Gasoline injection systems over the years

The primary purpose of the fuel-injection system is to provide the engine with an air/fuel mixture which is best suited to the prevailing operating state. Over the years, these systems have been continually improved, a significant feature of this improvement being the constant increase in the amount of electronic components used.

While the development objective in the 1970s lay primarily in increasing power and comfort, the emphasis switched from the 1980s onwards to reducing emissions. A further requirement, which began to be taken increasingly seriously, was the reduction of fuel consumption and with it also the reduction of CO_2 emissions.

Overview

Development of gasoline injection systems

An important milestone in the development history of control systems for gasoline engines was the introduction of electronically controlled fuel-injection systems. Where previously mechanically controlled fuel-injection systems had been used, Bosch with D-Jetronic introduced in 1967 for the first time an electronic system in which fuel was injected via electromagnetically actuated fuel injectors intermittently onto the intake valve of each cylinder (multi-point injection).

However, wide-range use of fuel-injection systems was only possible with lower-cost designs. Mechanical K-Jetronic and Mono-Jetronic with only one single, centrally situated electromagnetic fuel injector (single-point injection) enabled fuel-injection technology to stretch also to mid-size and small cars.

The carburetor was rendered completely obsolete on account of the advantages of gasoline injection with regard to fuel consumption, power output, engine performance and emission behavior. In particular, the reduction of pollutant emissions could only be achieved thanks to the advances made in fuel-injection technology in conjunction with exhaust-gas treatment (three-way catalytic converter). The emission limits laid down by legislators for hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxide (NO_X) called for fuel-injection systems which were able to adjust the mixture composition within very narrow limits.

Table 1 shows the development of Bosch fuel-injection systems. Today, only the Motronic engine-management system with multi-point injection is still used. Only with this type of fuel injection in conjunction with complex engine management is it possible to comply with today's stringent emission limits.

1 Development of fuel-injection systems

Year	System	Features
1967	D-Jetronic	– Analog-technology multi-point injection system – Intermittent fuel injection – Intake-manifold-controlled
1973	K-Jetronic	– Mechanical-hydraulic multi-point injection system – Continuous fuel injection
1973	L-Jetronic	– Electronic multi-point injection system (initially analog, later digital technology) – Intermittent fuel injection – Air-flow sensing
1981	LH-Jetronic	– Electronic multi-point injection system – Intermittent fuel injection – Air-mass sensing
1982	KE-Jetronic	– K-Jetronic with electronically controlled additional functions
1987	Mono-Jetronic	– Single-point injection system – Intermittent fuel injection – Air-flow calculation via throttle-valve angle and engine speed

Table 1

K. Reif (Ed.), *Gasoline Engine Management,* Bosch Professional Automotive Information,
DOI 10.1007/978-3-658-03964-6_5, © Springer Fachmedien Wiesbaden 2015

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 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.

1952 saw a Bosch direct-injection unit being featured as standard equipment on a small car for the first time. A unit was then 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.

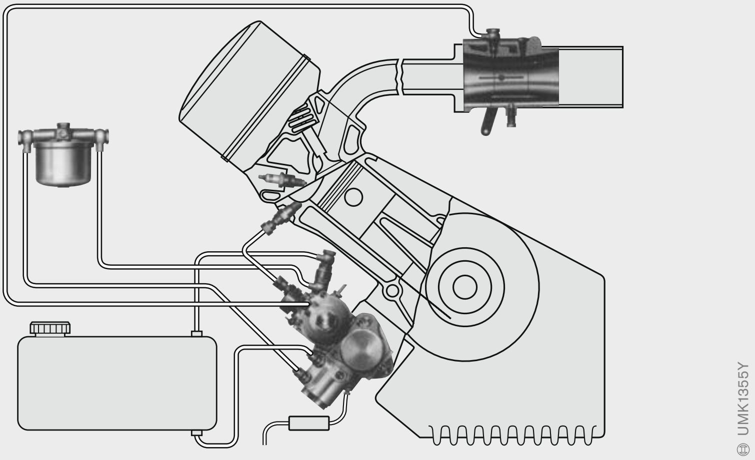
In 1976, the K-Jetronic was the first automotive system to incorporate a Lambda closed-loop control.

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.

Bosch gasoline fuel injection from the year 1954



Beginnings of mixture formation

At a time when the first atmospheric engines were being designed by various inventors, a common problem was forming an ignitable mixture. The question of whether or not such an internal-combustion engine would be able to function at all. The solution was very much dependent on the ignition mechanism.

The basics of the carburetor were developed as early as the 18th Century. Inventors' efforts at the time were directed at vaporizing liquid fuels in such a way that they could be used to operate a lighting or heating device.

1 Principle of a wick carburetor

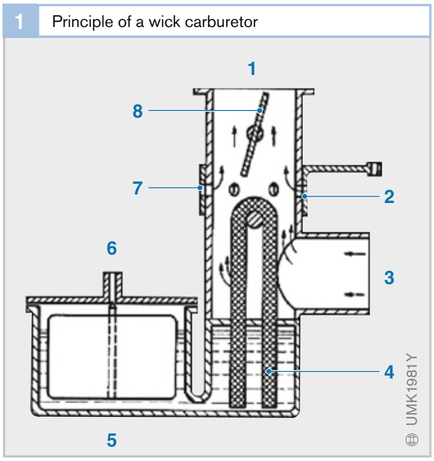


Fig. 1
1 Air/fuel mixture to engine
2 Annular slide valve
3 Air inlet
4 Wick
5 Float chamber with float
6 Fuel inlet
7 Auxiliary air
8 Throttle valve

2 Principle of a surface carburetor

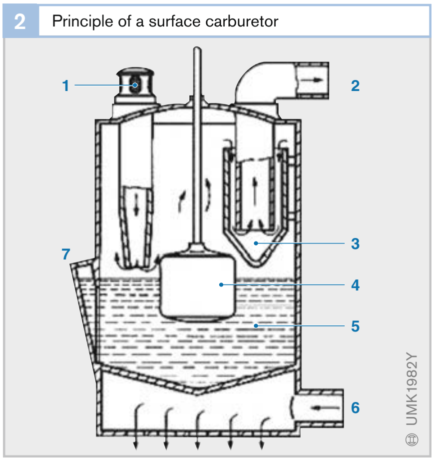


Fig. 2
1 Air inlet
2 Air/fuel mixture to engine
3 Fuel separator
4 Float
5 Fuel
6 Engine exhaust gases
7 Fuel filler neck

In 1795 Robert Street was the first to suggest to vaporize turpentine or creosote in an atmospheric engine. Around 1825 Samuel Morey and Eskine Hazard developed a two-cylinder engine for which they also designed the first carburetor. It was granted British patent no. 5402. Up to that time, mixture-formation systems were essentially fueled with turpentine or kerosene.

However, this situation changed in 1833, when Eilhardt Mitscherlich, professor of chemistry at the University of Berlin, managed to split benzoic acid by thermal cracking. The result was the so-called "Faraday's olefiant gas", which he called "benzene", the precursor of today's gasoline.

William Barnett designed the first carburetor for gasoline. He was awarded patent no. 7615 in 1838.

During this time, these designs were either wick carburetors (Fig. 1) or surface carburetors (Fig. 2). The first carburetor to be used in a vehicle was a wick carburetor. The wick drew up the fuel, similar to the oil-lamp principle. The wick was then exposed to an air stream in the engine, causing air and fuel to blend. By contrast, in the surface carburetor, in which the fuel was heated by the engine's exhaust gases, the result was a layer of vapor just above the fuel surface. This was then blended to form the required air-fuel mixture by introducing an air stream.

In Berlin in 1882 Siegfried Marcus applied for a patent for the brush carburetor (Fig. 3) that he had invented. This mixture generator used the interaction of a rapidly rotating cylindrical brush (3) driven by a drive pulley (1) and a fuel stripper (2) to form a mist of atomized fuel in the brush chamber (4). The fuel mist was then drawn into the engine via the inlet (5). The brush carburetor maintained its dominance for about 11 years.

3 Brush carburetor by Siegfried Marcus

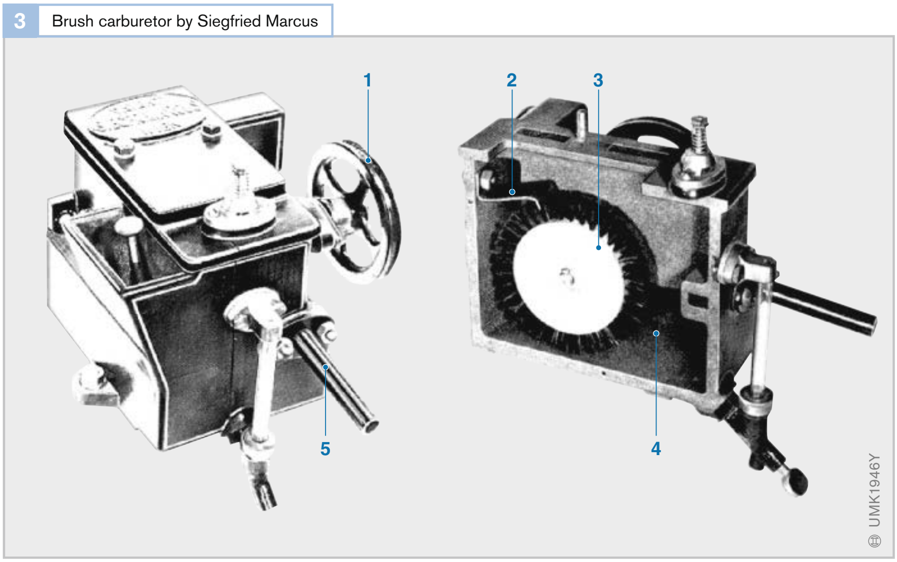


Fig. 3

1	Drive pulley
2	Fuel stripper
3	Rotating brush
4	Brush chamber
5	Intake fitting

In 1885 Nikolaus August Otto succeeded in his struggle to master the engine powered by hydrocarbon fuels (alcohol/gasoline); he had been working toward this goal since 1860. The first gasoline-engine, working on the four-stroke principle and equipped with a surface carburetor and an electrical ignition device of Otto's own construction, garnered the highest praise and profound recognition at the World Fair at Antwerp. This design was later built and sold in great numbers by the firm of Otto & Langen in Deutz over many years (Fig. 4).

4 Spark ignition engine by Nikolaus August Otto

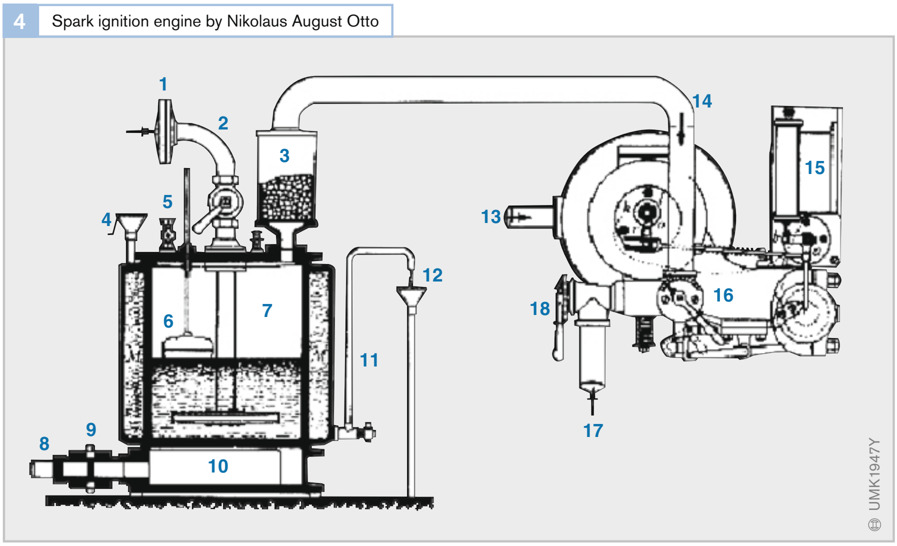
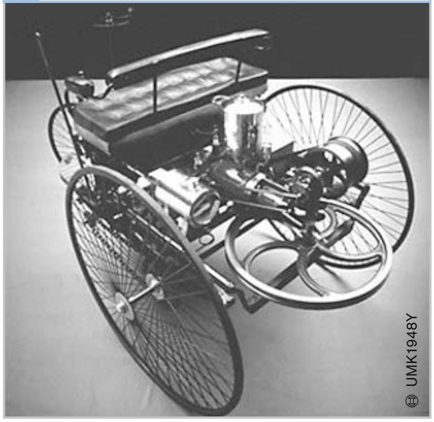


Fig. 4

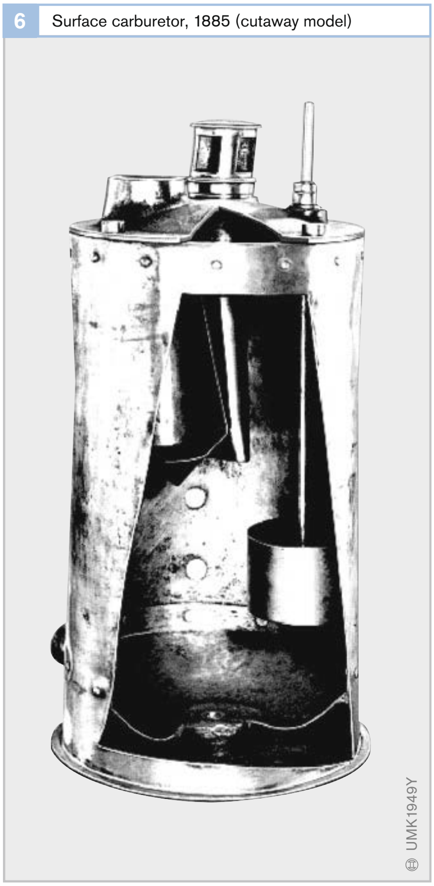
A	Carburetor
B	Engine with ignition system
1	Air inlet
2	Air tube
3	Gravel canister (flame shield)
4	Water funnel
5	Fuel filler neck
6	Float
7	Fuel reservoir
8	Exhaust-gas inlet
9	Shutoff valve
10	Heating pad
11	Cooling-water jacket
12	Water tubing
13	Coolant inlet
14	Gas inlet
15	Ignition device
16	Gas shutoff valve
17	Air inlet
18	Air shutoff valve

In the same year Carl Benz installed a surface carburetor of his own design in his first “Patent Motor Carriage” (Fig. 5). A short while later, he improved the original design of his carburetor by adding a valve float, as he put it, “to always maintain the fuel level automatically at the same height”.

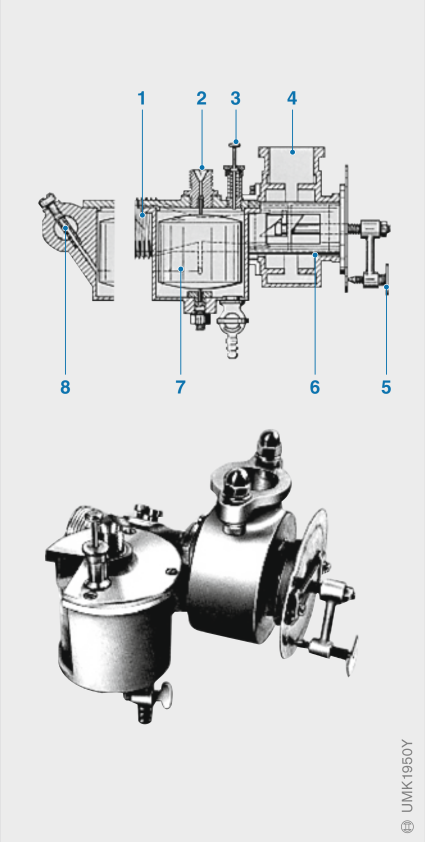
In 1893 Wilhelm Maybach introduced his jet-nozzle carburetor (Fig. 7). In this device, the fuel was sprayed from a fuel nozzle onto a baffle surface, which caused the fuel to distribute in a cone-shaped pattern (Fig. 8).



5 Benz Motor Carriage with surface carburetor (vertically positioned)



6 Surface carburetor, 1885 (cutaway model)



7 Jet-nozzle carburetor by Wilhelm Maybach

Fig. 7

1 Air inlet
2 Fuel inlet
3 Spring-loaded swab
4 Air/fuel mixture outlet
5 Rotating-slide stop
6 Rotating-slide for mixture control
7 Float
8 Jet nozzle

1906/07 saw the introduction of the Claudel carburetor and the carburetor designs of François Bavery, both of which brought further advancement to carburetor design. In these carburetors, which were to become famous under the ZENITH brand name, the lean-fuel auxiliary or compensation jet delivers a virtually unchanged air/fuel mixture despite increasing air velocity (Fig. 9).

The same period also saw applications for the carburetor patents of Mennesson and Goudard. Their designs became world-famous under the SOLEX brand (Fig. 10).

The years that followed produced a proliferation of carburetor designs. In this context, some of their names, e.g. SUM, CUDELL, FAVORIT, ESCOMA, and GRAETZIN, deserve special mention. After the Haak carburetor was patented in 1906 and manufactured by the firm of PALLAS, Scüttler and Deutrich developed the PALLAS carburetor in 1912. It had a ring float and combination jet (Fig. 11).

In 1914 the Royal Prussian War Ministry sponsored a competition for benzol (benzene) carburetors. Even at that time the test specifications included the condition that the exhaust gases should be as clean as possible. Of the competing products bearing 14 different brand names, it was a ZENITH carburetor that won 1st prize. All the carburetors were examined at the test facility of the Technical University at Charlottenburg, and subjected to a demanding 800-km winter trial by the German army administration in automobiles of identical horsepower.

8 Principle of jet-nozzle carburetor

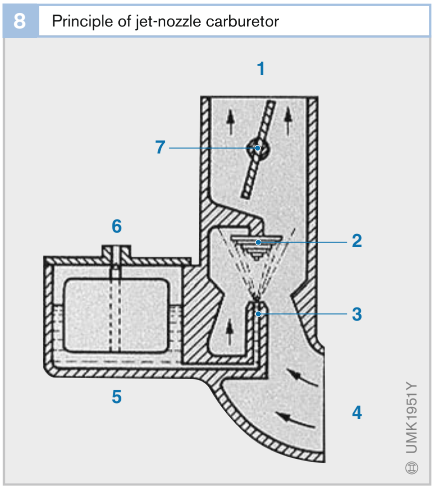
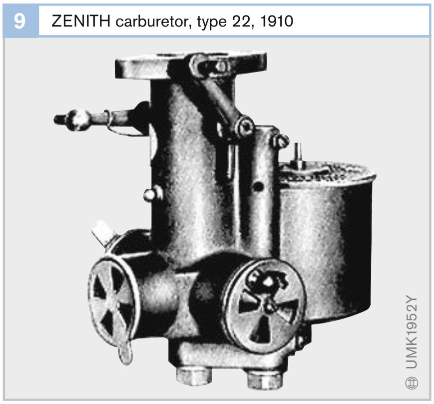
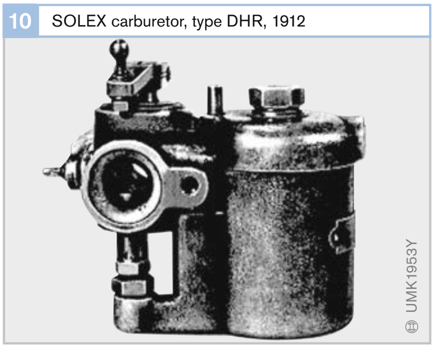


Fig. 8
1 Air/fuel mixture to engine
2 Baffle surface
3 Fuel jet (jet nozzle)
4 Air inlet
5 Float chamber with float
6 Fuel inlet
7 Throttle valve

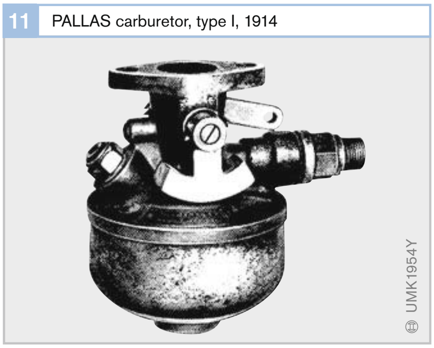
9 ZENITH carburetor, type 22, 1910



10 SOLEX carburetor, type DHR, 1912



11 PALLAS carburetor, type I, 1914



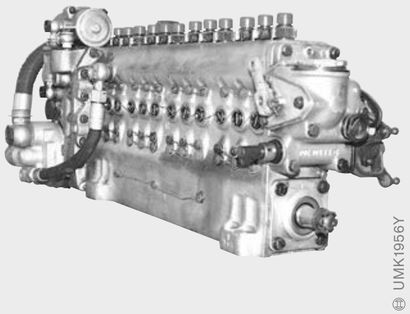
The period that followed marked the beginning of various attempts at detail work and specialization. A variety of model configurations and auxiliary devices was developed, e.g. rotating slides and preliminary throttles serving as start-assist measures, diaphragm systems replacing the float in aircraft carburetors, and pump systems providing acceleration aids. The diversity of these modifications was so extensive that any descriptive attempt would exceed the scope of this chapter.

In the 1920s, to obtain greater engine power, single and twin carburetors (carburetors featuring two throttle valves) were installed in the form of multiple carburetor systems (several single or twin carburetors with synchonized controls). In the decades that followed, the great variety of carburetor variants made by various manufacturers increased even further.

In parallel with the ongoing carburetor development for aircraft engines, the 1930s saw the development of the first gasoline-injection systems with direct injection (example in Fig. 12). This engine required two 12-cylinder in-line fuel-injection pumps, each of which was mounted on the crankcase between the cylinder banks (not visible in Fig. 12). A pump of this type is shown in Fig. 13. It has a total length of about 70 cm (27.5 in.).

In the late 1930s direct-injection systems were used in conjunction with the 9-cylinder radial BMW engines (Fig. 14) in the legendary three-engine Junkers Ju 52 aircraft. Especially noteworthy is the “boxer” (reciprocal) configuration of the

13 12-cylinder in-line fuel-injection pump (length approx. 70 cm)



12 Aircraft engine by Daimler-Benz, with 24 cylinders in in-line-X configuration, type DB 604

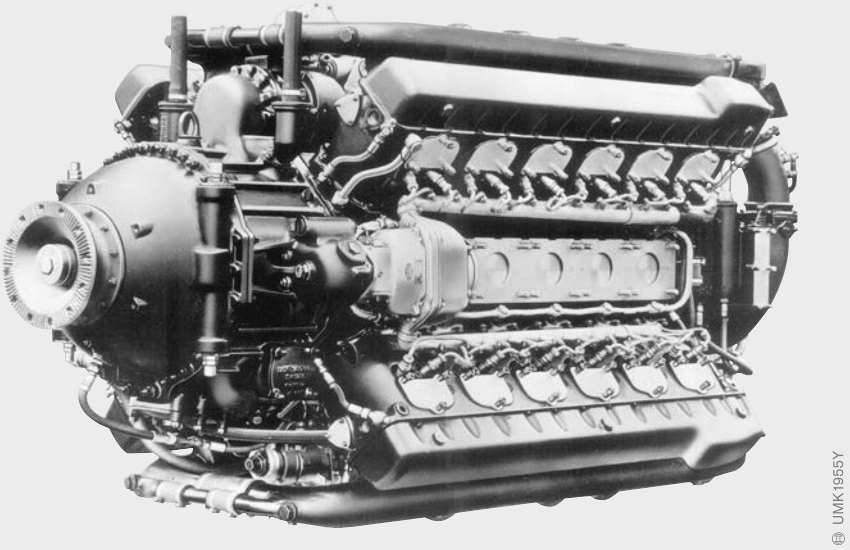
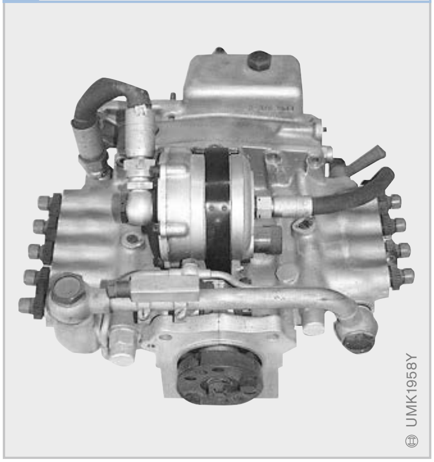


Fig. 12
This aircraft engine was produced by the Daimler-Benz AG between 1939 and 1942.
There were models ranging from 48.5-liter displacement and 2350 HP (1741 kW) to 50.0-liter displacement and 3500 HP (2593 kW), all featuring gasoline direct injection by Bosch.
The engine had a total length of 2.15 m.
(Photo: DaimlerChrysler Classic, Corporate Archives)

14 BMW radial engine with 9 cylinders

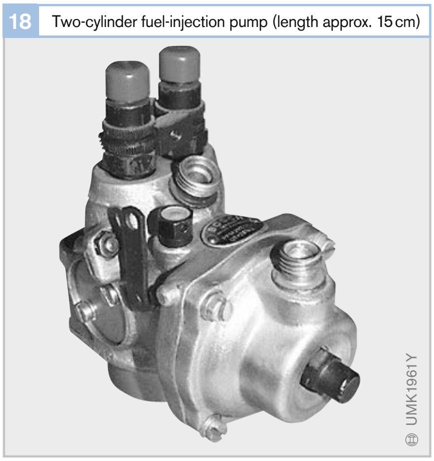
15 Bosch fuel-injection pump in "boxer" (reciprocal) variant (length approx. 35 cm)



16 Gutbrod Superior 600 convertible (1950–1954; 1952 and later with direct injection)

17 Goliath GP700E (1951–1957; after 1954 with direct injection)

18 Two-cylinder fuel-injection pump (length approx. 15 cm)



mechanical fuel-injection pump (Fig. 15) by Bosch.

In the 1950s this type of fuel-injection system working with direct fuel injection also made its debut in passenger cars. One example was the "Gutbrod Superior" of 1952 (Fig. 16), and the Goliath GP700E introduced in 1954 (Fig. 17). These two vehicles were compact cars powered by two-cylinder, two-stroke engines with a displacement of less than 1000 cc. Their fuel-injection pumps were also compact in size (Fig. 18).

A component diagram of this two-cylinder fuel-injection system, which entered the annals of automotive history as the first gasoline direct-injection system in passenger cars, appears in Figure 19 (next page).

19 Components of Bosch gasoline direct injection for the two-cycle engines in Gutbrod and Goliath cars

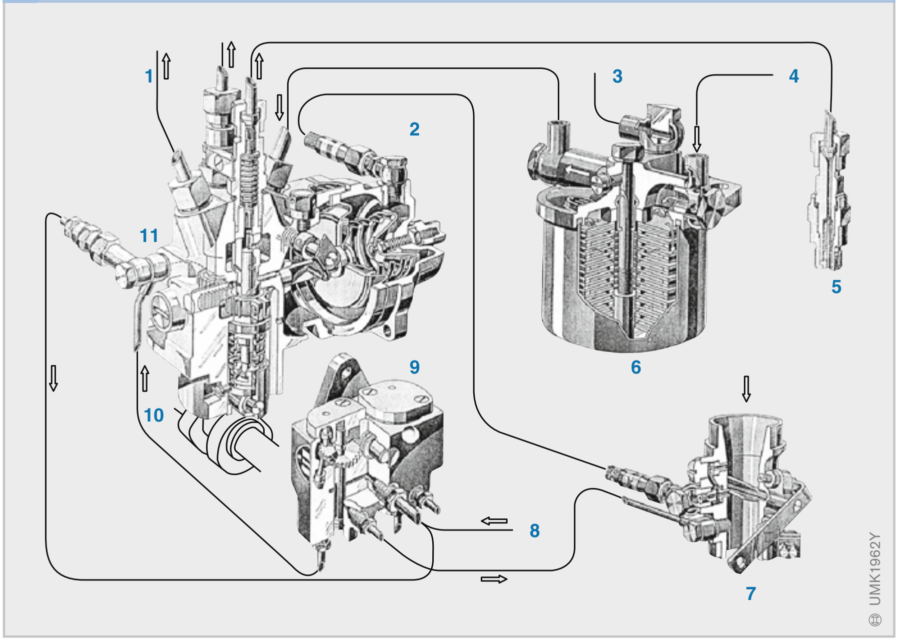


Fig. 19

1 Venting tube
2 Mixture-control-unit diaphragm block
3 Venting tube
4 From fuel tank
5 Fuel injector
6 Fuel filter
7 Mixture-control-unit flap supports
8 From oil reservoir
9 Lubricating-oil pump
10 Fuel-injection pump
11 Overflow valve

However, the Mercedes-Benz 300 SL sports car (Fig. 20) featured a Bosch-built gasoline direct-injection system. It was presented to the public on February 6, 1954 at the International Motor Sports Show in New York. Installed at a 50-degree slant, the car's 6-cylinder in-line engine (M198/11) had a displacement of 2996 cc, and delivered 215 HP (159 kW).

A fundamentally different facet of air/fuel mixture formation for gasoline engines appeared during the latter part of WWII and for a while thereafter: the wood-gas generator.

The wood gas emitted by the glowing charcoal was used to form an ignitable air/fuel mixture (Fig. 21). However, it was hard to overlook the physical size of these wood gasifier systems (Fig. 22).

20 Mercedes-Benz 300 SL (1954)

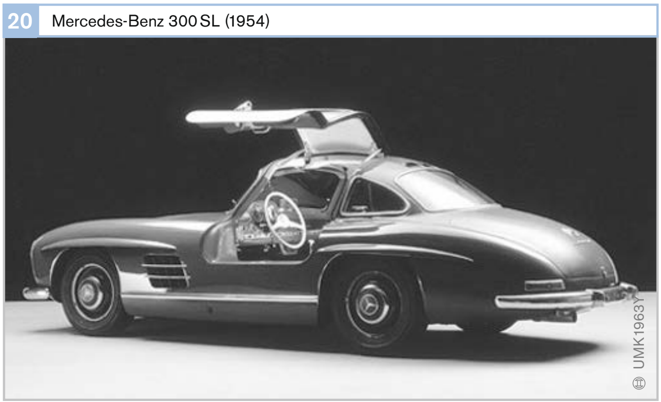


Fig. 20
Photo:
DaimlerChrysler Classic,
Corporate Archives

21 Schematic of a wood-gas generator system

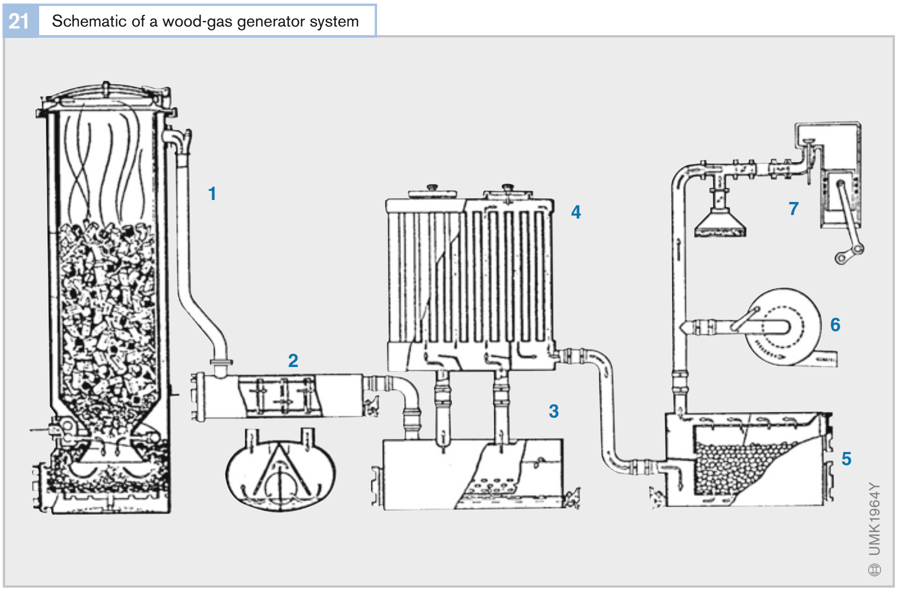
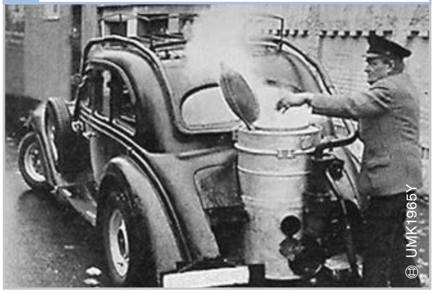


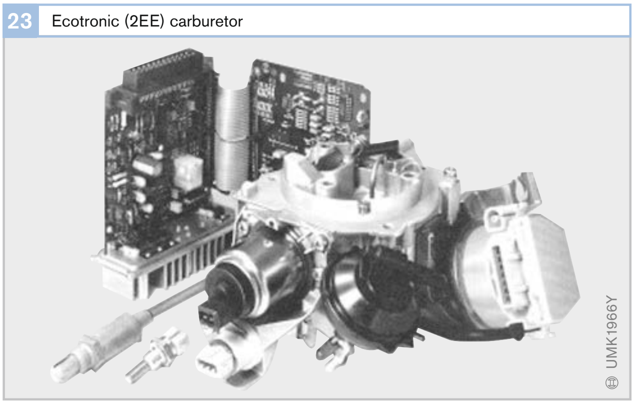
Fig. 21
1 Gas generator
2 Baffle plate cleaner
3 Settling tank
4 Gas cooler
5 Secondary cleaner
6 Bellows blower
7 Regulator group

Due to the gradual tightening-up of emission standards, the automotive industry has increasingly shunned the carburetor. In the early 1990s, however, there was a successful design by Bosch and Pierburg that equipped a modified conventional carburetor with modern-day actuators: the Ecotronic carburetor (Fig. 23). This carburetor made it possible to comply with the prevailing emission standards at the time, while at the same time ensuring economical fuel consumption.

22 Wood-gas generator system on a 1936 Adler Diplomat



23 Ecotronic (2EE) carburetor



At the conclusion of this brief review of the history of air/fuel mixture formation, it should be stated that the various carburetor types continued to be used well into the 1990s as standard equipment in passenger cars. In compact cars in particular, the carburetor enjoyed sustained popularity due to its lower cost.

Evolution of gasoline injection systems

Since 1885, when the first manifold-injection system was used on a fixed industrial engine, many changes have occurred in the field of gasoline-injection systems. Later attempts included a floatless carburetor with attached fuel-injection device installed in aircraft engines in 1925, and an electrically triggered fuel-injection device in a racing motorcycle in 1930. That was before Bosch finally developed a mechanically driven gasoline-injection pump for the Gutbrod Superior 600 and Goliath GP 700 vehicles in 1951. These were the first passenger cars with gasoline injection. The system was designed as a direct-injection system. Even the legendary Mercedes 300 SL was equipped with gasoline direct injection featuring a mechanical inline pump.

After passing though several development stages of manifold-injection systems (described below), the current trend is again headed for direct-injection systems.

D-Jetronic

System overview

The Bosch-engineered D-Jetronic comprises a gasoline-injection system that is essentially controlled by intake-manifold pressure and engine speed. Hence the designation D-Jetronic (D stands for “drucksensorgesteuert” – German for pressure-sensor-controlled).

The electronic control unit (Fig. 1, Pos. 1) receives signals for intake-manifold pressure, intake-air temperature, cooling-water (coolant) and/or cylinder-head temperature, throttle-valve position and movement, and starting, engine speed, and start of injection. The ECU processes these data, and sends electrical pulses to the fuel injectors (2). The ECU is interconnected with the electrical components via a multiple connector and wiring harness.

The fuel injectors spray the fuel into the intake manifolds of the cylinders. The pressure sensor (3) sends engine-load data to the ECU. The temperature sensors communicate the temperatures of air (13) and coolant (4) to the ECU. The thermo-time switch (5)

1 D-Jetronic system schematic

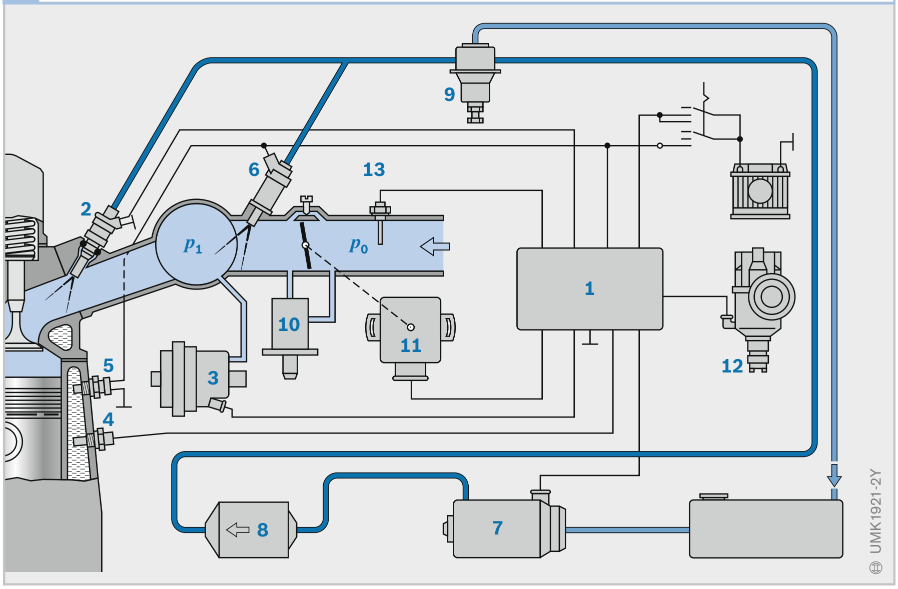


Fig. 1
1 ECU
2 Fuel injector
3 Pressure sensor
4 Coolant-temperature sensor
5 Thermo-time switch
6 Electric start valve
7 Electric fuel pump
8 Fuel filter
9 Fuel-pressure regulator
10 Auxiliary-air device
11 Throttle-valve switch
12 Injection trigger
13 Air-temperature sensor

p_0 Atmospheric pressure
p_1 Pressure in the intake manifold

switches the electric start valve (6), which injects additional fuel into the intake manifold during low-temperature starts. The electric fuel pump (7) continuously delivers fuel to the fuel injectors. The fuel filter (8) is integrated in the fuel line to remove contaminants. The fuel-pressure regulator (9) maintains a constant fuel pressure in the fuel lines. The temperature-dependent function of the auxiliary-air device (10) provides additional air during engine warm-up. The throttle-valve switch (11) sends engine idle and full-load states to the ECU.

Method of operation

Pressure measurement

Upstream of the throttle valve inside the intake manifold, the pressure is equal to the ambient atmospheric pressure. The pressure downstream of the throttle valve is lower, and changes with the throttle-valve position. This reduced intake-manifold pressure serves as the measured quantity for engine load, which is the most important information. Engine load is derived from the measure of the volume of air drawn into the engine. The information pertaining to the pressure in the intake manifold is determined by the pressure sensor.

The pressure sensor (Fig. 2) contains two aneroid capsules which shift the armature of a coil. The measuring system is pneumatically connected via a line to the intake manifold. As the load increases, i.e., as pressure in the intake manifold increases, the aneroid capsules are compressed and the armature is drawn deeper into the coil. This changes its inductance. The device is therefore a measuring transducer that converts a pneumatic pulse into an electrical signal. The induction-type pulse generator in the pressure sensor is connected to an electronic timer in the ECU. It determines the duration of the electrical pulses required to trigger the fuel injectors. In this way, the intake-manifold pressure is directly converted to an injection duration.

Fuel injection

Specific contacts in the ignition distributor (injection trigger, Fig. 1, Pos. 12) determine – in accordance with camshaft adjustment – the beginning of the pulse for opening the fuel injectors. Injection duration is mainly dependent on engine load and engine speed. Pressure sensor and injection trigger supply the required signals to the ECU. This enables the fuel injectors to inject fuel in metered quantities by means of electrical pulses.

Adaptation to operating conditions

Adaptations under different operating conditions are required to ensure good engine performance:

- Full load: The fuel quantity is determined for maximum power
- Acceleration enrichment: Additional injection pulses are applied during acceleration
- Altitude compensation: It is possible by taking into account the pressure differential between intake manifold and free atmosphere to obtain good adaptation of fuel injection to different altitudes
- Intake-air temperature: The temperature-dependent density differences of the air can be taken into account by recording the outside temperature

2 Pressure sensor at idle $p_1 \leftarrow p_0$

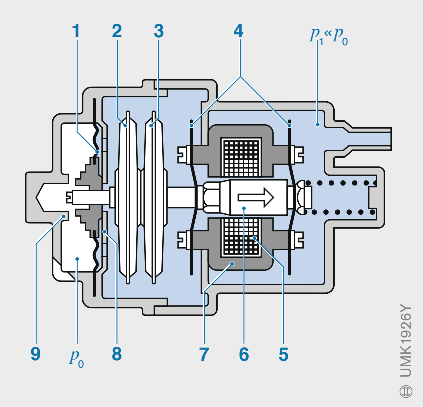


Fig. 2
Basic function:
Aneroid capsules 2 and 3 expanded

1	Diaphragm
2	Aneroid capsule
3	Aneroid capsule
4	Leaf spring
5	Coil
6	Armature
7	Core
8	Part-load stop
9	Full-load stop
p_0	Atmospheric pressure
p_1	Pressure in the intake manifold

K-Jetronic

System overview

K-Jetronic is a mechanically-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. Hence the system designation K-Jetronic (Kontinuierlich = German for continuous).

Specific operating conditions of the engine require corrective intervention in mixture formation and this is carried out by K-Jetronic in order to optimize starting and driving performance, power output and exhaust-gas composition.

The K-Jetronic fuel-injection system covers the following functional areas:

- Fuel supply
- Air-flow measurement and
- Fuel metering

Mode of operation

An electrically driven roller-cell pump (Fig. 3, Pos. 2) pumps the fuel from the fuel tank (1) at a pressure of over 5 bar to a fuel accumulator (3) and through a filter (4) to the fuel distributor (9). The pressure regulator integrated in the fuel distributor holds the delivery pressure in the fuel system (system pressure) at about 5 bar.

From the fuel distributor, the fuel flows to the fuel injectors (6). The fuel injectors inject the fuel continuously into the engine's intake ports engine. 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.

The amount of air, corresponding to the position of the throttle valve (16), 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 (10), which, in turn, controls the fuel distributor.

Injection occurs continuously, i.e., without regard to the position of the intake valve. When the intake valve is closed, the mixture is stored.

3 K-Jetronic system schematic

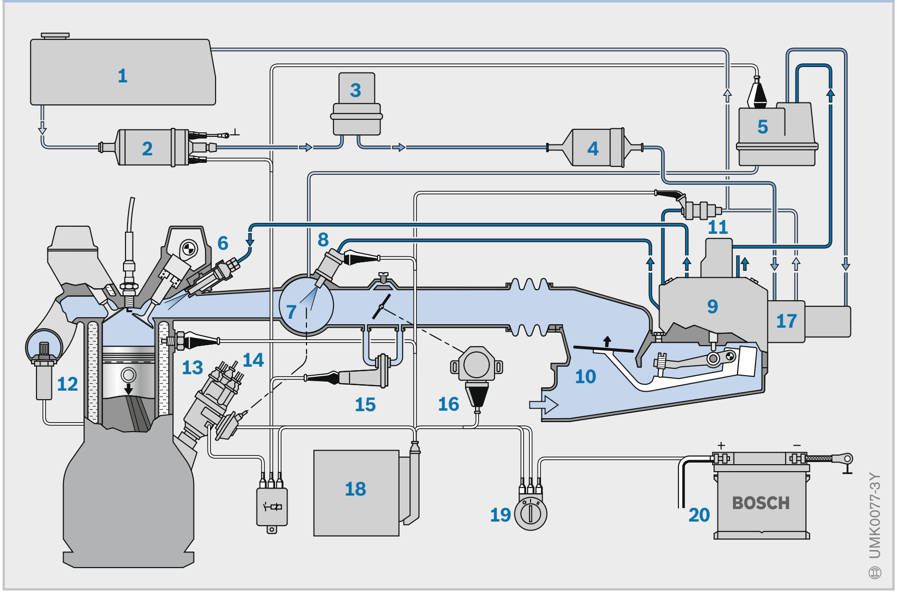


Fig. 3
1 Fuel tank
2 Electric fuel pump
3 Fuel accumulator
4 Fuel filter
5 Warm-up regulator
6 Fuel injector
7 Intake manifold
8 Cold-start valve
9 Fuel distributor
10 Air-flow sensor
11 Timing valve
12 Lambda sensor
13 Thermo-time switch
14 Ignition distributor
15 Auxiliary-air device
16 Throttle-valve switch
17 Primary-pressure regulator
18 ECU (for version with lambda closed-loop control)
19 Ignition/starting switch
20 Battery

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 limitation and lambda closed-loop control are possible.

Mixture-control unit

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.

Air-flow sensor

The quantity of air drawn in by the engine is a precise measure of its power. The air-flow sensor (Fig. 4) installed ahead of the throttle valve operates according to the suspended-solid-particle principle and measures the quantity of air drawn in by the engine. The intake air quantity serves as the main control variable for determining the basic injection quantity.

The air-flow sensor consists of an air funnel (1), in which a moving sensor plate (2) is located. The air flowing through the air funnel deflects the sensor plate by a specific distance from its rest position. A lever system (12) transmits the movements of the sensor plate to a control plunger (8), which determines the basic injection quantity required for basic functions. 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 (13) ensures the correct zero position in the switched-off phase.

4 Updraft air-flow sensor

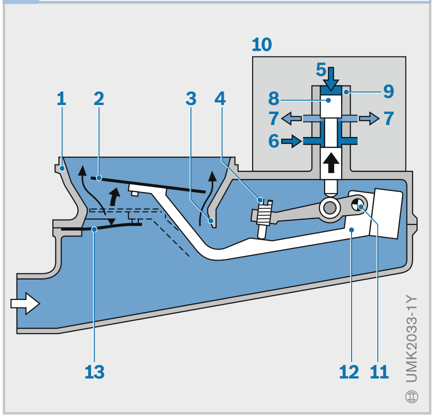


Fig. 4
1 Air funnel
2 Sensor plate
3 Relief cross-section
4 Mixture adjusting screw
5 Control pressure
6 Fuel inlet
7 Metered quantity of fuel
8 Control plunger
9 Barrel with metering slits
10 Fuel distributor
11 Pivot
12 Lever
13 Leaf spring

Fuel distributor

Depending upon the position of the plate in the air-flow sensor, the fuel distributor (10) meters the basic injection quantity to the individual engine cylinders.

Depending upon its position in the barrel with metering slits (9), 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 injectors.

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. In the event of larger sensor-plate travel, the control 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.

Differential-pressure valves

Differential-pressure valves (Fig. 5, next page) in the fuel distributor result in a specific pressure drop at the metering slits. If the sensor-plate travel is to result in a change of basic injection quantity in the same proportion, then a constant drop in pressure must be guaranteed at the metering slits, regardless of the amount of fuel flowing through them. The differential-pressure valves maintain the differential pressure between the upper chamber (5) and the lower chamber (8) at a constant level, regardless of fuel throughflow.

Flat-seat valves are used as differential-pressure valves. They are fitted in the fuel distributor and one such valve is allocated to each metering slit. A diaphragm separates the upper and lower chambers of the valve.

The control pressure is tapped from the primary system pressure through a throttle bore. This throttle bore serves to isolate 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 the cold engine is started, the control pressure is about 0.5 bar. As the engine warms up, the warm-up regulator increases the control pressure to about 3.7 bar. The control pressure acts through a damping orifice 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 orifice dampens a possible oscillation of the sensor plate which could result due to pulsating air-intake flow.

5 Differential-pressure valve with system and control pressures

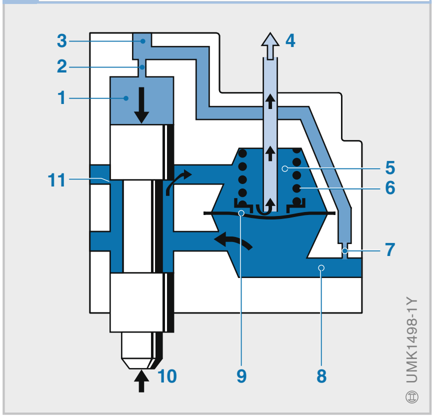


Fig. 5
1 Control-pressure effect (hydraulic force)
2 Damping orifice
3 Line to warm-up regulator
4 To intake valve
5 Pressure in upper chamber of differential-pressure valve (0.1 bar < primary pressure)
6 Control spring
7 Isolating throttle bore
8 Pressure in lower chamber = primary pressure (delivery pressure)
9 Diaphragm
10 Effect of air pressure via sensor-plate lever
11 Metering slits

6 Fuel injector

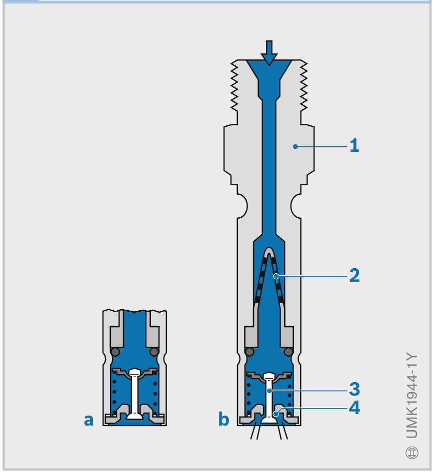


Fig. 6
a In rest position
b In actuated position

1 Valve housing
2 Filter
3 Valve needle
4 Valve seat

The level of the control pressure influences 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 (11) 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.

Fuel injectors

The fuel injectors (Fig. 6) open at a given pressure and inject the fuel metered to them into the intake manifolds and onto the cylinder intake valves. They open automatically as soon as the opening pressure exceeds, for example, 3.5 bar. The valve needle (3) vibrates at high frequency (chatter) as the fuel is injected. When the engine is switched off, the injectors 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 manifolds once the engine has stopped.

Adaptation to operating states

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

- Basic mixture adaptation: Basic adaptation of the air/fuel mixture to the idle, part-load and full-load operating conditions is effected by shaping the air funnel appropriately in the air-flow sensor. This adaptation is achieved by designing the air funnel so that it becomes wider in stages.

- Cold-start enrichment: As a function of engine temperature, the cold-start valve injects an additional quantity of fuel for a limited period during starting in order to compensate for the fuel lost through condensation from the inducted mixture. The injection period of the cold-start valve is limited by a thermo-time switch depending on the engine temperature. This consists of an electrically heated bimetal strip which, depending on its temperature, opens or closes a contact.
- Warm-up enrichment: Mixture control for warm-up operation is effected via the control pressure by the warm-up regulator (control-pressure regulator). When the engine is cold, the warm-up regulator reduces the control pressure to a degree dependent on engine temperature and thus causes the metering slits to open further.
- Idle stabilization: As it warms up, the engine receives more air via the auxiliary-air device. 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.
- Full-load enrichment: Engines operated in the part-load range with a very lean mixture require enrichment during full-load operation in addition to mixture correction resulting from the shape of the air funnel. This extra enrichment is performed by a specially designed warm-up regulator, which regulates the control pressure as a function of the intake-manifold pressure.
- Transition response during acceleration: If, at constant engine speed, the throttle valve is quickly opened, the amount of air which enters the combustion chambers plus the amount of air which is needed to bring the manifold pressure up to the new level flows through the air-flow sensor. This causes the sensor plate to briefly “overswing” past the fully opened throttle point. This “overswing” results in more fuel being metered to the engine (acceleration enrichment) and ensures good transition response.
- Overrun fuel cutoff: A solenoid valve actuated by a speed relay opens the air bypass to the sensor plate in overrun mode at a specific engine speed. The sensor plate then reverts to the zero position and interrupts fuel metering.

Lambda closed-loop control

The lambda closed-loop control system (Fig. 7) required for operation of a three-way catalytic converter necessitates the use of an electronic control unit (2). The important input variable for this ECU is the signal supplied by the lambda oxygen sensor (1).

In order to adapt the injected fuel quantity to the required air-fuel ratio at $\lambda = 1$, the pressure in the lower chambers (5) of the fuel distributor (4) is varied. If, for instance, the pressure in the lower chambers is reduced, the differential pressure at the metering slits (6) increases, whereby the injected fuel quantity is increased. In order to permit the pressure in the lower chambers to be varied, these chambers, by comparison

7 K-Jetronic system with lambda closed-loop control

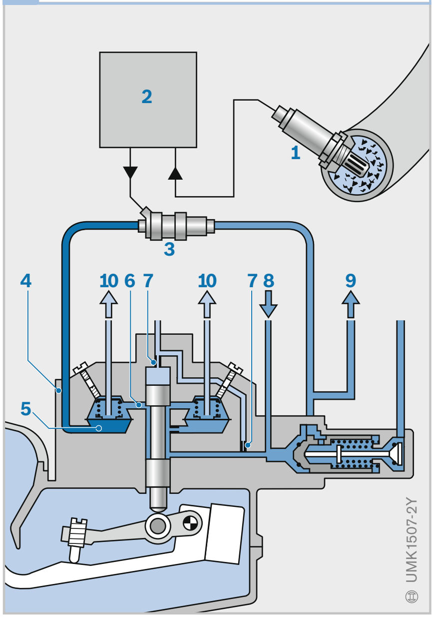


Fig. 7
1 Lambda sensor
2 ECU
3 Timing valve (variable restrictor)
4 Fuel distributor
5 Lower chambers of differential-pressure valves
6 Metering slits
7 Isolating throttle bore (fixed restrictor)
8 Fuel inlet
9 Fuel return
10 To fuel injector

with the standard K-Jetronic fuel distributor, are isolated from the primary pressure via a fixed restrictor (7).

A further restrictor (3) connects the lower chambers and the fuel return. 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 on the ratio of closing time to opening time. An electromagnetic valve, the timing valve, is used as the variable restrictor. It is controlled by electrical pulses from the lambda controller.

KE-Jetronic

The system design of KE-Jetronic is essentially identical to that of K-Jetronic. The distinguishing difference is the electronic mixture control, which in this system is performed by means of an electrohydraulic pressure actuator (Fig. 8). This pressure actuator is mounted on the fuel distributor. The actuator is a differential-pressure controller which functions according to the nozzle/baffle-plate principle, and its pressure drop is controlled by the current input from the ECU.

8 Electrohydraulic pressure actuator

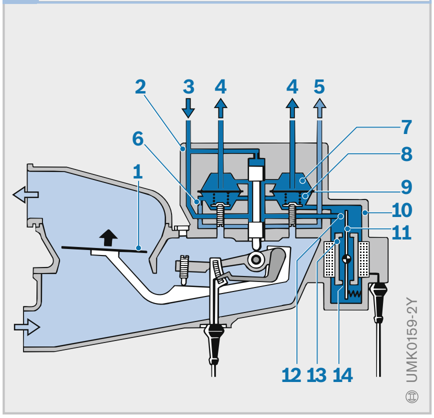


Fig. 8
1 Sensor plate
2 Fuel distributor
3 Fuel inlet (primary pressure)
4 Fuel to fuel injectors
5 Fuel-return line to pressure regulator
6 Fixed restrictor
7 Upper chamber
8 Lower chamber
9 Diaphragm
10 Pressure actuator
11 Baffle plate
12 Nozzle
13 Magnetic pole
14 Air gap

L-Jetronic

System overview

L-Jetronic (Fig. 9) is an electronically controlled fuel-injection system which injects fuel intermittently into the intake manifolds. It does not require any form of drive.

The electric fuel pump (2) supplies the fuel to the engine and generates the pressure necessary for injection. Fuel injectors (5) inject the fuel into the individual intake manifolds. An electronic control unit (4) controls the fuel injectors. The ECU evaluates the signals delivered by the sensors and generates the appropriate control pulses for the fuel injectors. The amount of fuel to be injected is defined by the opening time of the fuel injectors.

Acquisition of operating data

Sensors detect the operating mode of the engine and communicate this in the form of electrical signals to the ECU. The main measured variables are the engine speed and the amount of air drawn in by the engine. These variables determine the basic injection period. The engine speed is either detected by the breaker point in the ignition distributor (in breaker-triggered ignition systems) or communicated by terminal 1 of the ignition coil to the ECU (in breakerless ignition systems).

The sensor plate in the air-flow sensor measures the total amount of air inducted by the engine. The measurement allows for all changes which may take place in the engine during the service life of the vehicle, e.g.

- Wear
- Deposits in the combustion chamber, and
- Changes in valve adjustment

Fuel metering

As the central unit of the system, the ECU evaluates the data delivered by the sensors pertaining to the engine operating state. The ECU uses these data to generate control pulses for fuel metering by the fuel injectors, whereby the quantity to be injected is determined by the length of time the injection valves are opened (intermittent injection).

The air/fuel ratio can be maintained at $\lambda = 1$ by means of lambda closed-loop control. The ECU compares the lambda-sensor signal with an ideal value (setpoint) and thereby activates a two-state controller.

The L-Jetronic output stage activates three or four fuel injectors in parallel. ECUs for six- and eight-cylinder engines have two output stages for three or four injectors each. Both output stages operate in unison. The injection cycle is selected so that for each revolution of the camshaft half the amount of fuel required by each working cylinder is injected twice.

Adaptation to operating states

In addition to the basic functions, the mixture has to be adapted during particular operating states. These adaptations (corrections) are necessary in order to improve the power delivered by the engine, the exhaust-gas composition, starting behavior, and performance. 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.

The following adaptations are possible with L-Jetronic:

- Cold-start enrichment: As a function of engine temperature, an additional quantity of fuel is injected for a limited period during starting. Enrichment is achieved by extending the injection period or by injecting an additional quantity of fuel via the cold-start valve. The injection period of the cold-start valve is limited by a thermo-time switch depending on the engine temperature.
- Post-start and warm-up enrichment: Engine cold starting is followed by its warming-up phase. During this phase, the engine needs warm-up enrichment 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

9 Schematic diagram of an L-Jetronic system with lambda closed-loop control

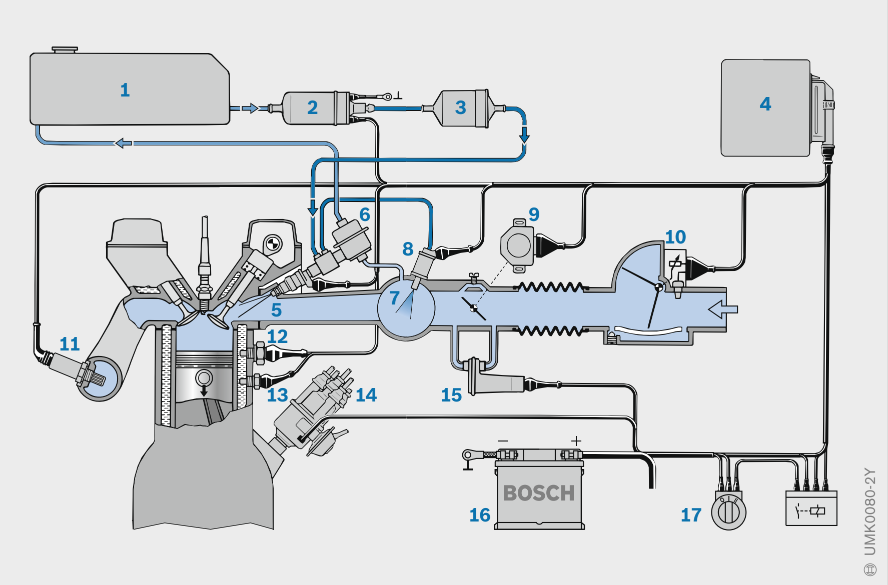


Fig. 9
1 Fuel tank
2 Electric fuel pump
3 Fuel filter
4 ECU
5 Fuel injector
6 Fuel rail and pressure regulator
7 Intake manifold
8 Cold-start valve
9 Throttle-valve switch
10 Air-flow sensor
11 Lambda sensor
12 Thermo-time switch
13 Engine-temperature sensor
14 Ignition distributor
15 Auxiliary-air device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

engine speed would be noticed after the additional fuel from the cold-start valve has been cut off. When post-start enrichment has finished, the engine needs only a slight mixture enrichment, this being controlled by the engine temperature.

- Acceleration enrichment: If the throttle valve is quickly opened (acceleration), the amount of air which enters the combustion chambers plus the amount of air which is needed to bring the manifold pressure up to the new level flows 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 and ensures good transition response. Since this acceleration enrichment is not sufficient during the warming-up phase, the ECU also evaluates an electrical signal representing the speed at which the sensor plate is deflected in this operating state.
- Idle-speed control: The air-flow sensor contains an adjustable bypass via which a small quantity of air can bypass the sensor plate. The idle-mixture-adjusting screw permits a basic setting of the air/fuel ratio by varying the bypass cross-section. An auxiliary-air device, which is connected as a bypass to the throttle valve, directs auxiliary air to the engine, depending on the engine temperature, in order to achieve smooth idling when the engine is cold.
- Air-temperature adaptation: The air mass crucial to combustion is dependent on the temperature of the inducted air. The intake port of the air-flow sensor incorporates a temperature sensor so that this influence can be taken into account.

L3-Jetronic

Specific systems have been developed from L-Jetronic. The most recent stage of development is L3-Jetronic, which differs from L-Jetronic in respect of the following details:

- The ECU is attached to the air-flow sensor and therefore no longer requires space in the passenger compartment
- The use of digital technology permits new functions with improved adaptation capabilities to be implemented as compared with the previous analog technology used

L3-Jetronic 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 garage/workshop if the microcomputer fails.

By contrast with L-Jetronic, the ECU 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 ECU computes the injection duration as a measure of the amount of fuel to be injected. It permits the required functions to be influenced.

L3-Jetronic performs corrective interventions in mixture formation with components such as the throttle-valve switch, auxiliary-air device, engine-temperature sensor, and lambda closed-loop control.

LH-Jetronic

LH-Jetronic is closely related to L-Jetronic. The difference lies in air-mass metering. The result of measurement is thus independent of the air density, which is itself dependent on temperature and pressure.

Air-mass meters

The hot-wire air-mass meter (HLM) and the hot-film air-mass meter (HFM) are thermal load sensors. They are installed between the air filter and the throttle valve and register the air-mass flow drawn in by the engine (kg/h). Both sensors operate according to the same principle.

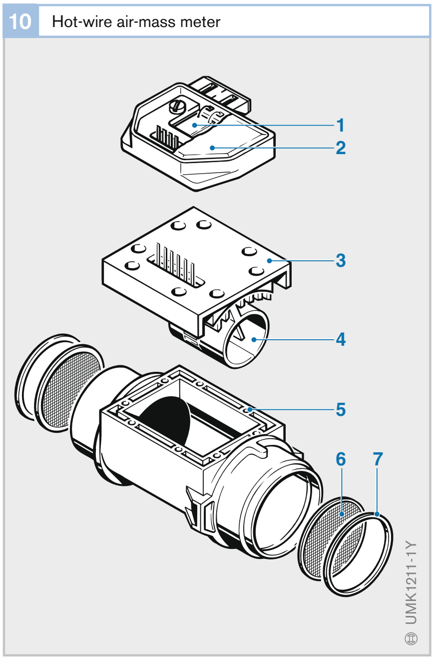
Hot-wire air-mass meter

In the case of the hot-wire air-mass meter (Fig. 10), 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 and function as temperature-dependent resistors. A voltage signal which is proportional to the air-mass flow is transmitted to the ECU.

Hot-film air-mass meter

In the case of the hot-film air-mass meter (Fig. 11), the electrically heated element is in the form of a platinum film resistor (heater element). The temperature of the heater element is registered by a temperature-dependent resistor (flow sensor).
The voltage across the heater element 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.

10 Hot-wire air-mass meter



11 Hot-film air-mass meter

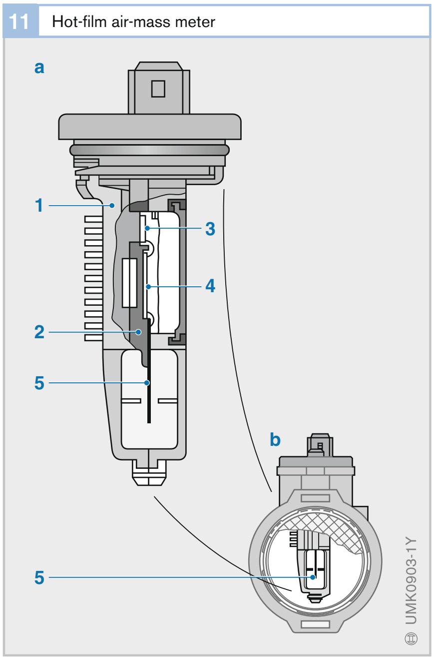


Fig. 10
1 Hybrid circuit
2 Cover
3 Metal insert
4 Inner tube with hot wire
5 Housing
6 Protective screen
7 Retaining ring

Fig. 11
a Hot-film sensor
b Plug-in tube with built-in hot-film sensor

1 Heat sink
2 Intermediate module
3 Power module
4 Hybrid circuit
5 Sensor element (heater element)

Mono-Jetronic

System overview

Mono-Jetronic (Fig. 12) is an electronically controlled low-pressure central injection system for four-cylinder engines with a centrally situated electromagnetic fuel injector (single-point injection) – in contrast to one fuel injector for each cylinder in the multipoint injection systems K-, KE-, L-, L3- and LH-Jetronic. The heart of Mono-Jetronic is the central injection unit with an electromagnetic fuel injector for intermittent fuel injection above the throttle valve.

The intake manifold distributes the fuel to the individual cylinders. A variety of different sensors are used to determine all the engine's operating parameters which are required for optimum mixture adaptation.

Input variables are, for example:

- Throttle-valve angle
- Engine speed
- Engine and intake-air temperatures
- Throttle-valve positions (idle/full load)
- Residual-oxygen content in the exhaust gas
- Automatic-transmission setting (depending on the vehicle equipment specification)
- Air-conditioner settings, and
- A/C-compressor switch setting.

Input circuits in the ECU condition these data for the microprocessor. The microprocessor processes the operating data, identifies the engine's operating state from these data, and calculates actuating signals depending on the data. Output stages amplify the signals and actuate the fuel injector, throttle-valve actuator and canister-purge valve (evaporative-emissions control system).

12 Mono-Jetronic system overview

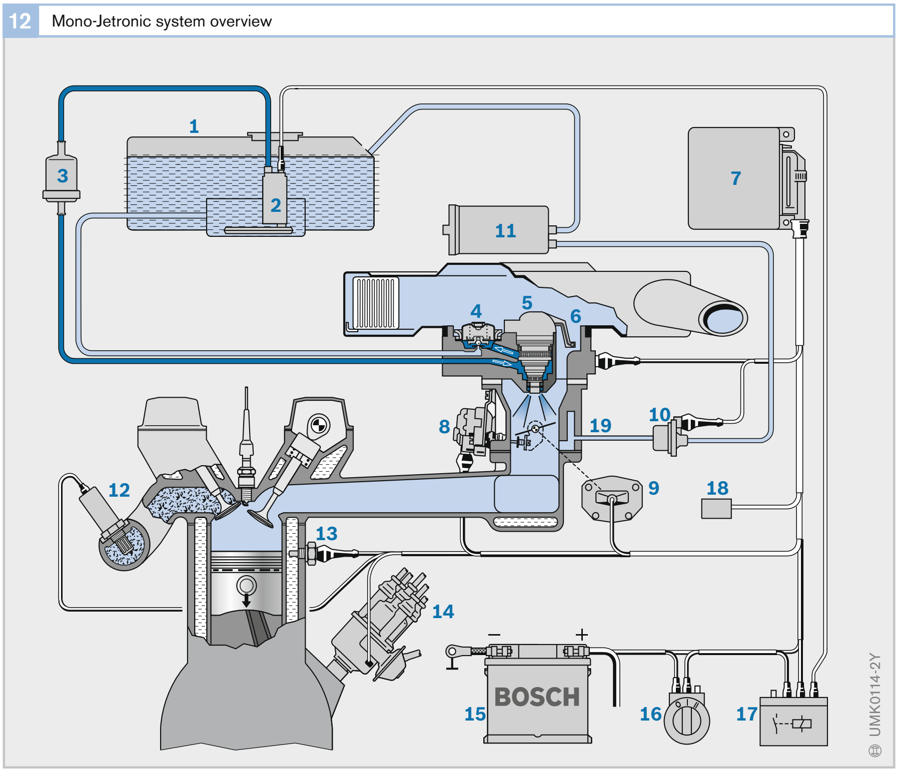


Fig. 12

1 Fuel tank
2 Electric fuel pump
3 Fuel filter
4 Pressure regulator
5 Electromagnetic fuel injector
6 Air-temperature sensor
7 ECU
8 Throttle-valve actuator
9 Throttle valve with throttle-valve potentiometer
10 Canister-purge valve
11 Carbon canister
12 Lambda sensor
13 Engine-temperature sensor
14 Ignition distributor
15 Battery
16 Ignition/starting switch
17 Relay
18 Diagnosis connection
19 Central injection unit

A typical Mono-Jetronic design is broken down into the following functional areas:

- Fuel supply
- Acquisition of operating data, and
- Processing of operating data

Mono-Jetronic's essential function is to control the fuel-injection process. Mono-Jetronic also incorporates a number of supplementary closed-loop and open-loop control functions with which it monitors components that influence exhaust-gas composition. These include:

- Idle-speed control
- Lambda closed-loop control, and
- Open-loop control of the evaporative-emissions control system

Central injection unit

The central injection unit (Fig. 13) is bolted directly to the intake manifold. It supplies the engine with finely atomized fuel, and is the heart of the Mono-Jetronic system. Its design is dictated by the fact that, in contrast to multi-point injection systems (e.g., L-Jetronic), gasoline injection takes place at a central point and the quantity of air inducted by the engine is determined indirectly by a combination of the two variables throttle-valve angle α and engine speed n.

The lower section of the central injection unit comprises the throttle valve (3) together with the throttle-valve potentiometer. The upper section accommodates the fuel system with the fuel injector (1), the pressure regulator (4) and the fuel passages (5, 6). In addition, the air-temperature sensor (2) is located on the upper-section cap.

The fuel flows to the injector via the lower passage (6). The upper passage (5) is connected to the lower chamber of the pressure regulator, from which point excess fuel enters the fuel-return line via the plate valve.

A shoulder on the fuel-injector strainer limits the open cross-section between the inlet and return passages to a defined dimension in such a way that the excess, uninjected fuel is split into two partial flows. One flow passes through the fuel injector, while the other flows around the fuel injector for cooling purposes.

13 Central injection unit (view with partial section)

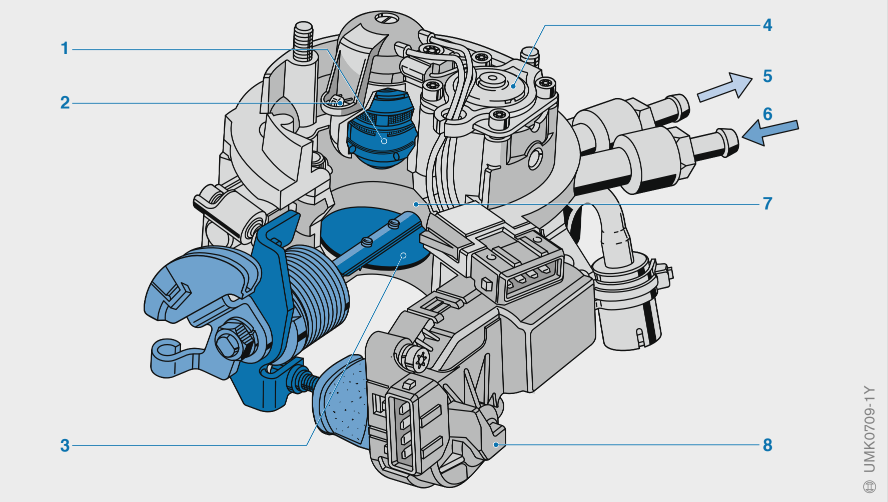


Fig. 13
1 Fuel injector
2 Air-temperature sensor
3 Throttle valve
4 Fuel-pressure regulator
5 Fuel return
6 Fuel inlet
7 Throttle-valve potentiometer (on throttle-valve-shaft extension, not shown)
8 Throttle-valve actuator

Fuel injector

One of Mono-Jetronic's most important functions is to distribute the air/fuel mixture uniformly to all the cylinders. Apart from intake-manifold design, distribution depends mainly on the fuel injector's location and position, and on the quality of its air-fuel mixture preparation.

The fuel injector is installed in the housing of the central injection unit's upper section, which is centered in the intake-air flow by a bracket. This installation position above the throttle valve ensures that the injected fuel is mixed thoroughly with the air that flows past. To this end, the fuel is finely atomized and injected in a cone-shaped jet between the throttle valve and the throttle-valve housing.

The fuel injector (Fig. 14) comprises the valve housing and the valve group. The valve housing contains the solenoid winding (4) and the electrical connection (1). The valve group includes the valve body, which holds the valve needle (6) and its solenoid armature (5). When no voltage is applied to the solenoid winding, a helical spring assisted by the primary system pressure forces the valve needle onto its seat. When the winding is energized, the needle lifts about 0.06 mm (depending on valve design) from its seat so that fuel can exit through an annular gap. The front end of the valve needle incorporates a pintle (7), which projects out of the valve-body bore; the shape of this pintle atomizes the fuel.

The size of the gap between the pintle and the valve body determines the static injector quantity, i.e., the maximum fuel throughflow when the injector is permanently open. The dynamic quantity injected during intermittent operation is also dependent on the valve spring, the mass of the valve needle, the magnetic circuit, and the ECU output stage. Because the fuel pressure is constant, the amount of fuel actually injected by the fuel injector depends solely on the valve's opening time (injection duration).

The fuel injector's pickup and dropout times vary according to battery voltage. The battery voltage is therefore measured continuously by the ECU and used to correct the injection duration.

Throttle-valve actuator

Through its actuator shaft (Fig. 15, Pos. 4), the throttle-valve actuator (Fig. 15) can adjust the throttle-valve lever and thereby influence the amount of air made available to the engine. In this way, the idle speed can be regulated when the accelerator pedal is not pressed (idle).

14 Fuel injector

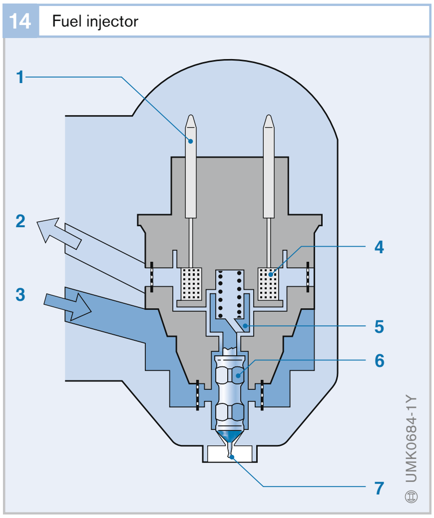


Fig. 14
1 Electrical connection
2 Fuel return
3 Fuel inlet
4 Solenoid winding
5 Solenoid armature
6 Valve needle
7 Pintle

15 Throttle-valve actuator

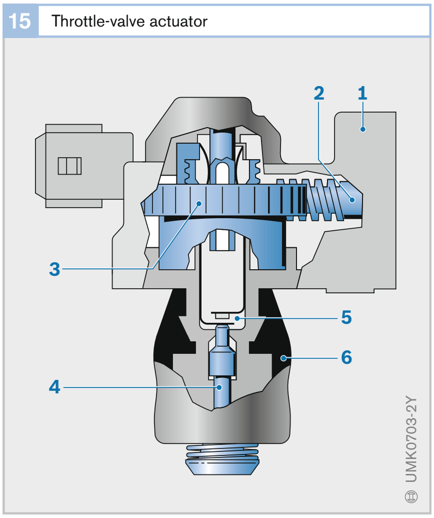


Fig. 15
1 Housing with electric motor
2 Worm
3 Worm gear
4 Actuator shaft
5 Idle contact
6 Rubber bellows

The throttle-valve actuator is powered by a DC motor (1), which drives the actuator shaft through a worm (2) and a worm gear (3). Depending upon the motor's direction of rotation (which in turn depends upon the polarity applied to it), the actuator shaft either extends and opens the throttle valve or retracts and reduces the throttle-valve angle.

The actuator shaft incorporates a switching contact, which closes when the shaft abuts against the throttle-valve lever and thus signals the idle operating state to the ECU.

Fuel-pressure regulator

The fuel-pressure regulator keeps constant at 100 kPa the difference between fuel and ambient pressures at the fuel-injector metering point. It is integrated in the hydraulic section of the central injection unit. A rubber-fabric diaphragm divides the fuel-pressure regulator into a fuel-pressurized lower chamber (Fig. 16, Pos. 6) and an upper chamber (5), in which a preloaded helical spring (4) is supported on the diaphragm. A movable valve plate, which is connected to the diaphragm through the valve holder, is pressed onto the valve seat by spring force (flat-seat valve). When the force resulting from the fuel pressure and the diaphragm surface exceeds the opposing spring force, the valve plate is lifted off its seat slightly. This allows fuel to flow back through the opened cross-section to the fuel tank. In this state of equilibrium, the differential pressure between the upper and lower chambers of the pressure regulator is 100 kPa. Venting ports maintain the spring chamber's ambient pressure at levels corresponding to those at the injector nozzle. The valve-plate lift varies depending on the delivery quantity and the actual fuel quantity required.

16 Pressure regulator

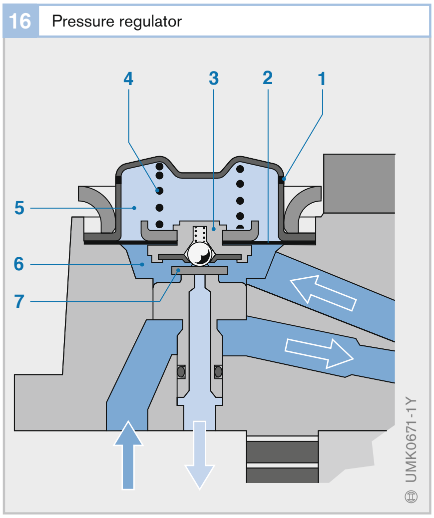


Fig. 16
1 Venting ports
2 Diaphragm
3 Valve holder
4 Pressure spring
5 Upper chamber
6 Lower chamber
7 Valve plate

Because of the constant fuel pressure compared with the ambient pressure at the point of injection, the injected fuel quantity is determined solely by the length of time (injection duration) the injector remains open for each triggering pulse.

Acquisition of operating data

Sensors monitor all essential operating data to furnish instantaneous information on current engine operating conditions. This information is transmitted to the ECU in the form of electrical signals, which are then converted into digital form and processed for use in actuating the various actuators or final controlling elements.

Throttle-valve angle

The air charge, which is crucial to calculating the injection duration, is determined indirectly by combining the two variables throttle-valve angle α and engine speed n (α/n-system). Here, the throttle-valve potentiometer in the central injection unit records the throttle-valve angle α.

The engine map range in which the air charge varies the most as a function of α is encountered with small throttle-valve angles α and at low engine speeds n, i.e., at idle and at low part load. It follows from this that a high angle resolution is required in these operating states.

The required high level of signal resolution is achieved by distributing the throttle-valve angle in the throttle-valve potentiometer for the range between idle and full load between two resistance paths (0°...24° and 18°...90°). In the ECU, the angle signals α are read in separately, each via its own analog-digital converter channel.

Engine speed
The engine-speed information required for α/n control is obtained by monitoring the periodicity of the ignition signal. The signals provided by the ignition system are processed in the ECU. At the same time, these signals are also used for triggering the injection pulses, whereby each ignition pulse triggers an injection pulse.

Further operating states
In addition, Mono-Jetronic records the following information:

- Engine temperature in order to be able to take into account the increased fuel demand when the engine is cold.
- Intake-air temperature for compensating the temperature-dependent air density.
- Idle position for activating overrun fuel cutoff; this information is supplied by the idle contact on the throttle-valve actuator.
- Full load for activating full-load enrichment; this information is derived from the throttle-valve signal.
- Battery voltage in order to be able to compensate the voltage-dependent pickup time of the electromagnetic fuel injector and the voltage-dependent delivery rate of the electric fuel pump.
- Switching signals of the air conditioner and automatic transmission in order to be able to adapt the idle speed to the increased power demand.

Processing of operating data

The ECU generates from the data supplied by the sensors the triggering signals for the fuel injector, the throttle-valve actuator and the canister-purge valve.

Lambda program map
In order to ensure a desired air/fuel ratio, it is necessary to select the injection duration so that it is proportional to the recorded air charge. In other words: The injection duration can be directly allocated to α and n. This allocation is effected by means of a lambda program map (Fig. 17) with the input variables α and n. The influence of the air density is fully compensated here. The intake-air temperature is measured as the air enters the central injection unit and is taken into account in the ECU with a correction factor.

Mixture adaptation
When the engine is started cold, effective fuel vaporization is inhibited by the following factors:

- Cold intake air
- Cold manifold walls
- High manifold pressure
- Low air-flow velocity in the intake manifold, and
- Cold combustion chambers and cylinder walls

These conditions call for mixture adaptation in the starting phase and in the post-start and warming-up phases.

17 Lambda program map

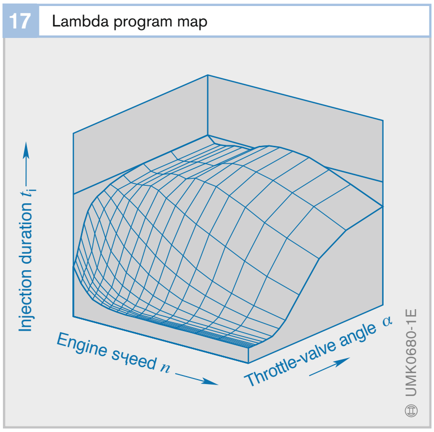


Fig. 17
Injection duration as a function of engine speed n and throttle-valve angle α

Likewise, various corrections are made to the mixture composition when the engine is hot:

- Intake-air-dependent mixture correction
- Transient compensation in the case of load changes which are triggered by throttle-valve movements: The injected fuel quantity must be increased in the event of rapid acceleration/opening up of the throttle (buildup of wall-applied fuel film in the intake manifold) and conversely reduced in the event of rapid deceleration/closing of the throttle (reduction of wall-applied fuel film again).
- Lambda closed-loop control
- Mixture adaptation which takes into account influences on account of tolerances or changes made to the engine and fuel-injection components over the course of time.

Further Mono-Jetronic functions are:

- Idle-speed control, which guarantees a constant engine speed at idle over the entire service life of the vehicle. The engine speed is maintained under all conditions (e.g. vehicle electrical system subjected to load, switched-on air conditioner).
- Altitude compensation, which compensates for lower intake-air density at high altitudes.
- Full-load enrichment so that maximum engine power can be delivered when the accelerator pedal is pressed to the floor.
- Engine-speed limitation in order to prevent the engine from incurring damage caused by excessive engine speeds.
- Overrun fuel cutoff so that exhaust-gas emissions are reduced when driving with the throttle valve closed (vehicle on overrun).

Lambda closed-loop control

Mono-Jetronic is equipped with a lambda closed-loop control function, designed to maintain the air/fuel ratio for the three-way catalytic converter at $\lambda = 1$. Adaptive mixture corrections are also performed, i.e., the self-learning system adapts itself to the changing conditions.

With this adaptive mixture control and the additionally superimposed lambda control loop, indirect recording of the inducted air mass by means of α/n control facilitates constancy of mixture. Air-mass metering no longer needs to be performed here.