter. The output stage of the L-Jetronic supplies 3 or 4 valves simultaneously with current. Control units for 6 and 8-cylinder engines have two output stages with 3 and 4 injection valves respectively. Both output stages operate in unison. The injection cycle of the L-Jetronic is selected so that for each revolution of the camshaft (= 1 working cycle) half the amount of fuel required by each working cylinder is injected twice.

In addition to controlling the fuel-injection valves through the series resistors, some control units have a regu-

Fig. 17: Mixture formation
Intermittent injection onto the engine intake valve.



lated output stage. In these control units, the fuel-injection valves are operated without series resistors. Control of the fuel-injection valve takes place then as follows: as soon as the valve armatures have picked up at the beginning of the pulse, the valve current is regulated for the rest of the pulse duration to a considerably reduced current, the holding current. Since these valves are switched on at the start of the pulse with a very high current, short response times are the result. By means of the reduction in current strength after switching on, the output stage is not subjected to such heavy loading. In this way, up to 12 fuel-injection valves can be switched with only one output stage.

Mixture formation

Mixture formation is carried out in the intake ports and in the engine cylinder.

The fuel-injection valve injects its fuel directly onto the engine intake valve and, when this opens, the cloud of fuel is entrained along with the air which is drawn in by the engine and an ignitable mixture is formed by the swirling action which takes place during the intake cycle (Fig. 17).

Adaptation to operating modes

In addition to the basic functions described up to now, the mixture has to be adapted during particular operating modes.

These adaptations (corrections) are necessary in order to optimize the power delivered by the engine, to improve the exhaust-gas composition and to improve the starting behavior and driveability. With additional sensors for the engine temperature and the throttle-valve position (load signal), the L-Jetronic ECU can perform these adaptation tasks. The characteristic curve of the air-flow sensor determines the fuel-requirement curve, specific to the particular engine, for all operating ranges.

Cold-start enrichment

When the engine is started, additional fuel is injected for a limited period depending on the temperature of the engine. This is carried out in order to compensate for fuel condensation losses in the inducted mixture and in order to facilitate starting the cold engine.

This extra fuel is injected by the cold-start valve into the intake manifold. The injection duration 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

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

There are two methods of cold-start enrichment:

- start control with the aid of the ECU and injection valves (Figure 18) or
- cold-start enrichment via thermo-time switch and cold-start valve (Figure 19).

Start control

By extending the period during which the fuel-injection valves inject, more fuel can be supplied during the starting phase. The electronic control unit controls the start procedure by processing the signals from the ignition and starting switch and the engine-temperature sensor (Figure 18). The construction and method of operation of the temperature sensor are described in Chapter "Warm-up enrichment".

Cold-start valve

The cold-start valve (Figure 20) is a solenoid-operated valve. The solenoid winding is located in the valve. In neutral position, a helical spring presses the movable solenoid armature against a seal, thereby shutting off the valve.

When a current is passed through the solenoid, the armature, which now rises from the valve seat, allows fuel to flow along the sides of the armature to a nozzle where it is swirled. The swirl nozzle atomizes the fuel very finely and as a result enriches the air in the intake

Fig. 18: Cold-start enrichment by start control

- 1 Engine-temperature sensor, 2 ECU, 3 Fuel-injection valves (injectors), 4 Ignition and starting switch.

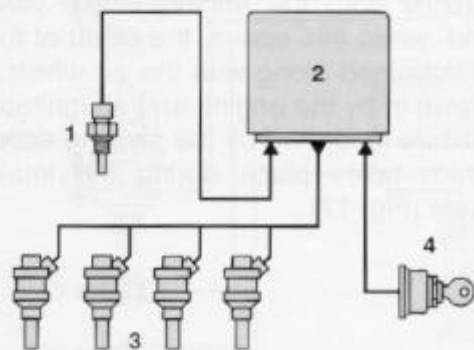


Fig. 19: Cold-start enrichment by cold-start valve

- 1 Cold-start valve, 2 Thermo-time switch, 3 Relay combination, 4 Ignition and starting switch.

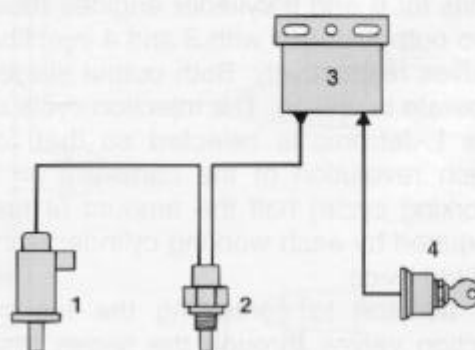


Fig. 20: Cold-start valve operated

1 Electrical connection, 2 Fuel inlet with filter strainer, 3 Valve (solenoid armature), 4 Solenoid winding, 5 Swirl nozzle, 6 Valve seat.

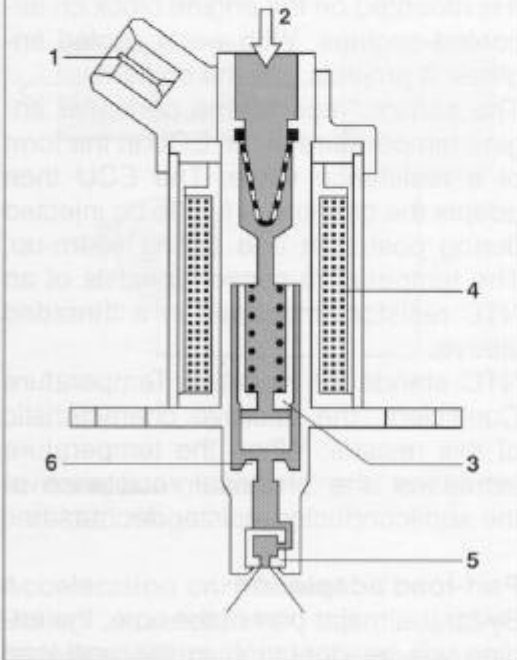
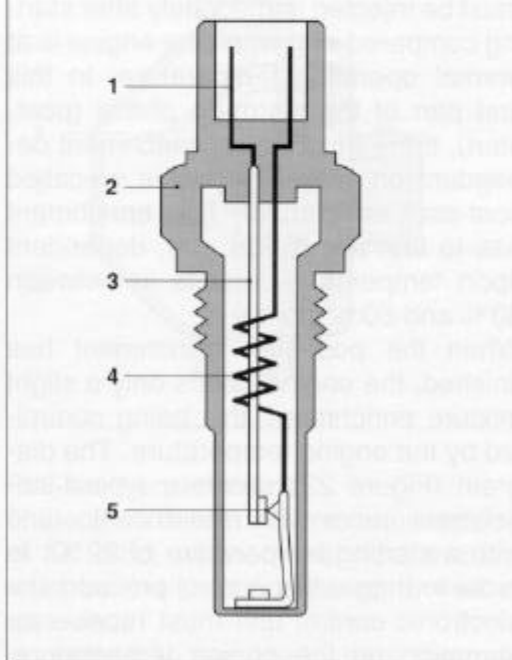


Fig. 21: Thermo-time switch

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



manifold downstream of the throttle valve with fuel. The cold-start valve is mounted on the intake manifold in such a way as to provide a favourable distribution of the air-fuel mixture to all engine cylinders.

Thermo-time switch

The thermo-time switch limits the duration of injection of the cold-start valve depending on the temperature of the engine.

The thermo-time switch (Figure 21) is an electrically heated bimetal switch which opens or closes a contact depending on its temperature. It is controlled via the ignition and starting switch. The thermo-time switch is attached in a position representative of the engine temperature. During a cold start, it limits the "on" period of the cold-start valve. In the case of repeated start attempts, or when starting takes too long, the cold-start valve ceases to inject.

The "on" period is determined by the thermo-time switch which is heated by

the heat of the engine as well as by its own built-in electric heater. The electrical heating is necessary in order to ensure that the "on" period of the cold-start valve is limited under all conditions, and engine flooding is prevented. During an actual cold start, the heat generated by the built-in heating winding is mainly responsible for the "on" period (switch-off, for instance, at -20°C after approx. 7.5 s). With a warm engine, the thermo-time switch has already been heated so far by engine heat that it remains open and prevents the cold-start valve from going into action.

Post-start and warm-up enrichment

During warm-up, the engine receives extra fuel.

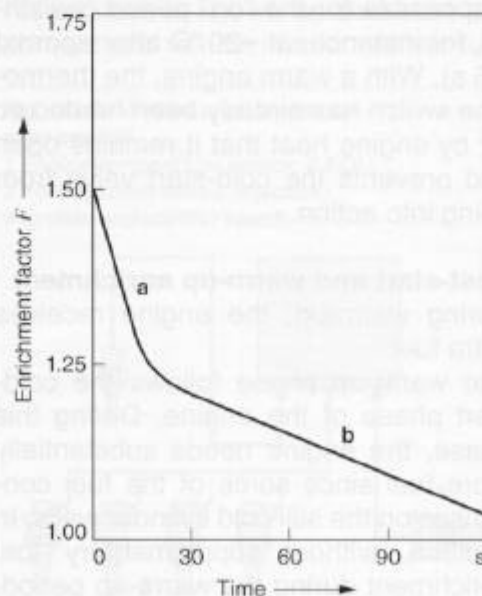
The warm-up phase follows the cold-start phase of the engine. During this phase, the engine needs substantially more fuel since some of the fuel condenses on the still cold cylinder walls. In addition, without supplementary fuel enrichment during the warm-up period, a major drop in engine speed would be

noticed after the additional fuel from the cold-start valve has been cut off.

For example, at a temperature of -20°C , depending on the type of engine, two to three times as much fuel must be injected immediately after starting compared with when the engine is at normal operating temperature. In this first part of the warm-up phase (post-start), there must be an enrichment dependent on time. This is the so-called post-start enrichment. This enrichment has to last about 30s and, dependent upon temperature, results in between 30% and 60% more fuel.

When the post-start enrichment has finished, the engine needs only a slight mixture enrichment, this being controlled by the engine temperature. The diagram (Figure 22) shows a typical enrichment curve with reference to time with a starting temperature of 22°C . In order to trigger this control process, the electronic control unit must receive information on the engine temperature. This comes from the temperature sensor.

Fig. 22: Warm-up enrichment curve
Enrichment factor F as a function of time:
a) Proportion mainly dependent on time,
b) Proportion mainly dependent on engine temperature.



Engine-temperature sensor

The engine-temperature sensor (Figure 23) measures the temperature of the engine and converts this into an electrical signal for the ECU.

It is mounted on the engine block on air-cooled engines. With water-cooled engines, it projects into the coolant.

The sensor "reports" the particular engine temperature to the ECU in the form of a resistance value. The ECU then adapts the quantity of fuel to be injected during post-start and during warm-up. The temperature sensor consists of an NTC resistor embedded in a threaded sleeve.

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

Part-load adaptation

By far the major part of the time, the engine will be operating in the part-load range. The fuel-requirement curve for this range is programmed in the ECU and determines the amount of fuel supplied. The curve is such that the fuel

Fig. 23: Engine-temperature sensor
1 Electrical connection, 2 Housing, 3 NTC resistor.

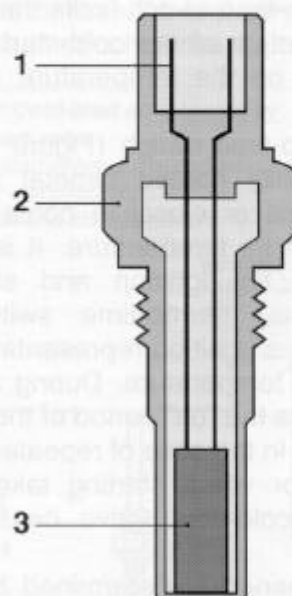


Fig. 24: Idle/full-load correction

1 Throttle valve, 2 Throttle-valve switch, 3 ECU

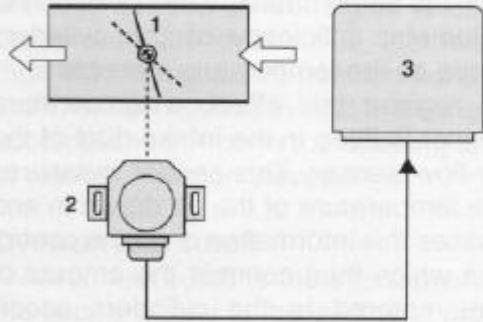
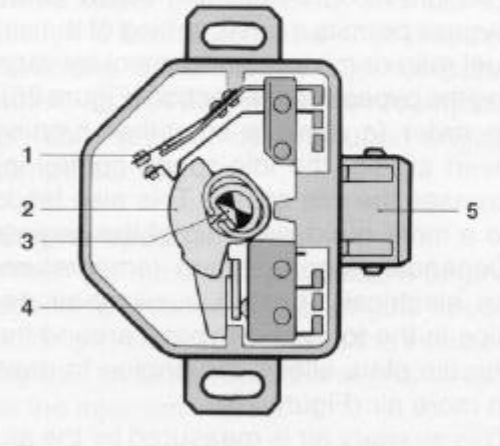


Fig. 25 Throttle-valve switch

1 Full-load contact, 2 Contoured switching guide, 3 Throttle-valve shaft, 4 Idle contact, 5 Electrical connection.



consumption of the engine is low in the part-load range.

Acceleration enrichment

During acceleration, the L-Jetronic meters additional fuel to the engine.

If the throttle is opened abruptly, the air-fuel mixture is momentarily leaned-off, and a short period of mixture enrichment is needed to ensure good transitional response.

With this abrupt opening of the throttle valve, the amount of air which enters the combustion chamber, plus the amount of air which is needed to bring the manifold pressure up to the new level, flow through the air-flow sensor. This causes the sensor plate to "overswing" past the wide-open-throttle point. This "overswing" results in more fuel being metered to the engine (acceleration enrichment) and ensures good acceleration response.

Since this acceleration enrichment is not adequate during the warm-up phase, the control unit also evaluates a signal representing the speed at which the sensor flap deflects during this operating mode.

Full-load enrichment

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

In contrast to part-load where the calibration is for minimum fuel consumption and low emissions, at full load it is necessary to enrich the air-fuel mixture. This enrichment is programmed in the electronic control unit, specific to the particular engine. The information on the load condition is supplied to the control unit by the throttle-valve switch.

Throttle-valve switch

The throttle-valve switch (Figure 25) communicates the "idle" and "full load" throttle positions to the control unit.

It is mounted on the throttle body and actuated by the throttle-valve shaft. A contoured switching guide closes the "idle" contact at one end of switch travel and the "full-load" contact at the other.

Controlling the idle speed

The air-flow sensor contains an adjustable bypass via which a small quantity of air can bypass the sensor flap.

The idle-mixture-adjusting screw in the bypass permits a basic setting of the air-fuel ratio or mixture enrichment by varying the bypass cross-section (Figure 26). In order to achieve smoother running even at idle, the idle-speed control increases the idle speed. This also leads to a more rapid warm-up of the engine. Depending upon engine temperature, an electrically heated auxiliary-air device in the form of a bypass around the throttle plate allows the engine to draw in more air (Figure 26).

This auxiliary air is measured by the air-flow sensor, and leads to the L-Jetronic providing the engine with more fuel. Precise adaptation is by means of the electrical heating facility. The engine temperature then determines how much auxiliary air is fed in initially through the bypass, and the electrical heating is mainly responsible for subsequently reducing the auxiliary air as a function of time.

Auxiliary-air device

The auxiliary-air device incorporates a perforated plate (Figure 27) which is actuated by the bimetallic strip and which controls the cross-section of the bypass passage.

Initially, the bypass cross-section opened by the perforated plate is determined by the engine temperature, so that during a cold start the bypass opening is adequate for the auxiliary air required. The opening closes steadily along with increasing engine temperature until, finally, it is closed completely. The bi-metal strip is electrically heated and this limits the opening time, starting from the initial setting which is dependent upon the engine temperature.

The auxiliary-air device is fitted in the best possible position on the engine for it to assume engine temperature. It does not function when the engine is warm.

Adaptation to the air temperature

The quantity of fuel injected is adapted to the air temperature. The quantity of air necessary for combustion depends upon the temperature of the air drawn in. Cold air is denser. This means that with the same throttle-valve position the volumetric efficiency of the cylinders drops as the temperature increases.

To register this effect, a temperature sensor is fitted in the intake duct of the air-flow sensor. This sensor measures the temperature of the air drawn in and passes this information on to the control unit which then controls the amount of fuel metered to the cylinders accordingly.

Fig. 26: Idle-speed control

- 1 Throttle valve, 2 Air-flow sensor,
- 3 Auxiliary-air device,
- 4 Idle-mixture-adjusting screw.

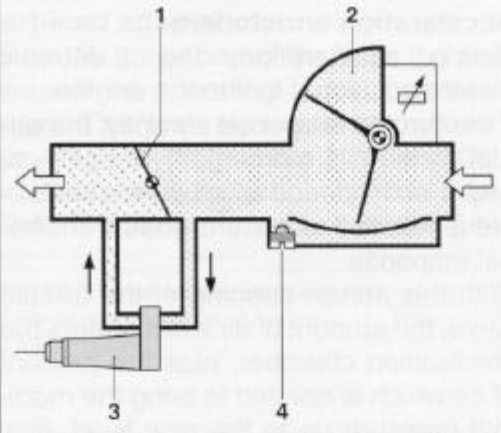
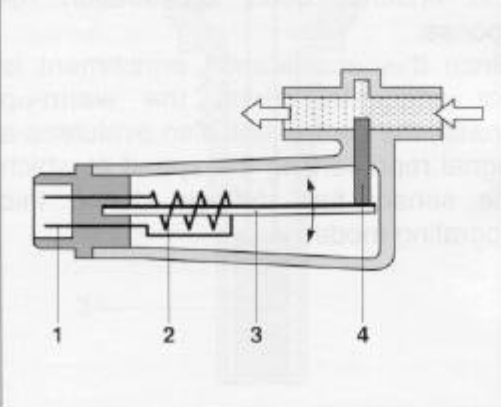


Fig. 27: Electrically heated auxiliary-air device

- 1 Electrical connection,
- 2 Electric heating element,
- 3 Bimetal strip, 4 Perforated plate.



Supplementary functions

Lambda closed-loop control

By means of the lambda closed-loop control, the air-fuel ratio can be maintained precisely at $\lambda = 1$. In the control unit, the lambda-sensor signal is compared with an ideal value (setpoint), thus controlling a two-position controller. The intervention in fuel-metering is accomplished through the opening time of the fuel-injection valves.

Overrun fuel cutoff

Overrun fuel cutoff is the interruption of the supply of fuel to the engine in order to reduce consumption and emissions

during downhill driving and braking. When the driver takes his foot off the accelerator pedal while driving, the throttle-valve switch signals "throttle-valve closed" to the ECU and fuel injection is interrupted. The engine-speed switching threshold for injection-pulse cutoff, as well as that for the resumption of fuel injection, depend upon engine temperature.

Engine-speed limiting

When the maximum permissible engine speed is reached, the engine-speed limiting system suppresses the injection signals and interrupts the supply of fuel to the injection valves.

Fig. 28: Lambda closed control loop of the L-Jetronic

The lambda closed control loop is superimposed upon the open-loop air-fuel mixture control. The injected fuel quantity, as determined by the A/F mixture control, is modified by the lambda closed-loop control in order to provide optimum combustion. U_L Intake-air quantity signal, U_λ Lambda-sensor signal.

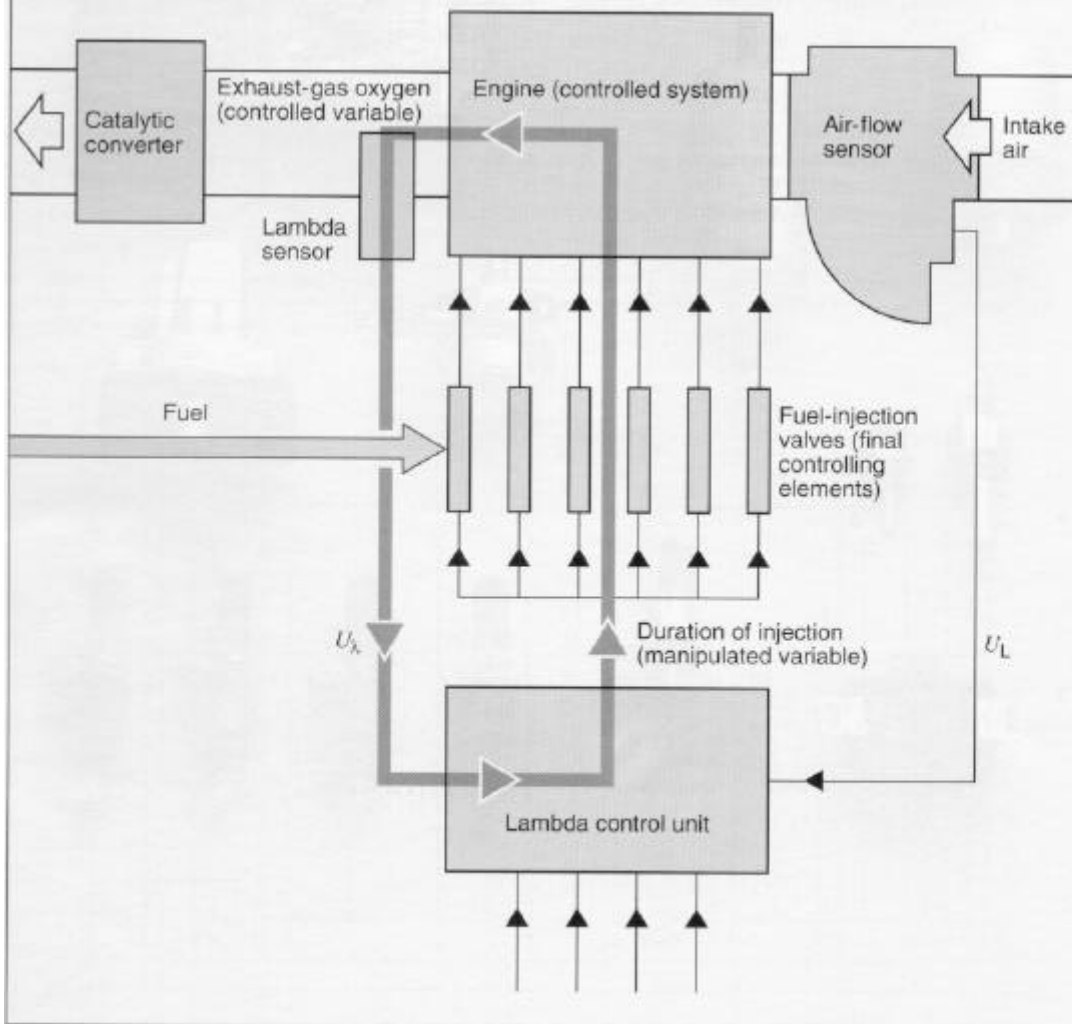
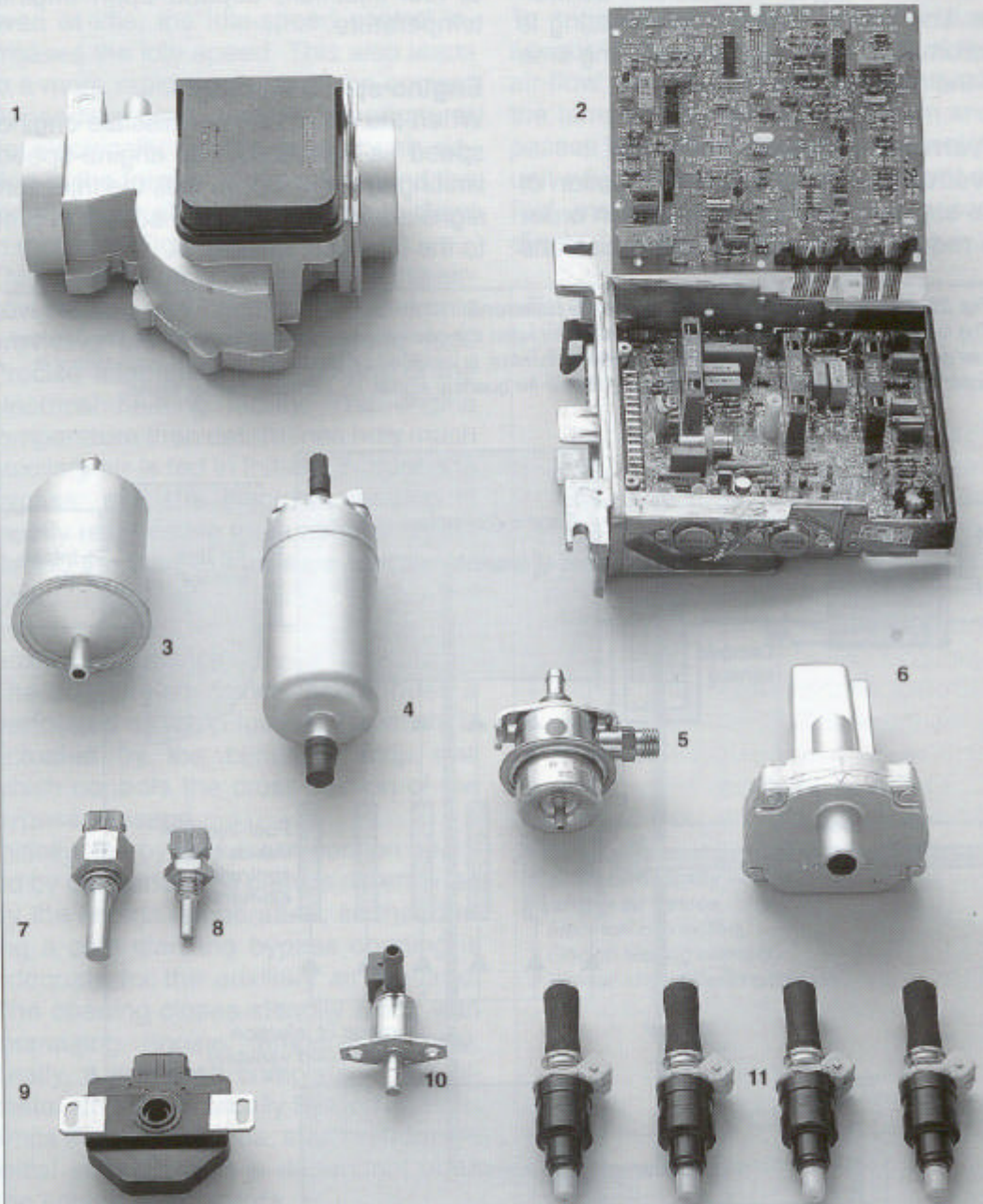


Fig. 29: Components of the L-Jetronic

1 Air-flow sensor, 2 ECU, 3 Fuel filter, 4 Fuel pump, 5 Fuel pressure regulator, 6 Auxiliary-air device,
7 Thermo-time switch, 8 Temperature sensor, 9 Throttle-valve switch, 10 Cold-start valve,
11 Fuel-injection valves (injectors).



Electric circuitry

The complete circuitry of the L-Jetronic has been designed so that it can be connected to the vehicle electrical system at a single point.

At this point, you will find the relay combination which is controlled by the ignition and starting switch, and which switches the vehicle voltage to the control unit and the other Jetronic components.

The relay combination has two separate plug connections, one to the vehicle electrical system and one to the Jetronic.

Safety circuit

In order to prevent the electric fuel pump from continuing to supply fuel following an accident, it is controlled by means of a safety circuit. When the engine is running, the air passing through the air-flow sensor causes a switch to be operated. This switch controls the relay combina-

tion which in turn switches the electric fuel pump. If the engine stops with the ignition still on, air is no longer drawn in by the engine and the switch interrupts the power supply to the fuel pump. During starting, the relay combination is controlled accordingly by terminal 50 of the ignition and starting switch.

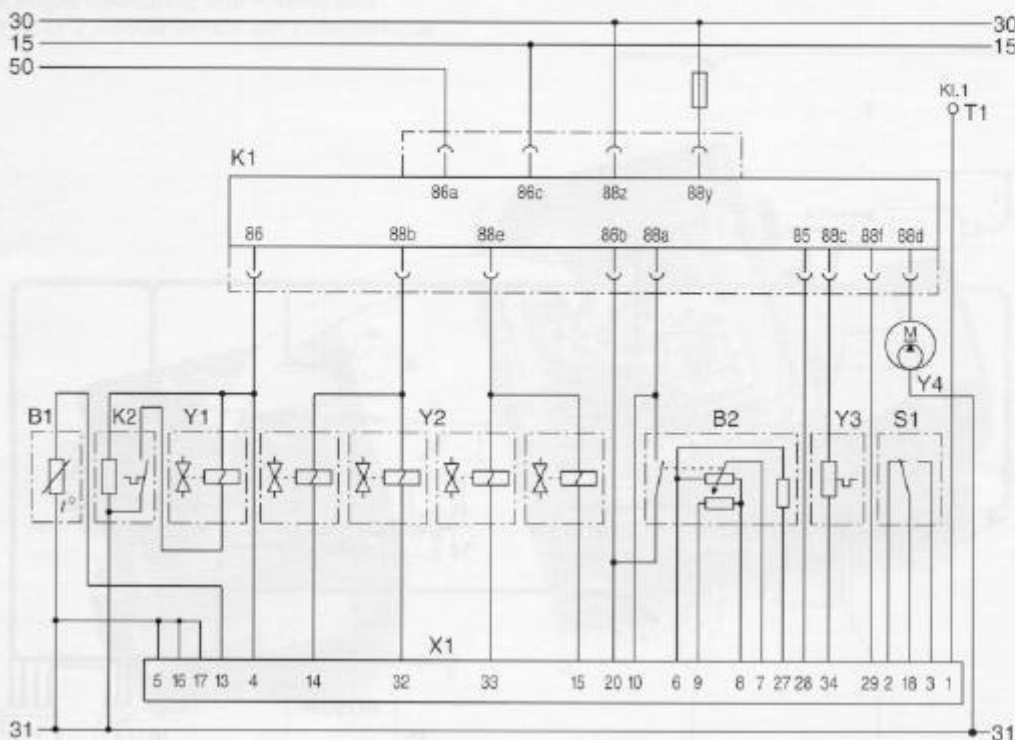
Terminal diagram

The example shown here is a typical terminal diagram for a vehicle with a 4-cylinder engine. Please note with the wiring harness that terminal 88z of the relay combination is connected directly and without a fuse to the positive pole (terminal post) of the battery in order to avoid trouble and voltage drops caused by contact resistances. Terminals 5, 16 and 17 of the control unit, as well as terminal 49 of the temperature sensor, must be connected with separate cables to a common ground point.

L-Jetronic

Fig. 30: Example of a connection diagram

L-Jetronic with closed-loop-controlled output stage. B1 Engine-temperature sensor, B2 Air-flow sensor, K1 Relay combination, K2 Thermo-time switch, S1 Throttle-valve switch, T1 Ignition coil, X1 ECU, Y1 Cold-start valve, Y2 Injection valve, Y3 Auxiliary-air device, Y4 Electric fuel pump.



L3-Jetronic

Specific systems for specific markets have in the meantime been developed on the basis of the L-Jetronic. These systems include the LE-Jetronic without lambda closed-loop control for Europe and the LU-Jetronic system with lambda closed-loop control for countries with strict exhaust gas emission legislation (e.g. the USA). The most recent stage of development is the L3-Jetronic which differs from its predecessors in respect of the following details:

- the control unit, which is suitable for installation in the engine compartment, is attached to the air-flow sensor and thus no longer requires space in the passenger compartment,
- the combined unit of control unit and air-flow sensor with internal connections simplifies the cable harness and reduces installation expense,
- the use of digital techniques permits new functions with improved adaptation

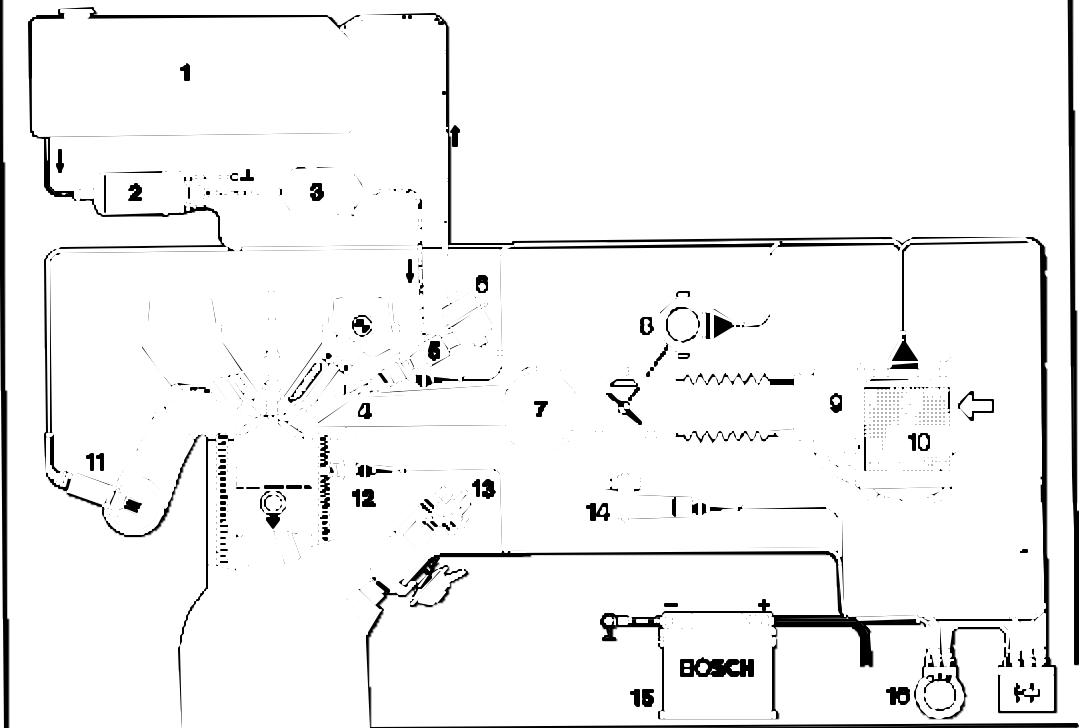
capabilities to be implemented as compared with the previous analog techniques used.

The L3-Jetronic system is available both with and without lambda closed-loop control. Both versions have what is called a "limp-home" function which enables the driver to drive the vehicle to the nearest workshop if the microcomputer fails. In addition the input signals are checked for plausibility, i.e. an implausible input signal (e.g. engine temperature lower than -40°C) is ignored and a default value stored in the control unit is used in its place.

Fuel supply

On this system, the fuel is supplied to the injection valves in the same way as on the L-Jetronic system via an electric fuel pump, fuel filter, fuel rail and pressure regulator.

Fig. 31: Schematic diagram of an L3-Jetronic system with lambda closed-loop control
1 Fuel tank, 2 Electric fuel pump, 3 Fuel filter, 4 Fuel-injection valve (injector), 5 Fuel rail, 6 Fuel-pressure regulator, 7 Intake manifold, 8 Throttle-valve switch, 9 Air-flow sensor, 10 ECU, 11 Lambda sensor, 12 Engine-temperature sensor, 13 Ignition distributor, 14 Auxiliary-air device, 15 Battery, 16 Ignition and starting switch.



Operating-data sensing system

The ignition system supplies the information on engine speed to the control unit. A temperature sensor in the coolant circuit measures the engine temperature and converts it to an electrical signal for the control unit. The throttle-valve switch signals the throttle-valve positions "idle" and "full load" to the control unit for controlling the engine in order to allow for the different optimization criteria in the various operating conditions. The control unit senses the fluctuations in the electrical vehicle supply and compensates for the resultant response delays of the fuel-injection valves by correcting the duration of injection.

sions of the potentiometer chamber in the air-flow sensor and of the control unit have been reduced to such an extent that the overall height of the entire unit does not exceed that of the previous air-flow sensor alone. Other features of the new air-flow sensor include the reduced weight due to the aluminum used in place of the zinc material for the housing, the extended measuring range and the improved damping behavior in the event of abrupt changes in the intake air quantity. Thus, the L3-Jetronic incorporates clear improvements both in respect of electronic components and in respect of mechanical components whilst requiring less space (Figs. 32 and 33).

Air-flow sensor

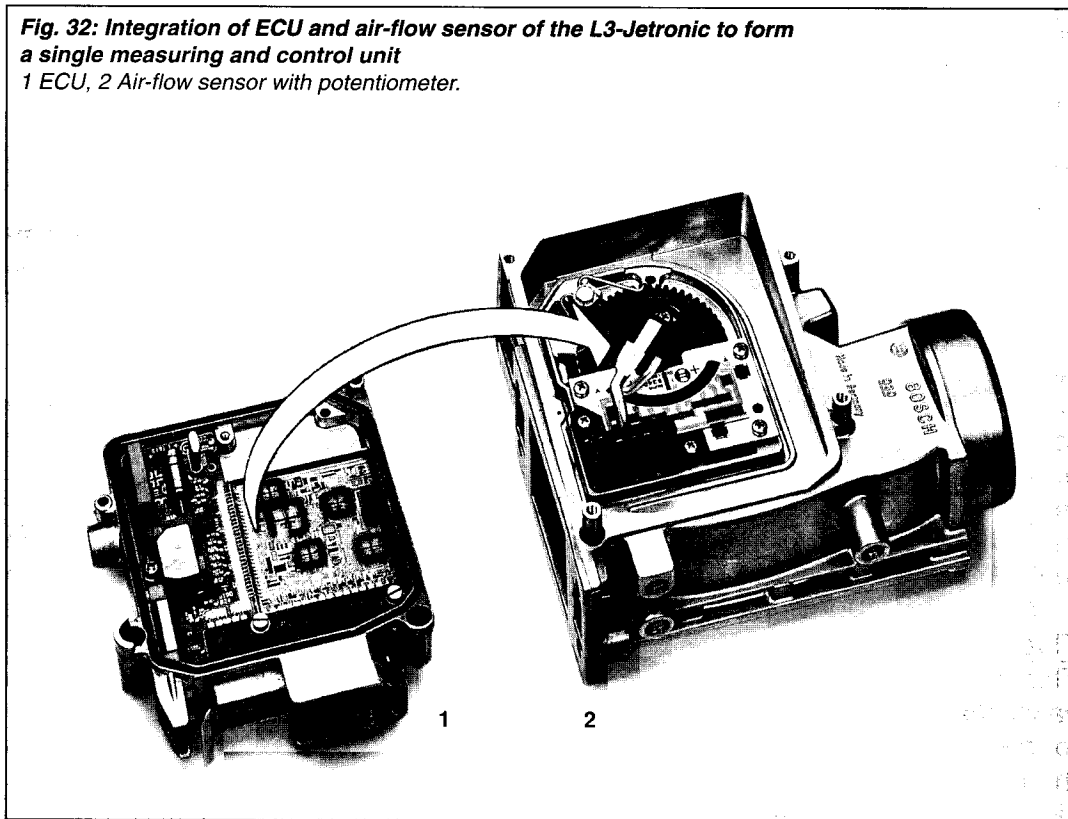
The air-flow sensor of the L3-Jetronic system measures the amount of air drawn in by the engine using the same measuring principle as the air-flow sensor of the conventional L-Jetronic system. Integrating the control unit with the air-flow sensor to form a single measuring and control unit requires a modified configuration however. The dimen-

Fuel metering

Fuel is injected onto the intake valves of the engine by means of solenoid-operated injection valves. One solenoid valve is assigned to each cylinder and is operated once per crankshaft revolution. In order to reduce the circuit complexity, all valves are connected electrically in parallel. The differential pressure between the fuel pressure and

Fig. 32: Integration of ECU and air-flow sensor of the L3-Jetronic to form a single measuring and control unit

1 ECU, 2 Air-flow sensor with potentiometer.



intake-manifold pressure is maintained, constant at 2.5 or 3 bar so that the quantity of fuel injected depends solely upon the opening time of the injection valves. For this purpose, the control unit supplies control pulses, the duration of which depends upon the inducted air quantity, the engine speed and other actuating variables which are detected by sensors and processed in the control unit.

Electronic control unit (ECU)

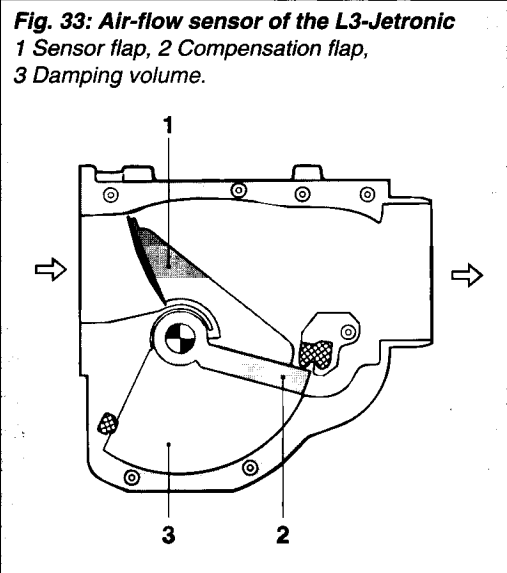
By contrast with the L-Jetronic system, the digital control unit of this system adapts the air-fuel ratio by means of a load/engine-speed map. On the basis of the input signals from the sensors, the control unit computes the injection duration as a measure of the amount of fuel to be injected. The microcomputer system of the control unit permits the required functions to be influenced. The control unit for attachment to the air-flow sensor must be very compact and must have very few plug connections in addition to being resistant to heat, vibration and moisture. These conditions are met by the use of a special-purpose hybrid circuit and a small PC board in the control unit. In addition to accommodating the microcomputer, the hybrid circuit also accommodates 5 other integrated circuits, 88 film resistors and 23 capacitors. The connections from the ICs to the thick-film board comprise thin gold wires which are a mere 33 thousandths of a millimeter in thickness.

Adaptation to operating conditions

During certain operating conditions (cold start, warm-up, acceleration, idle and full load), the fuel requirement differs greatly from the normal value so that it is necessary to intervene in mixture formation.

Throttle-valve switch

This switch is operated by the throttle-valve shaft and has a switching contact for each of the two end positions of the throttle valve. When the throttle valve is closed (idle) or fully open (full load), the



switch issues a switching signal to the control unit.

Auxiliary-air device

A plate which is moved by a bimetallic spring or expansion element supplies extra air to the engine during the warm-up phase. This results in the higher idle speed which is required during the warm-up phase for smooth running of the engine.

A closed-loop idle-speed control system, in the form of a separate system, can be used instead of the auxiliary-air device to control the idle speed.

Engine-temperature sensor

The engine-temperature sensor, a temperature-dependent resistor, controls warm-up enrichment. The overrun fuel cutoff function, and the speed limiting function at maximum permissible engine speed, permit fuel economy and a reduction in pollutant emission.

Lambda closed-loop control

In the control unit, the signal from the lambda sensor is compared with an ideal value (setpoint), thus controlling a two-position controller. Dependent upon the result of the comparison, either an excessively lean air-fuel mixture is enriched or an excessively rich mixture is leaned. Fuel metering is influenced via the opening time of the injection valves.

LH-Jetronic

The LH-Jetronic is closely related to the L-Jetronic. The difference lies in the hot-wire air-mass meter which measures the air mass inducted by the engine. The result of measurement is thus independent of the air density which is itself dependent upon temperature and pressure.

Fuel supply

The fuel is supplied to the injection valves through the same components as with the L-Jetronic.

Operating-data sensing system

The information on engine speed is supplied to the control unit by the ignition system. A temperature sensor in the coolant circuit measures the engine temperature and converts it to an electronic signal for the control unit. The throttle-valve switch signals the throttle-valve positions "idle" and "full load" to the control unit for engine control in

order to allow for the different optimization criteria in the various operating conditions. The control unit detects the fluctuations in the vehicle electrical supply and compensates for the resultant response delays of the injection valves by correcting the duration of injection.

Air-mass meters

The hot-wire and hot-film air-mass meters are "thermal" load sensors. They are installed between the air filter and the throttle valve and register the air-mass flow [kg/h] drawn in by the engine. Both sensors operate according to the same principle.

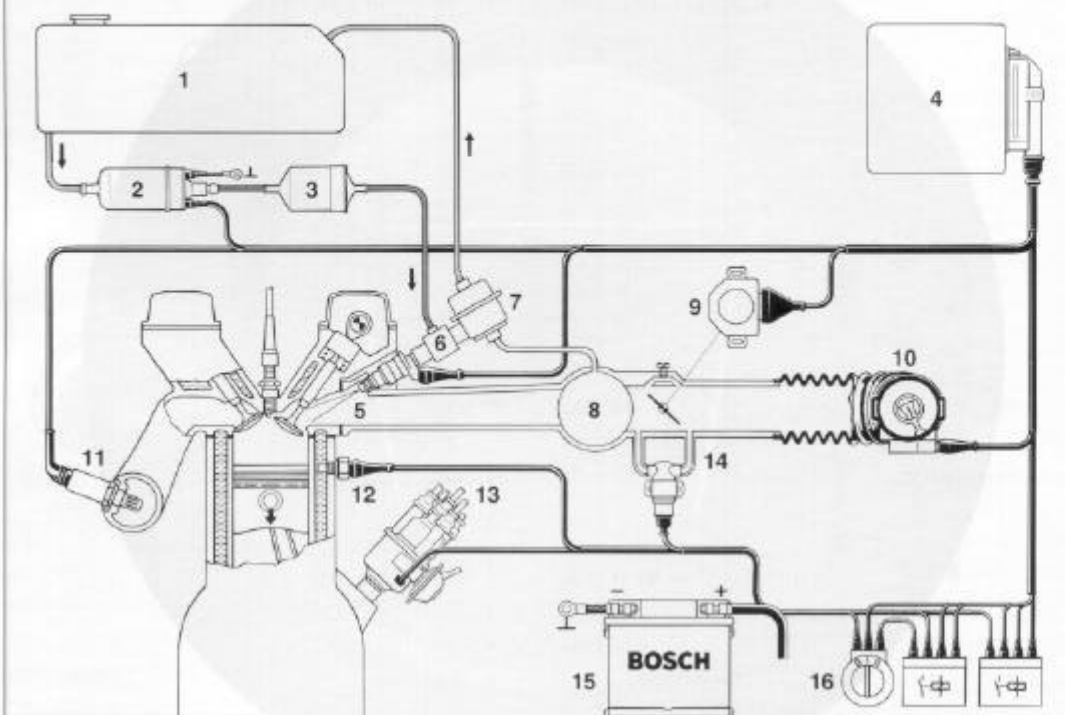
Hot-wire air-mass meter

With the hot-wire air-mass meter, the electrically heated element is in the form of a 70 μm thick platinum wire. The intake-air temperature is registered by a temperature sensor. The hot wire and the intake-air temperature sensor are part of a bridge circuit in which they function as

L-Jetronic

Fig. 34: Schematic diagram of an LH-Jetronic system

1 Fuel tank, 2 Electric fuel pump, 3 Fuel filter, 4 ECU, 5 Fuel-injection valve (injector), 6 Fuel rail, 7 Fuel-pressure regulator, 8 Intake manifold, 9 Throttle-valve switch, 10 Hot-wire air-mass meter, 11 Lambda sensor, 12 Engine-temperature sensor, 13 Ignition distributor, 14 Rotary idle actuator, 15 Battery, 16 Ignition and starting switch.



temperature-dependent resistances. A voltage signal which is proportional to the air-mass flow is transmitted to the ECU (Figs. 35 and 36).

Hot-film air-mass meter

With the hot-film air-mass meter, the electrically heated element is in the form of a platinum film resistance (heater). The heater's temperature is registered by a temperature-dependent resistor (throughflow sensor). The voltage across the heater is a measure for the air-mass flow. It is converted by the hot-film air-mass meter's electronic circuitry into a voltage which is suitable for the ECU (Fig. 37).

Fuel metering

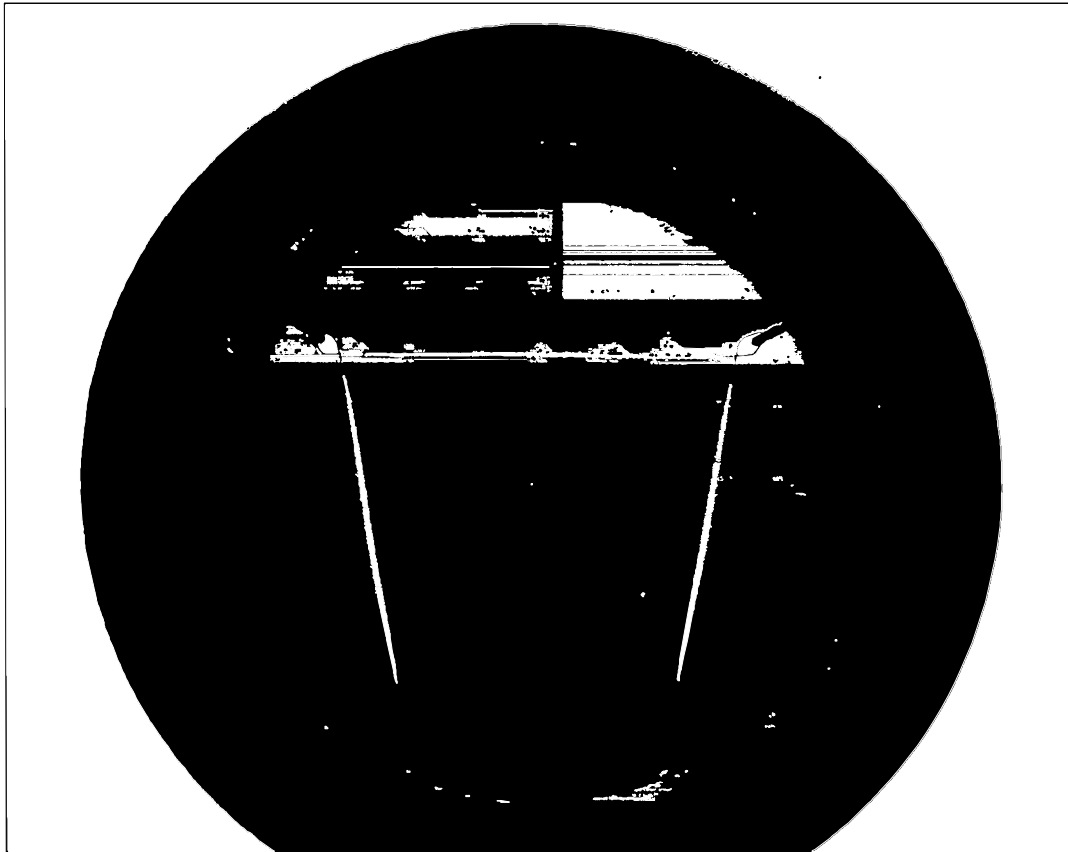
Fuel is injected by means of solenoid-operated injection valves onto the intake valves of the engine. A solenoid valve is assigned to each cylinder and is operated once per crankshaft revolution. In order to reduce the circuit complexity, all valves are connected electri-

cally in parallel. The differential pressure between the fuel pressure and intake-manifold pressure is maintained constant at 2.5 or 3 bar so that the quantity of fuel injected depends solely upon the opening time of the injection valves. For this purpose, the control unit supplies control pulses, the duration of which are dependent upon the inducted air quantity, the engine speed and other actuating variables which are detected by sensors and processed in the control unit.

Electronic control unit (ECU)

By comparison with the L-Jetronic system, the digital control unit of this system adapts the air-fuel ratio by means of a load/engine-speed map. On the basis of the input signals from the sensors, the control unit computes the injection duration as a measure of the quantity of fuel to be injected. The microcomputer system of the control unit permits the required functions to be influenced.

Fig. 35: Hot-wire air-mass meter. The 70 μm thin platinum wire is suspended inside the measuring venturi.



Adaptation to operating conditions

During certain operating conditions (cold start, warm-up, acceleration, idle and full load), the fuel requirement differs greatly from the normal value, thus necessitating an intervention in mixture formation.

Throttle-valve switch

This switch has a switching contact for each of the two end positions of the throttle valve. It issues a switching signal to the control unit when the throttle valve is closed (idle) or fully open (full load).

Rotary idle actuator

The idle speed can be reduced and stabilized with the idle-speed control function. For this purpose, the rotary idle actuator opens a bypass line to the throttle valve and supplies the engine with more or less air. Since the hot-wire air-mass meter senses the extra air, the injected fuel quantity also changes as required.

Engine-temperature sensor

The engine-temperature sensor, a temperature-dependent resistor, controls warm-up enrichment.

Supplementary functions

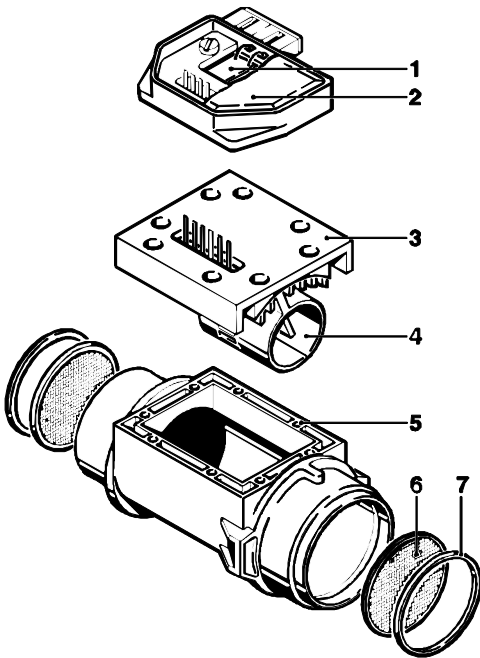
The overrun fuel cutoff function, and the speed limiting function at maximum permissible engine speed, permit fuel economy and a reduction in pollutant emission.

Lambda closed-loop control

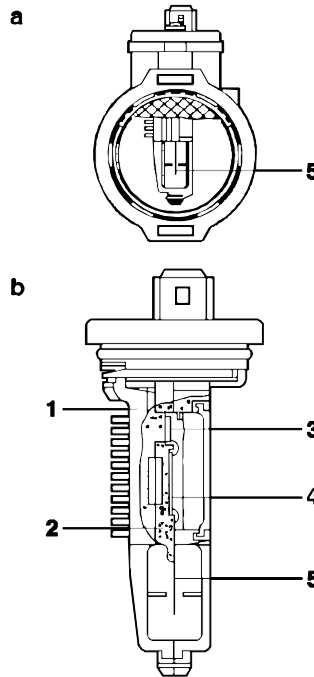
The lambda sensor supplies a signal which represents the instantaneous mixture composition. In the control unit, the signal of the lambda sensor is compared with an ideal value (setpoint), thus controlling a two-position controller. Dependent upon the result of comparison, either an excessively lean air-fuel mixture is enriched or an excessively rich mixture is leaned. Fuel metering is influenced via the opening time of the injection valves.

Fig. 36: Hot-wire air-mass meter

1 Hybrid circuit, 2 Cover, 3 Metal insert, 4 Venturi with hot wire, 5 Housing, 6 Screen, 7 Retaining ring.

**Fig. 37: Hot-film air-mass meter**

a) Housing, b) Hot-film sensor (fitted in the middle of the housing).
1 Heat sink, 2 Intermediate module, 3 Power module, 4 Hybrid circuit, 5 Sensor element.



Emissions-control technology

Exhaust-gas constituents

It is not possible to obtain complete combustion from the cylinders in the engine, not even by supplying an excess of oxygen. The less thorough the combustion process, the greater the proportion of pollutants in the engine's exhaust gases. It is thus necessary to improve the spark-ignition engine's exhaust pattern (for instance, with the aid of a catalytic converter) in order to reduce the load on the environment (Figures 1 and 2).

The objective of all concepts aimed at achieving reductions in the concentrations of the pollutant emissions limited

by various regulations is the same: to maintain low fuel consumption, high performance and good drivability while holding the emissions of harmful substances to a minimum.

In addition to a high proportion of harmless components, exhaust gases also include secondary constituents which – at least in high concentrations – can cause damage to the environment. These pollutants represent approximately one percent of the total exhaust gas, and consist of carbon monoxide (CO), nitrous oxides (NO_x) and hydrocarbons (HC). The effects of air-fuel mixture on the concentrations of these substances is of particular interest: The response pattern for NO_x is inverted relative to that for CO and HC.

Fig. 1: Pollution sources in Germany (since 3 October, 1990)

The figures do not include emissions from natural sources or CO₂ emissions.

Data source: 5th Federal Government Report on Emissions, 15 December 1992.

Figures in parentheses: West/East Germany as percent of total.

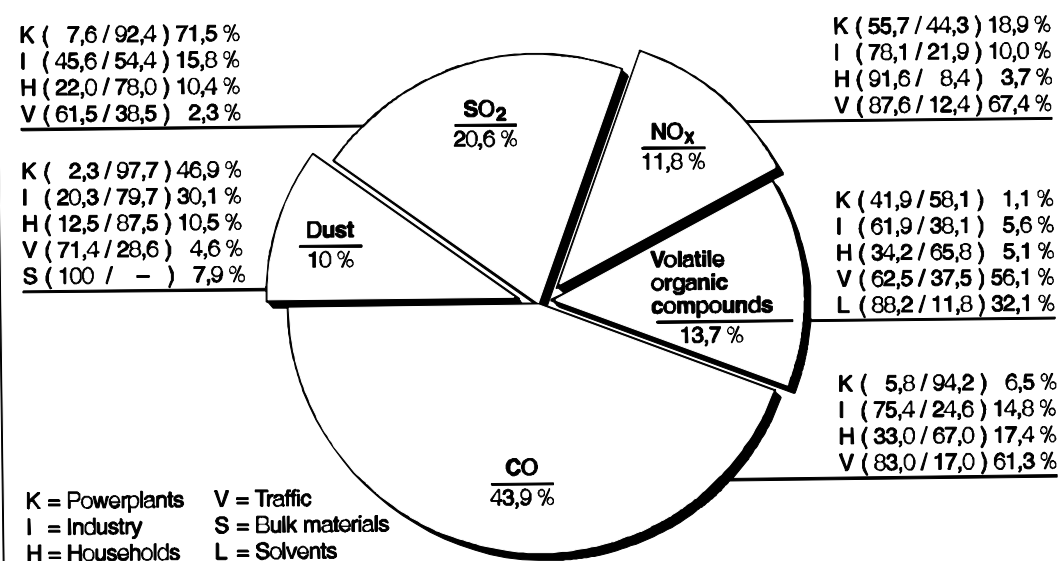
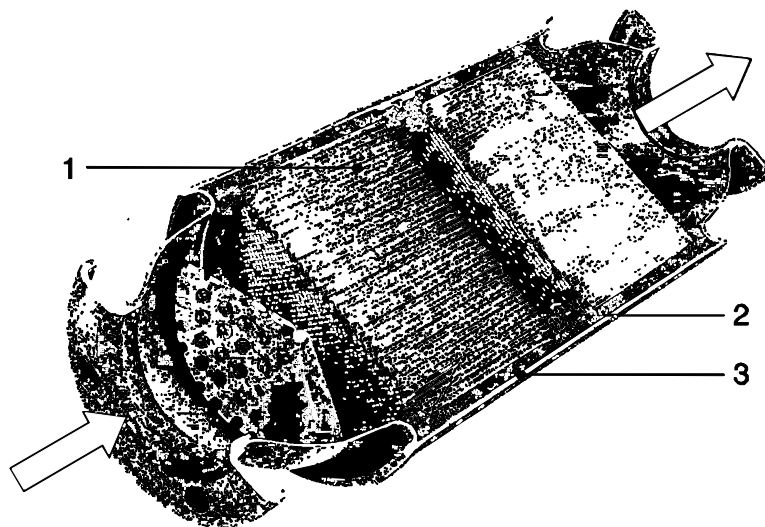


Fig. 2: Catalytic converter for reducing harmful emissions of CO, HC and NO_x
1 Ceramic material coated with catalytically active substances, 2 Steel-wool retainer, 3 Housing.



Main components

The main exhaust-gas components are nitrogen, carbon dioxide and water vapor. These substances are non-toxic. Nitrogen (N₂) is the element most abundant in the atmosphere. Although it is not directly involved in the combustion process, at approx. 71% it represents the major exhaust-gas component. Small amounts of nitrogen react with oxygen to form nitrous oxides.

Complete combustion converts the hydrocarbons contained in the fuel's chemical bonds into carbon dioxide (CO₂) which makes up about 14% of the exhaust gas. The hydrogen contained in the fuel's chemical structure combusts to form water vapor (H₂O), most of which condenses as it cools (producing the vapor cloud which can be seen emerging from the exhaust on cold days).

Secondary components

The secondary components carbon monoxide, hydrocarbons and incompletely-oxidized hydrocarbons are the result of incomplete combustion, while nitrous oxides form in response to secondary reactions that accompany all air combustion processes. Carbon monoxide (CO) is a colorless, odorless gas. It acts as a toxic

substance by inhibiting the blood's ability to absorb oxygen. For this reason an engine should never be run in an enclosed space unless an exhaust-gas extraction system has been connected and switched on.

The hydrocarbons assume the form of unburned fuel components as well as new hydrocarbons formed during combustion. Aliphatic hydrocarbons are odorless and have a low boiling point. The closed-chain aromatic hydrocarbons (benzol, toluol, polycyclic hydrocarbons) emit a distinct odor, and are considered carcinogenic with continuous exposure. Partially-oxidated hydrocarbons (aldehydes, cetones, etc.) emit a disagreeable odor. When exposed to sunlight they decay to form substances that are considered to act as carcinogens in people continually exposed to high concentrations. The term NO_x is employed to identify the various oxides of nitrogen (mostly NO and NO₂) that result as oxygen combines with atmospheric nitrogen during high-temperature combustion.

NO is colorless and odorless and is gradually converted to NO₂ in the atmosphere. Pure NO₂ is a toxic reddish-brown gas with a pungent odor. At the levels found in air with high pollutant concentrations, NO₂ can irritate the mucous membranes in the respiratory system.

