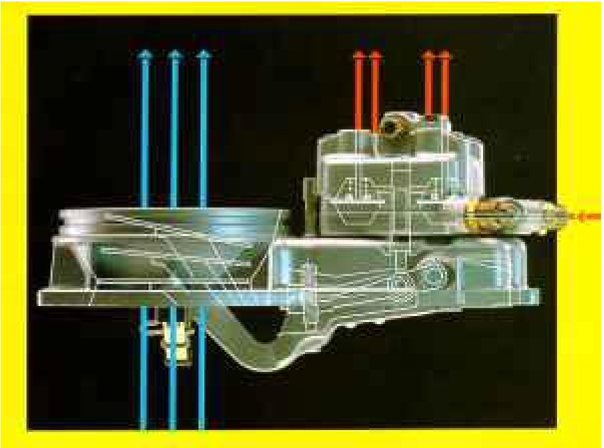
Bosch K-Jetronic Fuel Injection Part 1



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

The air-fuel ratio
Essentially, the power, the fuel consumption and the exhaust-gas composition of a spark-ignition engine depend upon the air-fuel ratio. Perfect ignition and perfect combustion only take place within particular air-fuel ratios. In the case of gasoline (petrol), the ideal air-fuel ratio is about 15:1. In other words, 15 kg of air are required for complete combustion of 1 kg of gasoline (stoichiometric ratio). Deviations from this ratio affect engine operation. The amount of fuel to be injected depends upon load, engine speed and the particular exhaust-gas regulations in force at the time. Depending upon the mode of operation, i.e. idle, part load or full load, a different air-fuel ratio is optimal in each case. Of decisive importance is the strict adherence to the particular most favourable air-fuel ratio at any one time.

The excess-air factor
The excess-air factor is identified by the symbol for Lambda.

Lambda = amount of air supplied ÷ theoretical air requirement

Lambda=1

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

Lambda<1

This means air deficiency, or a rich mixture, and increased power.

Lambda>1

This means air excess, or lean mixture, lower fuel consumption, less power.

Lambda> 1.3

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

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

In spark-ignition systems, fuel management is by means of either a carburettor or a fuel-injection system. Although, up to now, the carburettor has been the most commonly used method, there has been a distinct trend in the last couple of years towards manifold fuel injection. This trend came about due to the advantages offered by fuel injection as regards the demands for fuel economy, high performance and, last but not least, a lower level of pollutants in the exhaust gas. These advantages are based on the fact that manifold fuel injection permits extremely precise metering of the fuel depending upon the operating conditions of the engine and its load, and taking environmental effects into account. With manifold fuel injection, the correct air-fuel ratio is maintained so precisely that the pollutant level in the exhaust gas is considerably lower. Since with this system, the carburettor is no longer required, the intake paths can be optimally designed and laid out. This results in better cylinder charge which in turn leads to a more favourable torque characteristic.

What types of mixture formation are available using fuel injection?

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

Electronically controlled systems

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

Mechanical systems

With mechanical fuel-injection systems, one differentiates between those which require a drive from the engine and those which do not. The engine-driven systems comprise a fuel-injection pump with an integrated governor. Their principle of operation is the same as that of the fuel-injection systems for Diesel engines. The other variation of the mechanical system is one which needs no drive and which injects continuously. This system, the K-Jetronic, is described in the following.

The K-Jetronic

The K-Jetronic is a mechanical fuel injection system from Bosch. It is divided into three main functional areas:

- Air-flow measurement
- Fuel supply
- Fuel induction

Air-flow measurement

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

Fuel supply

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

Fuel induction

The amount of air, corresponding to the position of the throttle plate, sucked in by the engine serves as the criteria for the metering of the fuel to the individual cylinders. The amount of air sucked in by the engine is measured by the air-flow sensor which, in turn, controls the fuel distributor. The air-f low sensor and the fuel distributor are assemblies which form Part of the mixture control unit. Injection takes place continuously, that is, without regard to the position of the intake valve. During the intake-valve closed phase, the fuel is "stored" in the intake tubes.

Fuel supply

Outline of system
The fuel is drawn out of the fuel thank by an electrically driven fuel pump. It is then forced, under pressure, through a pressure accumulator and a fine filter to the fuel distributor, which is located in the mixture control unit. The pressure is held constant by a pressure regulator in the mixture control unit from where it flows to the fuel-injection valves. The injection valves inject fuel continuously into the intake ports of the engine cylinders. The designation K-Jetronic stems from his fact ("K" stands for the German word for "continuous"). When the intake valves open, the air-fuel mixture is drawn into the cylinders. The individual subassemblies of the fuel-supply system are described in the following

Electric fuel pump
The electric fuel pump is a roller-cell pump the electric motor of which is permanently surrounded by fuel. The fuel pump is driven by a permanent magnet electric motor. The rotor disc which is eccentrically mounted in the pump housing is fitted with metal rollers in notches around its circumference which are pressed against the thrust ring of the pump housing by centrifugal force and act as seals. The fuel is carried in the cavities, which form between the rollers. The fuel flows directly around the electric motor. There is no danger of explosion, however, because there is never an ignitable mixture in the pump housing. The pump delivers more fuel than the maximum requirement of the engine so that the pressure in the fuel system can be maintained under all operating conditions. During starting, the pump runs as long as the ignition key is operated. The pump continues to run when the engine has started. A safety circuit is incorporated to stop the pump running and fuel being delivered if the ignition is switched on but the engine has stopped turning (for instance in the case of an accident).

Fuel accumulator
The fuel accumulator maintains the pressure in the fuel system for a certain time after the engine has been switched off. When the engine is running it serves to deaden the noise of the electric fuel pump. After the engine has been switched off, the fuel accumulator maintains the pressure in the fuel system in order to facilitate re-starting, particularly when the engine is hot. The design of the accumulator housing is such that it deadens the noise from the fuel pump when the engine is running. The interior of the fuel accumulator is divided into two chambers by means of a diaphragm. One chamber serves as the accumulator volume for the fuel, the other chamber contains a spring. During operation the accumulator chamber is filled with fuel. This causes the diaphragm to bend back against the force of the spring until it is halted by the stops in the spring chamber. The diaphragm remains in this position, which corresponds to the maximum accumulator volume, as long as the engine is running.

Fuel filter
Due to the extremely close tolerances of various components in the system, it is necessary to fit a special fine filter for the fuel in order to guarantee faultless performance of the K-Jetronic. The fuel filter retains particles of dirt which are present in the fuel and which would otherwise adversely affect the functioning of the injection system. The fuel filter contains a paper filter element, which is backed up by a strainer. This combination results in a high degree of cleaning being achieved. A supporting plate is used to hold the filtering elements in place in the filter housing. It is of utmost importance that the direction of flow indicated on the housing is complied with. The filter is fitted in the fuel line downstream of the fuel accumulator.

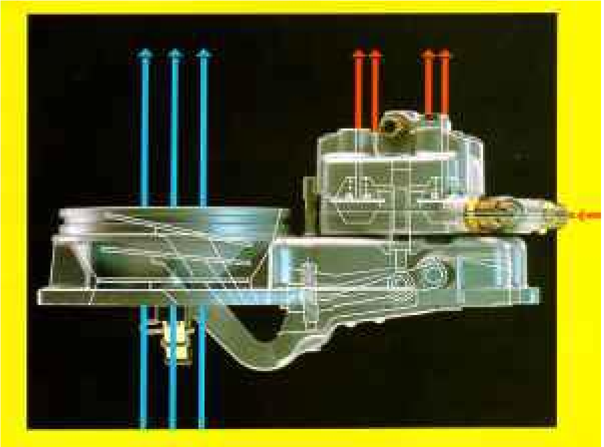
Primary-pressure regulator
The primary-pressure regulator maintains the pressure in the fuel system constant. The pressure regulator incorporated in the fuel-distributor housing maintains the delivery pressure (= primary pressure) at about 5 bar. Due to the fact that the fuel pump delivers more fuel than the engine needs, a plunger shifts in the pressure regulator and opens a port through which excess fuel can return to the fuel tank. The pressure in the fuel system and the force exerted by the spring on the plunger in the pressure regulator balance each other out. If for instance, the fuel pump delivers slightly less fuel, the plunger is shifted by the spring into the corresponding new position and in doing so reduces the open section of the port through which excess fuel flows back to the tank. This means that less fuel leaves the system at this point, and as a result the primary pressure in the system increases to the specified

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

Fuel-injection valve

The fuel-injection valves open at a certain pressure and inject fuel into the intake tubes. The fuel is atomised by the oscillation of the valve needle. The injection valves inject the fuel allocated by the fuel distributor into the intake ports directly in front of the intake valves of the cylinders. The injection valves are secured in a special holder in order to insulate them from engine heat. The insulation prevents vapour bubbles forming in the fuel injection lines which would lead to poor starting behaviour when the engine is hot. The injection valves have no metering function. They open of their own accord when the opening pressure of 3.3 bar is exceeded. They are fitted with a valve needle which vibrates ("chatters") audibly at high frequency when fuel is injected. This means that excellent fuel atomisation is achieved, even with the smallest of injected quantities. When the engine is switched off, the injection valve closes tightly and forms a seal when the fuel-system pressure has dropped below the injection-valve opening pressure. As a result, no more fuel can drip into the intake ports after the engine has been switched off.

Bosch K-Jetronic Fuel Injection Part 2



Fuel Management

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

Air-flow sensor
The air-flow sensor operates according to the suspended-body principle and measures the amount of air drawn in by the engine. All the air drawn in by the engine flows through an air-flow sensor which is connected upstream of the throttle plate. The air-flow sensor is fitted with an air funnel in which is located a movable sensor plate (the suspended body). The air drawn in through the air funnel shifts the sensor plate by a certain amount out of its zero position. The movement of the sensor plate is transmitted to a control plunger by a lever system. This plunger determines the quantity of fuel required. Considerable pressure shocks can occur in the intake system if backfiring takes place in the intake manifold. For this reason, the airflow sensor is so designed that the sensor plate can swing back in the opposite direction, past its zero position, and thus open a relief cross-section in the funnel. A rubber buffer limits the swing-back in the downward direction (in the case of the updraft air-flow sensor, the swing-back in the upwards direction is also limited by a rubber buffer). A leaf spring ensures that the sensor plate assumes the correct zero position when the engine is stationary. The sensor-plate movements are transmitted to the control plunger in the fuel distributor by means of a lever system. The weight of the sensor plate and the lever system are balanced by a counterweight.

Fuel distributor
The fuel distributor meters (allocates) the correct amount of fuel to the individual cylinders in accordance with the position of the air-flow sensor plate. As already mentioned, the position of the sensor plate is a measure of the amount of air drawn in by the engine. The position of the plate is transmitted to the control plunger by a lever. The control plunger controls the amount of fuel which is to be injected. Depending upon its position in the barrel with metering slits, the control plunger opens or closes the slits to a greater or lesser degree. The fuel flows through the open section of these slits to the differential pressure valves and then to the fuel-injection valves. If sensor-plate travel is only small, then the control plunger is only lifted slightly and as a result only a small section of the slot is opened for the passage of fuel. With larger plunger travel, the plunger opens a larger section of the slits and more fuel can flow. There is, therefore, a linear relationship between sensor-plate travel and the slit section in the barrel, which is opened for fuel flow. The force applied to the control plunger by the sensor plate travel is opposed by another force, which comes from the so-called control pressure. One of the functions of this control pressure is to ensure that the control plunger follows the movements of the sensor plate immediately and does not, for instance, stay in the (upper) end position when the sensor plate moves back down again. Further important functions of the control pressure are discussed in the chapters dealing with warm-up and full-load enrichment

Control pressure
The control pressure is tapped off from the primary pressure through a restriction bore, which serves to decouple the control-pressure circuit and the primary pressure circuit from one another. A connection line joins the fuel distributor and the warm-up regulator (control pressure regulator). When starting the cold engine the control pressure is about 0.5 bar. As the engine warms up, the warm-up regulator increases the control pressure to about 3.7 bar. The control pressure acts through a damping restriction on the control plunger and thereby develops the force, which opposes the force of the air in the air-flow sensor. In doing so, the restriction dampens a possible oscillation of the sensor plate, which could result due to pulsating air-intake flow. The control pressure influences the fuel distribution. If the control pressure is low, the air drawn in by the engine can deflect the sensor plate further. This results in the control plunger opening the metering slits further and the engine being allocated more fuel. On the other hand, if the control pressure is high the air drawn in by the engine cannot deflect the sensor plate so far and, as a result, the engine receives less fuel. In order to fully seal off the control pressure circuit with absolute certainty when the engine has been switched off, and at the same time to maintain the pressure in the fuel circuit, the return line of the warm-up regulator is fitted with a non-return valve.

This (push-up) valve is actually in the primary-pressure regulator and is held open during operation by the pressure-regulator plunger. When the engine is switched off and the plunger of the primary-pressure regulator returns to its zero position, the non-return valve is closed by a spring.

Differential-pressure valves
The differential-pressure valves in the fuel distributor serve to hold the drop in pressure at the metering slits constant. The air-flow sensor has a linear characteristic. This means that if double the quantity of air is drawn in, the sensor-plate travel is also doubled. If this (linear) travel is to result in a change of delivered fuel in the same relationship, in this case double the travel = double the quantity, then a constant drop in pressure must be guaranteed at the metering slits independent of the amount of fuel flowing through them. The differential-pressure valves maintain the drop in pressure at the metering slits constant independent of fuel through flow. The difference in pressure is 0.1 bar, this facilitates a high degree of control accuracy. The differential-pressure valves are of the flat-seat type. They are fitted in the fuel distributor and one such valve is allocated to each metering slit. The upper and lower chambers of the valve are separated by a diaphragm. The lower chambers of all the valves are connected with one another by a ring main and are subjected to the primary pressure (delivery pressure from fuel-supply pump). The valve seat is located in the upper chamber. Each upper chamber is connected to a metering slit and its corresponding fuel-injection line. The upper chambers are completely sealed off from each other. The diaphragms are spring-loaded and it is this helical spring that produces the pressure differential. If more fuel flows into the upper chamber through the metering slit, the diaphragm is bent downwards and enlarges the valve cross-section at the outlet line leading to the injection valve until the differential pressure of 0.1 bar set by the spring again prevails. If less fuel flows, the diaphragm bends back towards its original position and decreases the valve cross-section at the outlet line until the differential pressure of 0.1 bar is again present. This causes an equilibrium of forces to prevail at the diaphragm which can be maintained for every quantity of fuel by controlling the valve cross-section.

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

Mixture Adaptation

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

Cold start
Depending upon the engine temperature, the start valve injects extra fuel into the intake manifold for a limited period during the starting process. During cold starting, part of the fuel in the mixture drawn in is lost due to condensation on the cold cylinder walls. In order to compensate for this loss and to facilitate starting the cold engine, extra fuel must be injected at the instant of start-up. This extra fuel is injected by the start valve into the intake manifold. The injection period of the start valve is limited by a thermo-time switch depending upon the engine temperature. This process is known as cold-start enrichment and results in a "richer" air-fuel mixture, i.e. the excess-air factor is temporarily less than 1.

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

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

temperature. It is comprised of an electrically heated bimetal strip which depending upon its temperature either opens or closes an electric contact. The complete device is fitted into a hollow threaded pin which in turn is located at a position where typical engine temperature prevails. The thermo-time switch determines the injection period of the start valve. In doing so, the warming-up of the switch due both to the engine heat and to the surrounding temperature, as well as its in-built electrical heating filament are the determining factors. The in-built heating facility is necessary in order to limit the maximum start-valve injection period. The mixture would otherwise become too rich and the engine would not start due to "flooding". During cold start the injection period depends mainly upon the electrical heating facility. (Switch off at -20°C after approx. 8 seconds). On the other hand, when the engine is already warmed-up the heat from the engine has heated the thermo-time switch to such a degree that it remains permanently open. As a result, an engine which is already at operating temperature is not provided with extra fuel for starting.

Warm-up

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

Warm-up regulator

The change of the control pressure is effected by the warm-up regulator which is so fitted to the engine that it ultimately adopts the engine temperature. In addition, the warm-up regulator is electrically heated which enables it to be precisely matched to the engine characteristic. It comprises a spring-controlled flat seat diaphragm-type valve and an electrically heated bimetal spring. In the cold state the bimetal spring exerts an opposing force to that of the valve spring and, as a result, reduces the effective pressure applied to the underside of the valve diaphragm. This means that the valve outlet cross-section is slightly increased at this point and more fuel is diverted out of the control-pressure circuit in order to achieve a low control pressure. As soon as the engine is cranked the bimetal spring is heated electrically and after starting it is also heated by the engine. The spring bends, and in doing so reduces the force opposing the valve spring which, as a result, pushes up the diaphragm of the flat-seat valve. The valve outlet cross section is reduced and the pressure in the control-pressure circuit rises. Warm-up enrichment is completed when the bimetal spring has lifted fully from the valve spring. The control pressure is now solely controlled by the valve spring and maintained at its normal level. The control pressure is about 0.5 bar at cold start and about 3.7 bar with the engine at operating temperature.

Auxiliary-air device

In order to overcome the increased friction in the cold state and to guarantee smooth idling, the engine receives more air-fuel mixture during the warm-up phase due to the action of the auxiliary-air device. When the engine is cold, the frictional resistances are higher than when it is at operating temperature. These must also be overcome by the engine during idle. For this reason, the engine is allowed to draw in more air by means of the auxiliary-air device which by-passes the throttle valve. Due to the fact that this auxiliary air is measured by the air-flow sensor and taken into account for fuel metering, the engine is provided with more air-fuel mixture. This results in idle stabilisation when the engine is cold. In the auxiliary-air device a perforated plate is pivoted by means of a bimetal spring and changes the open cross section of the bypass line. Dependent upon temperature the plate assumes a given position, so that in the case of a cold engine a correspondingly larger cross section of the bypass line is opened. As the temperature increases the open area is decreased until, finally, it is closed completely. The bimetal is heated electrically. This means that the opening time can be limited according to engine type. The auxiliary-air device is so located that it is heated up by the engine to the engine temperature. This ensures that the auxiliary-air device does not respond when the engine is warm.

Load conditions

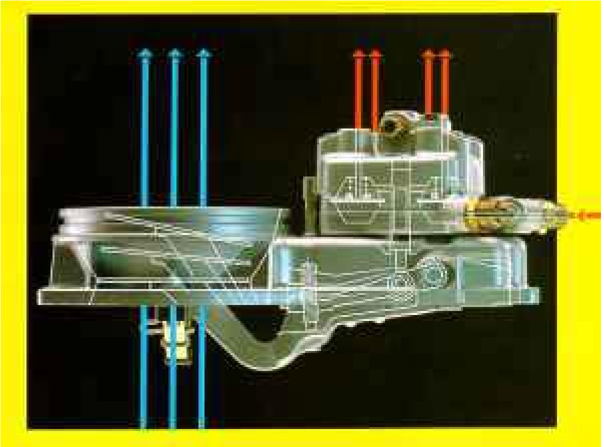
The adaptation, or correction, of the air-fuel mixture to the operating conditions of idle, part load and full load is carried out by means of appropriately shaping the air funnel in the air-flow sensor. If the funnel had a purely conical shape, the result would be a mixture with a constant air-fuel ratio throughout the whole of the sensor plate range of travel (metering range). As has already been mentioned though, it is necessary to meter to the engine an air-fuel mixture which is optimal for particular operating conditions such as idle, part load and full load. In practice, this means a richer mixture at idle and full load, and a leaner mixture in the part-load range. This adaptation is achieved by designing the air funnel so that it becomes wider in stages If the cone shape of the funnel is flatter than the basic cone shape (which was specified for a particular mixture, e.g. for Lambda= 1) this results in a leaner mixture. If the funnel walls are steeper than in the basic model the sensor plate is lifted further for the same air throughput, more fuel is therefore metered and the mixture is richer. Hence, the funnel is so shaped that a richer mixture is produced at idle and full load, and a leaner mixture at part load (full-load and idle enrichment).

Mixture enrichment by means of control-pressure reduction In those cases where engines are operated with a very lean mixture in the part load range, an extra mixture enrichment must be provided at full load in addition to the mixture adaptation resulting from the shape of the air funnel. This extra enrichment is carried out by a specially designed warm-up regulator. This regulates the control pressure depending upon the manifold pressure. In this model of the warm-up regulator, two valve springs are used instead of one. The outer of the two springs is supported on the housing as is the case with the normal-model warm-up regulator. The inner spring though, is supported on a diaphragm which divides the regulator into an upper and a lower chamber. The manifold pressure is effective in the upper chamber which is connected to the intake manifold, behind the throttle valve, by means of a hose. Depending upon the model, the lower chamber is subjected to atmospheric pressure either directly or by means of a second hose leading to the air filter. Due to the low manifold pressure in the idle and part-load ranges, which is also present in the upper chamber, the diaphragm lifts to its upper stop. The inner spring is now at maximum pretension. The pretension of both springs, as a result, determines the particular control pressure for these two ranges. When the throttle valve is opened further at full load, the pressure in the intake manifold increases, the diaphragm leaves the upper stops and is pressed against the lower stops. The inner spring is relieved of tension and the control pressure reduced by the specified amount as a result. In this manner, mixture enrichment is achieved.

Acceleration response
The good acceleration response is a result of the sensor plate "overswing". Acceleration During the transition from one operating condition to the other, changes in the mixture ratio occur which are utilised to improve the driveability. If at constant engine speed the throttle valve is suddenly opened, the amount of air which enters the combustion chamber, plus the amount of air which is needed to bring the manifold pressure up to the new level, flow through the airflow sensor. This causes the sensor plate to briefly "overswing" past the fully opened throttle point. This "overswing" results in more fuel being metered to the engine (acceleration enrichment) and ensures good acceleration response.

Controlling the air-fuel mixture
In order to adapt the injected fuel quantity to the ideal air-fuel ratio of Lambda= 1, the pressure in the lower chambers of the fuel distributor is varied. If for instance the pressure is reduced, the differential pressure at the metering slots climbs accordingly with the result that the injected fuel quantity is also increased. In order to be able to vary the pressure in the lower chambers, these are decoupled (in contrast to the conventional K-Jetronic fuel distributor) from the primary pressure. Decoupling is by means of a fixed throttle. A further throttle connects the lower chambers with the fuel return. This throttle is variable. If it is open, the pressure in the lower chambers can reduce. If it is closed, the primary pressure is present in the lower chambers. If this throttle is opened and closed rapidly, it is possible to vary the pressure in the lower chambers to correspond to the ratio between open time and close time. An electromagnetic valve, the timing valve, is used as the variable throttle. It is controlled by electrical pulses from the Lambda control unit.

Bosch K-Jetronic Fuel Injection Part 3



Electrical Circuitry

If the engine stops but the ignition remains switched on, the electric fuel pump is switched off. The K-Jetronic system is equipped with a number of electrical components, such as electric fuel pump, warm-up regulator, auxiliary-air device, start valve and thermo-time switch. The electrical supply to all of these components is controlled by the control relay which itself is switched by the ignition-start switch. Apart from its switching functions, the control relay also has a safety function. A commonly used circuit is described in the following.

Function
When cold-starting the engine, voltage is applied to the start valve and the thermo-time switch through terminal 50 of the ignition-start switch. If the cranking process takes longer than between 8 and 15 seconds, the thermo-time switch switches off the start valve in order that the engine does not "flood". In this case the thermo-time switch performs a time switch function. If the temperature of the engine is above about +35°C when the starting process is commenced, the thermo-time switch will have already open-circuited the connection to the start valve, which as a result does not inject extra fuel. In this case the thermo-time switch performs as a temperature switch. Voltage from the start-ignition switch is still present at the control relay, which switches on as soon as the engine runs. The rotational speed reached when the starting motor cranks the engine is high enough to generate the "engine running" signal which is taken from the ignition pulses coming from terminal 1 of the ignition coil. These pulses are processed by an electronic circuit in the control relay, which switches on after the first pulse and applies voltage to the electric fuel pump, the auxiliary-air device and the warm-up regulator. The control relay remains switched on as long as the ignition is switched on and the engine is running. If the pulses from terminal 1 of the ignition coil stop because the engine has stopped turning, for instance in the case of an accident, the control relay switches off about 1 second after the last pulse is received. This safety circuit prevents the fuel pump from pumping fuel when the ignition is switched on but the engine is not turning.

Exhaust gas techniques

Exhaust-gas composition
Fuel combustion in the engine working cylinder is more or less incomplete. The less complete the combustion, the higher is the emission of toxic substances in the exhaust gas. Perfect, or total, combustion of the fuel is impossible even when surplus air is available in plenty. In order to reduce the load on the environment, it is imperative that engine exhaust-gas emissions are reduced drastically. All measures taken to reduce the toxic emissions in compliance with a variety of legal requirements, aim at achieving as clean an exhaust gas as possible, while at the same time featuring optimum fuel-economy figures, excellent drive ability, high mileage figures, and low installation costs. In addition to a large percentage of harmless substances, the exhaust gas of a spark-ignition engine contains components which are harmful to the environment when they occur in high concentrations. About 1 % of the exhaust gas is harmful, and consists of carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbons (HC). The major problem in this respect is the fact that although these three toxic substances are dependent upon the air-fuel ratio, when the concentration of CO and HC increases the concentration of NO_x decreases, and vice versa.

Carbon monoxide

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

Oxides of nitrogen

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

Hydrocarbons

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

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

- The catalytic converter promotes the after burning of CO and HC to harmless carbon dioxide (CO_2) and water (HO).
- At the same time, the catalytic converter reduces the nitrogen of oxide present in the exhaust gas to neutral nitrogen (N).

It is therefore perfectly clear that the catalytic after treatment of the exhaust gas is considerably more effective than for instance the purely thermal after burning of the exhaust gases in a thermal reactor. Using a catalytic converter, more than 90% of the toxic substances can be converted to harmless substances. The three-way catalytic converter has come into widespread use (here, the term "3-way" means that all three toxic substances CO, HC and NOx are degraded at the same time). The converter shell contains a ceramic "honeycomb" which is coated with a precious metal, preferably with platinum and rhodium. When the exhaust gas flows through this honeycomb, the platinum and rhodium accelerate the chemical degradation of the toxic substances. Only lead-free gasoline may be used with such converters because the lead otherwise destroys the catalytic properties of the noble-metal catalyst. This means that lead-free gasoline is a prerequisite for the employment of catalytic converters. The catalytic conversion principle presupposes that the engine burns an optimum air-fuel mixture. Such an optimum, or stoichiometric, air-fuel mixture is characterised by the excess-air factor of Lambda= 1.00, and it is imperative that the excess-air factor is maintained precisely at this figure otherwise the catalytic converter cannot operate efficiently. Even a deviation of only 1 % has considerable adverse effects upon the after treatment. But the best open-loop control is incapable of holding the air-fuel mixture within such close tolerances, and the only solution is to apply an extremely accurate closed-loop control, featuring almost zero lag, to the air fuel mixture management system. The reason is that although an open-loop mixture control calculates and meters the required fuel quantity, it does not monitor the results. Here, one speaks of an open control loop. The closed loop control of the mixture on the other hand measures the composition of the exhaust gas and uses the results to correct the calculated injected fuel quantity. This is referred to as a closed control loop. This form of control is particularly effective on fuel-injection engines because they do not have the additional delay times resulting from the long intake paths typical of carburettor engines.

Lambda closed-loop control

Lambda sensor
The Lambda sensor inputs a voltage signal to the ECU which represents the instantaneous composition of the air-fuel mixture. The Lambda sensor is installed in the engine exhaust manifold at a point which maintains the necessary temperature for the correct functioning of the sensor over the complete operating range of the engine.

Operation

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

Construction

The ceramic sensor body is held in a threaded mounting and provided with a protective tube and electrical connections. The surface of the sensor ceramic body has a microporous platinum layer which on the one side decisively influences the sensor characteristic while on the other serving as an electrical contact. A highly adhesive and highly porous ceramic coating has been applied over the platinum layer at the end of the ceramic body that is exposed to the exhaust gas. This protective layer prevents the solid particles in the exhaust gas from eroding the platinum layer. A protective metal sleeve is fitted over the sensor on the electrical connection end and crimped to the sensor housing. This sleeve is provided with a bore to ensure pressure compensation in the sensor interior, and also serves as the support for the disc spring. The connection lead is crimped to the contact element and is led through an insulating sleeve to the outside of the sensor. In order to keep combustion deposits in the exhaust gas away from the ceramic body, the end of the exhaust sensor which protrudes into the exhaust-gas flow is protected by a special tube having slots so designed that the exhaust gas and the solid particles entrained in it do not come into direct contact with the ceramic body. In addition to the mechanical protection thus provided, the changes in sensor temperature during transition from one operating mode to the other are effectively reduced. The voltage output of the sensor, and its internal resistance, are dependent upon temperature. Reliable functioning of the sensor is only possible with exhaust-gas temperatures above 350°C (unheated version), and above 200°C (heated version).

Heated Lambda oxygen sensor

To a large extent, the design principle of the heated Lambda sensor is identical to that of the unheated sensor. The active sensor ceramic is heated internally by a ceramic heating element with the result that the temperature of the ceramic body always remains above the function limit of 250°C. The heated sensor is equipped with a protective tube having a smaller opening. Amongst other things, this prevents the sensor ceramic from cooling down when the exhaust gas is cold. Amongst the advantages of the heated Lambda sensor are the reliable and efficient control at low exhaust-gas temperatures (e.g. at idle), the minimum effect of exhaust-gas temperature variations, the rapid coming into effect of the Lambda control following engine start, short sensor-reaction which avoids extreme deviations from the ideal exhaust-gas composition, versatility regarding installation because the sensor is now independent of heating from its surroundings.

Lambda closed-loop control circuit

By means of the Lambda closed-loo control the air-fuel ratio can be maintained precisely at Lambda= 1.00. The Lambda closed-loop control is an add-on function, which, in principle, can supplement every controllable f uel-management system. It is particularly suitable for use with Jetronic gasoline-injection systems or Motronic. Using the closed-loop control circuit formed with the aid of the Lambda sensor, deviations from a specified air-fuel ratio can be detected and corrected. This Control principle is based upon the measurement of the exhaust-gas oxygen by the Lambda sensor. The exhaust-gas oxygen is a measure for the composition of the air-fuel mixture supplied to the engine. The Lambda sensor acts as a probe in the exhaust pipe and delivers the information as to whether the mixture is richer or leaner than Lambda= 1.00. In case of a deviation from this Lambda= 1.00 figure, the voltage of the sensor output signal changes abruptly. This pronounced change is evaluated by the ECU which is provided with a closed loop control circuit for this purpose. The injection of fuel to the engine is controlled by the fuel-management system in accordance with the information on the composition of the air-fuel mixture received from the Lambda sensor. This control is such that an air-fuel ratio of Lambda= 1 is achieved. The sensor voltage is a measure for the correction of the fuel quantity in the air-fuel mixture. The signal which is processed in the closed-loop control circuit is used to control the actuators of the Jetronic installation. In the fuel-management system of the K-Jetronic (or carburettor system), the closed-loop control of the mixture takes place by means of an additional control unit and an electromechanical actuator (frequency valve). In this manner, the fuel can be metered so precisely that depending upon load and engine speed, the air-fuel ratio is an optimum in all operating modes. Tolerances and the ageing of the engine have no effect whatsoever. At values above Lambda = 1.00, more fuel is metered to the engine, and at values below Lambda = 1.00, less. This continuous, almost lag-free adjustment of the air-fuel mixture to Lambda= 1.00, is one of the prerequisites for the efficient after treatment of the exhaust gases by the downstream catalytic converter.

Control functions at various operating modes

Start

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

Acceleration and full load (WOT)

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

Deviations in air-fuel mixture

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

Engine Backfires in Intake

Check for Proper CO Adjustment: A lean mixture adjustment can result in a backfire under load or when starting.

Check Engine Air Tubing between Airflow Sensor and Throttle: Holes or other leaks in the tubing that runs from the airflow sensor to the throttle assembly can result in a lean air-fuel ratio. A lean ratio can result in a backfire under load or when starting.

Check for Vacuum Leaks: Vacuum leaks can result in a lean mixture, and a lean mixture can result in a backfire. One of the best techniques for locating a vacuum leak is to run a little propane around the intake system.

Engine Misfires under Load

Ignition Problems: The most likely cause of a misfire is always the ignition system, regardless of the fuel system.

Inadequate Fuel Delivery (engine running lean): An insufficient supply of fuel can be the result of a binding airflow sensor or control plunger, restricted injectors, incorrect control or system pressure. Also perform an equal flow and spray pattern test on the injectors.

Poor Power

Incorrect Tune-Up Specs or Worn Tune-Up Parts: As with a carbureted engine the most likely cause of poor power is the basic tune-up specifications of timing, dwell and air-fuel ratio. Also, worn distributor caps, spark plugs, points and plug wires can seriously impact the performance of the K-Jetronic with Lambda engine.

Control Pressure Too High: High control pressure will limit the travel of the control plunger, thereby limiting the amount of fuel that can flow into the engine. When the engine begins to run lean, power can suffer.

Restricted Injectors: Restricted injectors can limit the amount of fuel that can pass through them, thereby limiting power.

Stumble or Sag on Acceleration

Sticking or Binding Airflow Sensor Plate: If the airflow sensor plate binds on the way up, fuel flow will be limited and the engine will sag or stumble.

Sticking or Binding Control Plunger: If the control plunger binds on the way up, fuel flow will be limited and the engine will stumble or sag.

Incorrect System or Warm Control Pressure: If the system pressure is too high or if the control pressure is too high (high system pressure will usually cause high control pressure) the movement of the control plunger will be limited and the engine will begin to run lean as the airflow increases. A lean running engine will sag or stumble on acceleration.

Unequal Injector Flow: Restricted injectors can limit the amount of fuel that can pass through them, thereby limiting power.

Engine Diesels

Binding or Sticking Airflow Sensor: In order for the engine to diesel or run-on after the engine is shut off there must be fuel entering the engine. One source of this fuel is an airflow sensor that is not dropping to the closed position as the engine is shut off.

Binding or Sticking Control Plunger: Inspect the control plunger for smooth movement without binding or sticking.

Leaking Injectors: Perform an injector flow test and inspect the injectors for proper seating when the airflow sensor drops to the rest position.

Leaking Cold-Start Injector: Remove injector, pressurize the system and inspect for leaks.

Excessive Fuel Consumption

Improperly Adjusted Air-Fuel Ratio: Check the CO adjustment as previously described.

Leaking Injectors: Remove the injectors from the cylinder head. Energize the fuel pump and watch the injector tips for evidence of dripping. If a drop forms, falls from the tip of the injector and is replaced by another drop, replace the offending injector.

Leaking Cold-Start Injector: Remove the cold-start injector from the cylinder head. Energize the fuel pump and watch the tip for evidence of dripping. If a drop forms, falls from the tip of the cold-start injector and is replaced by another drop, replace it.

What to Do, and When

Lack of Fuel Pressure

When there is no fuel pressure, the first thing to do is confirm that there is fuel in the tank. I have seen several methods, at various levels of sophistication, to confirm fuel quantity. Of all these methods the best and simplest is to pour a gallon or so of fuel into the tank.

If there is an adequate amount of fuel in the tank, the next item of business is to confirm fuel pump operation. Place a mechanic's stethoscope on the fuel pump and have someone crank the engine. If the fuel pump is located inside the fuel tank, then place the stethoscope on the fuel tank. As the engine is cranked the hum of the fuel pump should be heard through the stethoscope. If no hum is heard, check electrical power to the pump.

Begin by inspecting the fuel pump fuse. If the fuel pump fuse is good, connect the alligator clip of a test light to the ground side of the fuel pump connector and probe the positive side of the fuel pump connector. If the test light goes on, then the pump is receiving power and has a good ground. If the test light fails to light up, connect the alligator clip to a good chassis ground and probe the positive terminal on the fuel pump. If the test light still fails to light up, check the fuel pump relay and inspect the fuel pump wiring harness. If the test light finally goes on, inspect the fuel pump ground.

Another reason for a lack of fuel pressure is restriction in the fuel lines or the fuel filter. Energize the fuel pump and begin loosening fittings along the fuel supply line.

USE EXTREME CAUTION THOUGH, AS THE FUEL WILL BE UNDER AS MUCH AS 100 PSI PRESSURE AND WILL TEND TO SPRAY OUT IN A FINE, HIGHLY FLAMMABLE MIST.

If there is only a small amount of pressure or volume present at a loosened fitting, inspect the components upstream of that fitting for restrictions. Restrictions are commonly found in the fuel filter and the in-tank pickup filter screen.

An obvious reason for no fuel pressure would be an external leak. Look for external leaks anywhere along the fuel lines or at the accumulator.

Jammed or Sticking Airflow Sensor

After removing the airflow sensor boot, inspect for proper adjustment of the sensor plate. Adjust as necessary. If the adjustment is OK, the binding is at the fulcrum—the only component of the K-system with Lambda that can be disassembled and reassembled without damaging it.

Remove the airflow sensor assembly from the car. On each side of the sensor you will find a disc held in place by an internal snap ring. Remove the snap rings and with a small screwdriver, wobble the disc back and forth until it falls out. There is a large counterweight on the end of the airflow sensor lever; loosen the large screw that holds the counterweight in place. At the same time this will loosen the fulcrum shaft. Carefully mount the airflow sensor assembly in a vise and using a brass drift, drive the shaft out of the assembly.

Wash all of the metal components in solvent, removing any varnish build-up that may have occurred over the years. Rinse the solvent off of the parts with hot water. The hot water will evaporate quickly, reducing the possibility of rusting.

Reassemble the airflow sensor using a very light film of point lube or similar lubricant. Make the sensor plate adjustments and reinstall on the car.

Auxiliary Air Valve Not Opening

There is really nothing that can be done for an auxiliary air valve that does not open, short of replacement. Verify that the valve is not receiving power all the time and replace it.

Cold-Start Injector Not Opening

The cold-start injector is a simple, normally closed solenoid-operated valve. If the cold-start injector does not open when the engine temperature is below 95 deg. F, disconnect the cold-start injector and connect a test light across the terminals. Crank the engine. If the test light goes on, the wiring harness is good. Loosen the fuel line at the cold-start injector and crank the engine again. If fuel leaks or sprays from the loosened line, replace the cold-start injector. If not, confirm fuel delivery to the fuel distributor and repair or replace the restricted fuel line. If the fuel line delivers fuel, then replace the cold-start injector.

If connecting the test light across the terminals and cranking the engine does not light the test light, confirm that the engine temperature is below 95 deg. F. Connect the test light alligator clip to the positive battery terminal and probe the harness connector of the cold-start injector. One of the two terminals should activate the test light, the other should not. If neither activates the test light, inspect the wire that runs from the cold-start injector to the thermo-time switch. If this is good, inspect the one that runs from the switch to ground for an open circuit. If both wires test satisfactorily, replace the thermo-time switch.

Sticking Control Plunger

A sticking control plunger normally indicates a damaged control plunger. Simply dropping the plunger when servicing the fuel distributor might be enough to damage it. Inspect the plunger for evidence of varnishing. If the plunger continues to stick or bind replace the fuel distributor. Care during installation will prevent damage to the new plunger.

Note: Control plungers are machined for a precise match to a given fuel distributor. Trying to use a control plunger from another fuel distributor can result in even more severe binding or leaking.

Restricted Injectors

Restricted injectors can best be diagnosed by performing the injector flow equality test. Cleaning a restricted injector(s) can be done with an injector cleaning system. These cleaning systems range in price from about $100 to more than $1,000.

Unless you are a business specializing in fuel-injection or tune-up service, purchasing a cleaning system such as this is probably not the best use of your money. As an alternative, remove the injectors from the intake system and leave them attached to their fuel supply lines. Place them in a safe container, then activate the fuel pump as described in the section on measuring pressures. Once the fuel pump is running, lift the airflow sensor plate all the way and allow fuel to flow through the injectors at full force. Lower the airflow sensor plate to its rest position, wait a few seconds, then slowly lift the plate between 1/8 and 1/4 in. Observe the injector spray pattern. If the pattern is good, reinstall the injectors and test drive. If the pattern is bad, replace the injectors.

temperature-sensitive resistor called a thermistor. As the coolant temperature increases, the resistance of the sensor drops.

The computer increases the current flow to the pressure actuator when the engine is cold, and slowly decreases it as the engine warms up. Additionally, this sensor is used to signal the system computer that the idle speed needs to be higher to compensate for cold engine operation.

Throttle Switch

The throttle switch is a two-contact switch. One set of contacts is closed when the throttle is closed. The other set is closed when the throttle is wide open.

Lambda Sensor

The CIS-E system uses a Lambda sensor to monitor exhaust gases. When a lean exhaust condition is detected, the Lambda sensor sends a low voltage (less than 0.5 volt) to the system computer. The computer responds by increasing the current flow through the electrohydraulic actuator, which decreases the lower chamber pressure and enriches the mixture.

When the engine begins to run rich, the Lambda sensor voltage increases. The system computer reduces the current flow through the electrohydraulic actuator and the injection system leans out.

How CIS-E Works

When the engine is cranked, air begins to flow into the engine. The airflow lifts the sensor plate which, in turn, lifts the control plunger in the fuel distributor. When the plunger is lifted, fuel flows from the lower chambers of the distributor through the metering slits into the upper chambers and off to the injectors. As the airflow changes the position of the plunger changes, thereby altering the amount of fuel entering the engine.

When the engine is started the cold-start valve will spray for about five to ten seconds. If the temperature of the engine is greater than 95 deg. F, the cold-start injector will not operate.

During engine warm-up the coolant sensor input to the system computer causes the computer to increase the current flow through the electrohydraulic actuator, enriching the mixture. As the engine warms up the current drops, leaning out the mixture. When the engine reaches operating temperature the coolant sensor gives way to the Lambda sensor.

During normal, warm operation the airflow sensor lifts the fuel distributor control plunger proportionally to the volume of air entering the engine. As the plunger is lifted, fuel flows through the metering slits from the lower to the upper chambers of the fuel distributor. If the pressures in the lower chamber are equal to or lower than the pressure in the upper chambers, then the diaphragm separating the upper and lower chambers is deflected downward and fuel can flow to the injectors. When the pressure inside the injectors exceeds 30 psi the injectors will open and fuel will flow into the intake manifold. The Lambda sensor signals the system computer to alter the current through the electrohydraulic actuator in order to trim and correct the air-fuel ratio.

The throttle switch is used in conjunction with the airflow sensor potentiometer to signal the system computer about engine load. If the system computer detects an increasing airflow and a wide-open throttle, the current through the electrohydraulic actuator is increased, the Lambda sensor is ignored and the mixture is enriched. When the throttle switch indicates a closed throttle and the airflow potentiometer indicates a decreasing airflow, the current through the electrohydraulic actuator is reversed. This reversed current cuts off fuel flow.

KE-Jetronic Adjustments

Because of the computer control of air-fuel ratio and idle speed, the number of manual adjustments on the KE-Jetronic system is limited.

Audi and Volkswagen

Seven adjustments need to be made on Audi and Volkswagen applications to accommodate the KE-system. During a normal tune-up these adjustments do not need to be tested. Should any major injection components such as the fuel distributor be replaced, however, these adjustments should be checked. They should also be checked if a driveability or fuel economy problem is present. These adjustments include: basic plate lever adjustment, sensor plate and lever centering, sensor plate rest position, sensor plate free play, airflow sensor potentiometer, throttle valve housing and throttle switch adjustment.

Basic Plate Lever Adjustment: Remove the fuel distributor from the airflow sensor housing. Using a depth gauge, measure the distance between the top of the housing and the roller on the plate lever. The distance should be 0.74 to 0.75 in. (18.9–19.1 mm). If an adjustment needs to be made, use a 3 mm Allen wrench to adjust the mixture screw.

Sensor Plate and Lever Centering: Remove the 6 mm bolt in the center of the airflow sensor plate. Coat the bolt with locking compound. Then reinstall the bolt, finger tight. Carefully center the plate by either eye-balling it or using a 0.004 in. feeler gauge. Tighten the 6 mm bolt. If the plate cannot be centered it may be necessary to remove the airflow sensor assembly from the car; turn it upside down and center the lever on its fulcrum shaft. When the sensor plate is centered, in order to verify that the plate and lever do not bind try to lift the plate by placing a magnet on the center bolt.

If the magnet easily lifts the lever and plate without sticking or binding, then the adjustment is complete.

Sensor Plate Rest Position: The top side of the airflow sensor plate should rest about 0.07 to 0.08 in. below the top edge of the narrowest part of the venturi cone. Although this sounds like a highly precise adjustment, you need only ensure that the top of the sensor plate rests just below the top edge of the narrowest part of the venturi. If the adjustment is incorrect, open or close the wire clip around the leaf spring just below the sensor plate.

Sensor Plate Free Play: The next adjustment to make is for the distance between the control plunger and the roller on the airflow sensor lever. Before checking this, the basic plate lever adjustment must be correct. Connect an ammeter in series with the electrohydraulic actuator. Verify that the current is between 4 and 16 milliamps. If the current is less than 4 milliamps, allow the engine to cool down before continuing. If the current is greater than 16 milliamps, warm the engine before continuing.

Crank the engine for ten seconds to build up fuel pressure. Lift the sensor plate until some resistance is felt. There should be some free play, but no more than 0.078 in. If this adjustment is not correct, remove the fuel distributor and verify the basic plate lever adjustment. If this adjustment is correct, adjust the control plunger stop screw.

Airflow Sensor Potentiometer: After verifying the basic lever adjustment, airflow sensor plate centering, sensor rest position and free play, the airflow sensor potentiometer adjustment can be made. Connect a high-impedance voltmeter to potentiometer terminal number 17. With the sensor plate in the rest position the voltage should be 0.2 to 0.3 volt. As the sensor plate is lifted, the voltage should increase smoothly to about 7.0 volts. If the increase in voltage is not smooth, replace the potentiometer. If the voltage specifications are incorrect, loosen the mounting screws and adjust.

Throttle Valve Housing: The minimum throttle adjustment is done with a thin piece of paper. Loosen the throttle plate stop screw and place the paper between the stop screw and the throttle. Adjust the screw until it barely pinches the paper. Then remove the paper and tighten the screw an additional half turn.

Throttle Switch: Connect an ohmmeter across the terminals of the closed-throttle switch. Continuity should be gained just before the throttle is closed.

Next, connect an ohmmeter across the terminals of the wide-open throttle switch. Continuity should be gained just before the throttle is wide open.

Mercedes-Benz

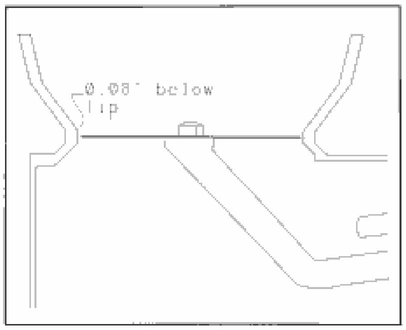
Two adjustments need to be made on Mercedes-Benz applications: airflow sensor plate adjustment, and airflow sensor potentiometer adjustment.

Airflow Sensor Plate Adjustment: Pressurize the fuel system. This can be done by removing the fuel pump relay and placing a jumper wire with a 16 amp fuse between terminals 7 and 8.

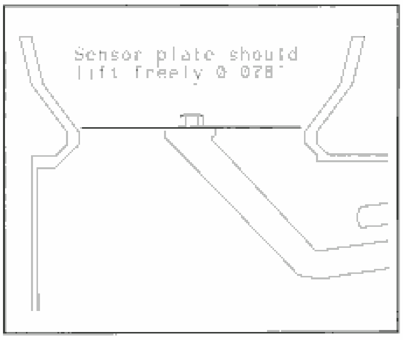
The airflow sensor plate should be centered in the narrowest part of the venturi. This usually means a gap all the way around the airflow sensor of about 0.002 in. If the sensor plate is not centered, loosen the center bolt and adjust. The sensor plate should not bind when pressed down.

The rest position of the sensor plate should place the top of the sensor plate 0.008 in. below the top edge of the narrowest part of the venturi.

The distance between the airflow sensor lever and the bottom of the control plunger (free play)



On Volkswagen-Audi products the top side of the airflow sensor plate should rest 0.08 in. below the upper edge of the narrowest part of the venturi.



Volkswagen-Audi sensor plate free play.

should be 0.040 to 0.080 in. If gently lifting the sensor plate does not reveal this tolerance, then adjust the free play by driving the guide pin up or down as required.

Airflow Sensor Potentiometer Adjustment: There should be between 3,200 and 4,800 ohms of resistance between terminals 14 and 18 of the airflow potentiometer when the airflow sensor is at rest. There should be between 560 and 1,060 ohms from terminal 14 to terminal 17. The reading should increase to between 3,760 and 5,640 when the sensor plate is lifted to its highest point. Adjust if necessary.

Troubleshooting the KE-Jetronic System

Of all the Bosch systems, the KE-system may be the most confusing to troubleshoot. The system combines electronics with mechanical fuel flow control. An analysis of driveability symptoms may point to either a mechanical or electronic problem, or not distinguish between the two. What follows is a logical sequence for analyzing any driveability problem.

Verify Engine Condition

Run a compression test and/or cylinder leakage test. Check the valve adjustment and camshaft condition. Then verify the condition of the ignition system. If all of these test satisfactorily, then check the injection system.

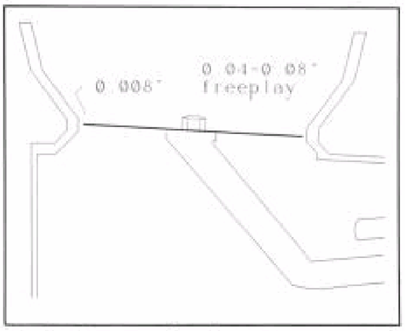
Test Fuel Pressure

As in all fuel-injection systems, any thorough system test must begin with fuel pressure. Connect a pressure gauge between the cold-start valve and the port on the lower chambers of the fuel distributor. Disconnect the electrical connector on the electrohydraulic actuator. Then activate the fuel pump. The pressure indicated should be between 75 and 82 psi.

If the pressure is low, check the fuel pump volume. The pump should be able to deliver 0.5 gpm (gallons per minute) or more. If the volume is low, check the fuel filter (including the one in the tank) and the line for kinks. If the pressure is low but the volume is acceptable, replace the system pressure regulator.

If the fuel pressure is high, disconnect the return line from the system pressure regulator and repeat the test. Ensure that the fuel from the regulator is captured in an approved fuel container. If the fuel pressure remains high, replace the pressure regulator. If the pressure drops, clean or repair the return line.

The next step is to measure lower chamber differential pressure, or the difference between the pressure in the lower chambers of the fuel distributor and system pressure. This measurement is done in two steps. The first step is to simulate pressure in the lower chambers with no correction



Mercedes-Benz sensor plate adjustments.

based on engine temperature and exhaust oxygen.

Disconnect the electrical connector on the differential pressure regulator and close the valve on the pressure gauge. Activate the fuel pump; the differential pressure should be between 2.9 and 7.0 psi. If the pressure does not meet these specifications, disconnect the return line from the lower chambers of the fuel distributor. A volume of approximately five ounces per minute should flow through the return line. If the pressure is wrong but the flow is correct, replace the differential pressure regulator. If the flow is incorrect, replace the fuel distributor.

If the first part of the test yields the correct pressure, then reconnect the differential pressure regulator with an ammeter in series, and proceed with the second part of the test. The second step is to simulate the differential pressure of a cold engine. Disconnect the coolant temperature sensor and place a 15,000 ohm resistor across the terminals. Activate the fuel pump. Differential pressure should be between 10.0 and 17.5 psi. The ammeter should read between 50 and 80 milliamps.

If the pressure is wrong but the current is correct, replace the differential pressure regulator.

If both the ammeter and pressure readings are incorrect, check the resistance through the differential pressure regulator. If the resistance is greater than 21.5 ohms or less than 17.5 ohms, replace the differential pressure regulator.

If the resistance reading is correct, check the ECU power and grounds. Also check the ground for the temperature sensor. If these are OK, replace the ECU.

Test Rest Pressure

Rest or residual pressure is a measurement of the KE-system's ability to retain pressure after the engine has been shut off. Open the valve on the pressure gauge and energize the fuel pump for about thirty seconds. Shut off the fuel pump and monitor the pressure for ten minutes. The pressure should not drop below 38 psi. If the pressure drops too low, remove the differential pressure regulator (electrohydraulic actuator) and inspect the O-rings. If the O-rings are functioning properly, or the pressure continues to drop when the test is repeated after replacement, pinch off the system pressure regulator return line. Repeat the test. If the pressure holds, replace the system pressure regulator. If the pressure still falls, replace the electrohydraulic actuator.

Check Pre-pump Delivery Volume

Some KE-injection systems use a pre-pump. When the symptoms include sagging, hesitation or stumbling, the delivery rate of this pump should be checked. The minimum flow rate is about one pint in twelve seconds.

Check Main Pump Delivery Volume

Main pump delivery volume should be approximately 0.5 gpm.

Test Injectors for Equal Flow

The injector equal-flow test is an effort to determine how much contamination or restriction there is in the injectors. Remove the injectors from the intake manifold, leaving them attached to the fuel lines. Place the nozzle of each injector in a graduated cylinder; energize the fuel pump. Lift the airflow sensor plate and place the tip of a screwdriver under the edge of the plate. Flow the injectors for about thirty seconds, then pull the screwdriver out. The volume of fuel that flowed through each injector should vary by only 10 percent.

Replace any injector that flowed 10 percent less than the others. If all injectors pass this test, repeat the test with the airflow sensor plate lifted about $^3/_4$ in. Again, the quantity that flowed through each injector should be within 10 percent of each other. If any injector flows 10 percent less than the rest, replace the injector.

> > It is not very precise to call an injection system "Jetronic". This is a
> > brand name that Bosch uses for all systems that only deal with fuel
> > injection, not ignition.
> >
> > Analog systems are D-jetronic (manufactured from about 1969 to 1974),
> > L-jetronic (1974 to mid-80's), most LE-jetronic (1981 to early 90's) and
> > all LU-jetronic (the same as LE but with closed-loop lambda control).
> >
> > Digital systems are LH-jetronic (from early 80's to mid 90's, most of
> > them but not all have closed-loop, LH 2.4 and later have adaptive lambda
> > correction and some diagnostic features), LE3-jetronic (the last
> > non-closed loop system, the ecu is integrated in the air flow meter) and
> > Mono-jetronic (a TBI system, only used with closed-loop and adaptive
> > lambda correction).
> >
> > The K-jetronic, an all-mechanical system should also be mentioned. It
> > may have a closed-loop add-on and is then called K-lambda-jetronic. A
> > similar but newer variant is called KE-jetronic, it exists both without
> > and with closed-loop. Most KE systems are analog but the KE3 is digital
> > (and then uses an ecu that is very similar to the Mono-jetronic ecu).
> >
> > Most digital Jetronic systems use an Intel MCS-51 CPU. Either a standard
> > 8051/8031 with a separate A/D converter, or an 80535/80C535. In some
> > cases, mask programmed 8051's may be found but they more commonly have
> > an external eprom. Anyway, all PCBs are designed for external eprom so
> > it is a simple task to solder an eprom socket and the address latch in
> > place, and change the jumper for the CPU's EA signal.
> > The eprom may be socketed or soldered in place depending on requirements
> > from each car manufacturer.
> >
> > Some older LH-jetronic (in particular, LH 2.2) use instead an 8049 CPU.
> > The very earliest LH systems might have an RCA 1802, like the early
> > Motronic systems.
> >
> > The simplest way to identify a Jetronic system is to look at the Bosch
> > part number of the ECU.
> > I.e. 0 280 000 561. The first six digits tell just that it is a Jetronic

> > CPU. The seventh digit indicates the number of cylinders, 0 means
4
> > cylinders, 1 means 6 cylinders and 2 means 8 cylinders. The
eighth digit
> > indicates the variant. 0 means D-jetronic, 1 and 2 means L-
jetronic, 3
> > means LE- and LU-jetronic, 5 and 9 means LH-jetronic, 7 means
> > Mono-jetronic and 8 means K-lambda and KE. The two last digits
are a
> > leap number.
> >
> > So, when asking about a "Jetronic" system, be sure to include the
> > variant of the system. I.e. mention that you have an LH 2.4 with
> > closed-loop.
> >
> > Best regards
> >
> > Torbjörn Forsman
> >
>

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0000741513	0438101003 0438101004	190E to 1986		$395.00
0000741913	0438101011 0438101012	190E 2.6, 260E, 300E, 300SE, 300SEL, 300TE		$465.00
0000742013	0438101025 0438101026	190E from 1987		$395.00
0000742313	0438101027 0438101028	190E 16V		$495.00
0000742413	0438101017 0438101018	420SEL, 560SEC, 560SEL, 560SL		$495.00
0000742513	0438101015 0438101016	500SL to 1992		$495.00
0000742713	0438101009 0438101010	190E 16V (European version)		$495.00
0000742813	0438101043 0438101044	300CE, 300SL 1990 - 92		$465.00

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1993-95 Chrysler Concord, New Yorker, LHS, Dodge Intrepid and Eagle Vision.

The K-Series fuel injection systems are continuous mechanical fuel injection systems used on a wide variety of European vehicles, including such makes as Volkswagon, Audi, BMW, Mercedes, Porsche, Volvo and Saab. The system is one of the most common fuel injection systems on the market today, but also is one of the least understood.

The K-Jetronic System constantly injects fuel into the engine as long as the car is running and air flow is present to move the sensor plate in the airflow sensor. The sensor plate is connected to an arm that pushes up on a plunger located in the fuel distributor. As airflow changes, the movement of the sensor plate and the plunger increase and decrease the volume of fuel injected into the engine. Since fuel is being injected constantly, fuel pressure will have a direct affect on driveability. As a matter of fact, fuel pressure is the single most critical element when diagnosing driveability problems in the K-Series fuel injection systems. An accurate fuel pressure gauge must be used when testing these systems, with a range of 0 to more than 100 psi. You will also need a digital volt ohm meter (DVOM) that can read milliamps.

You will work with three types of pressures when diagnosing these systems: system pressure, control pressure (also known as counter pressure) and rest pressure.

System pressure is the total fuel pressure produced by the fuel pump on a constant basis. The fuel pump must be able to maintain this pressure during all driving conditions from idle to wide open throttle. As a rule, system pressure will run about 5 to 5.5 bar pressure, or 75 to 85 psi (1 bar = about 15 psi) and the pump should be able to produce a minimum volume of 1 pint in 15 seconds. When deadheaded, the K-Series fuel pump will produce about 1.5 times the system pressure or about 110 to 120 psi. System pressure is a function of volume of fluid moved against a restriction, so to maintain system pressure at the desired level, there must be some type of restriction built into the fuel system. This restriction is more commonly known as the fuel pressure regulator. The fuel pressure regulator restricts the return of fuel to the tank by a calibrated amount, maintaining system pressure at the desired level. On early K-Jet systems, this regulator was a slide valve (also known as a push valve) internal to the fuel distributor. Fuel pressure could be adjusted by adding or removing shims from the valve. On later K-Jet systems, the regulator is the conventional diaphragm type.

Control pressure (or counter pressure) is the pressure that is metered to the top of the fuel plunger on a K-Jet system. By changing the counter pressure, the resistance to plunger movement is changed, allowing enrichment and enleanment of the fuel mixture to the engine. On a car equipped with K-Jet, this pressure is controlled by the warm-up regulator.

The warm-up regulator only compensates for engine temperature and is therefore a rather coarse control of fuel mixture. (Some K-Jet warm-up regulators also have a vacuum port to help with the acceleration enrichment and deceleration enleanment function.) Typical control pressures on a K-Jet warm-up regulator are

55 psi with the engine at full operating temperature and 20 to 30 psi on a cold engine. (The colder the engine, the lower the pressure.)

A car equipped with K-Jet Lambda also changes control pressure with a warm-up regulator (with pressures similar to a plain K-Jet system), but also controls lower chamber pressure in the fuel distributor by bleeding pressure through a frequency valve. By modifying lower chamber pressure, a change in volume of injected fuel is made, enriching or enleaning the mixture. The frequency valve is nothing more than an electrically duty-cycled fuel pressure regulator controlled by an on-board computer in response to an oxygen sensor signal. This system provides a more precise and rapid control of fuel mixture. Typical duty cycle on a properly running engine is 45 percent to 55 percent duty and fluctuating. A quick test of this system is to start the engine and test the frequency valve for vibration or noise -- it should vibrate. Also, unplugging the oxygen sensor will put the system in open loop and fix the frequency valve at a 50 percent duty cycle.

The KE-Jet system provides quicker response and more precise control of fuel mixture than the K-Jet Lambda system and is the current K-Jet system in use. This system uses a device called a differential pressure regulator to control fuel mixture in response to both engine temperature and oxygen sensor signals. In the KE-Jet system, counter pressure is broken down into primary counter pressure and control counter pressure. Primary counter pressure is the pressure applied to the top of the fuel plunger. This pressure stays constant and is the same as system pressure.

Control counter pressure is modified by the differential pressure regulator and is actually the lower chamber pressure in the fuel distributor. By modifying lower chamber pressure, the fuel mixture can be enriched or enleaned in response to temperature and oxygen sensor signals. Typical control counter pressures are 4 to 7 psi less than system pressure on a fully warmed engine and 17 to 20 psi less than system pressure on a cold engine (typical system pressures are 5.0 to 5.5 bar or 75 to 85 psi). The signal to the differential pressure regulator from the computer is measured in milliamps of current. To test this signal, a DVOM must be placed in series with the differential pressure regulator. Typical current values are 80 milliamps cold engine (15k ohm resistor in place of coolant temp sensor to simulate a cold engine condition); 120 milliamps during cranking (this is a crank enrich function to aid starting); and 8 to 12 milliamps warm idle. (Note: always check service manual for values.) These values correspond to the fuel pressures listed. In other words, at 80 milliamps current you should show 17 to 20 psi less than system pressure.

Rest pressure is the fuel pressure maintained in the system by the fuel accumulator after engine shutdown. The fuel accumulator is a large spring-loaded diaphragm that maintains a pressure of about 1.5 to 2.0 bar for 30 minutes or more after engine shutdown. This rest pressure provides for fast restart and prevents fuel percolation or boiling (vapor lock). Always check the service manual for the car line you are working on for proper rest pressures and times. Typical symptoms caused by accumulator problems are extended crank time and hard start hot.

With an understanding of the system and the proper tools, K-Jetronic fuel system service is a straightforward procedure that can keep your service bays full all year long. Give me a call if you have any questions!

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

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

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

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

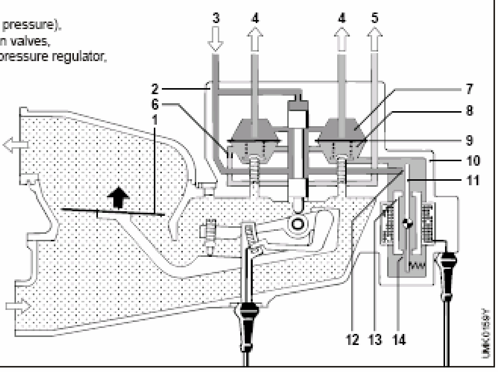
Design
The electro-hydraulic pressure actuator (Figure 20) is mounted on the fuel distributor. The actuator is a differential-pressure controller which functions according to the nozzle/baffle-plate principle, and its pressure drop is controlled by the current input from the ECU. In a housing of non-magnetic material, an armature is suspended on a frictionless taut-band suspension element, between two double magnetic poles. The armature is in the form of a diaphragm plate made from resilient material.

Fig. 20

Electro-hydraulic pressure actuator fitted to the fuel distributor

The control signal from the ECU intervenes in the position of the baffle plate (11).
This, in turn, varies the fuel pressure in the upper chamber of the differential-pressure valves and, as a result, the quantity of fuel delivered to the injection valves (injectors). Using this principle, adaptation and correction functions can be incorporated.

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



Section through the electro-hydraulic pressure actuator

1 Fuel inlet (primary pressure),
2 Nozzle,
3 Baffle plate,
4 Fuel outlet,
5 Magnetic pole,
6 Electromagnet coil,
7 Permanent-magnet flux,
8 Permanent magnet (turned through 90 degrees from the focal plane),
9 Adjustment screw for basic moment of force,
10 Electromagnetic flux,
11 Armature
(L_1 to L_4= air gaps).

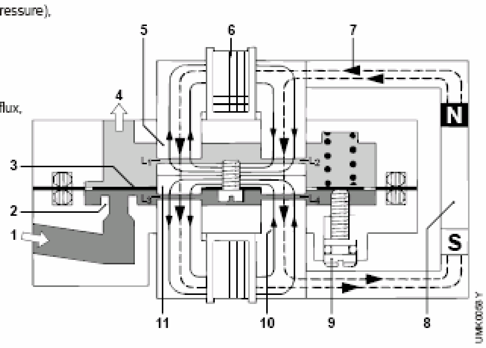


Fig. 21

Function
The magnetic flux of a permanent magnet (broken lines in Figure 21) and that of an electromagnet (unbroken lines) are superimposed upon each other in the magnetic poles and their air gaps. The permanent magnet is actually turned through 90 degrees referred to the focal plane. The paths taken by the magnetic fluxes through the two pairs of poles are symmetrical and of equal length, and flow from the poles, across the air gaps to the armature, and then through the armature.
In the two diagonally opposed air gaps (Figure 21 L_2, L_3), the permanent-magnet flux, and the electro-magnet flux resulting from the incoming ECU control signal are added, whereas in the other two air gaps (Figure 21 L_1, L_4) the fluxes are subtracted from each other. This means that, in each air gap, the armature, which moves the baffle plate, is subjected to a force of attraction proportional to the square of the magnetic flux.
Since the permanent-magnet flux remains constant, and is proportional to the control current from the ECU flowing in the electromagnet coil, the resulting torque is proportional to this control current. The basic moment of force applied to the armature has been selected so that, when no current is applied from the ECU, there results a basic differential pressure which corresponds preferably to $\lambda = 1$. This also means that, in the case of control current failure, limp-home facilities are available without any further correction measures being necessary.
The jet of fuel which enters through the nozzle attempts to bend the baffle plate away against the prevailing mechanical and magnetic forces. Taking a fuel throughflow which is determined by a fixed restriction located in series with the pressure actuator, the difference in pressure between the inlet and outlet is proportional to the control current applied from the ECU. This means that the variable pressure drop at the nozzle is also proportional to the ECU control current, and results in a variable lower-chamber pressure. At the same time, the pressure in the upper chambers changes by the same amount. This, in turn, results in a change in the difference at the metering slits between the upper-chamber pressure and the primary pressure and this is applied as a means for varying the fuel quantity delivered to the injection valves.
As a result of the small electromagnetic time constants, and the small masses which must be moved, the pressure actuator reacts extremely quickly to

C. Diagnosing Bosch KE-Jetronic Injection

If you've done much work on European cars, you've encountered Robert Bosch K-Jetronic mechanical fuel injection, which first appeared in the early seventies. It's an efficient, multi-port, continuous (the "K" stands for that word auf Deutsch) spray system that works so well it allowed some car makers to avoid adding catalytic converters for a few years after everybody else needed them to comply with emissions regulations. Yet, it's less expensive than regular electronic port injection, better than TBI (Throttle Body Injection) because it doesn't allow stratification of the blend in the manifold, and relatively simple -- that is, once you understand it.

Mechanical, but electronic, too

As with just about everything else automotive, K-Jet didn't escaped change in the last decade. When three-way catalysis became necessary in order to meet NOx limits, a means of keeping the air/fuel mix closer to the ideal stoichiometric ratio (that is, 14.7:1 air to fuel by weight) than could possibly be achieved mechanically was needed. So, this injection set-up got add-on electronics to give closed-loop operation and satisfy the Feds. First, this was called K-Jetronic with Lambda (that Greek letter has come to represent the stoichiometric blend), but later came a more elegantly simple version, KE-Jetronic. You'll find it on several Volkswagen and Audi models from '84 up, even the entry-level Fox (a neat little car that, in our opinion, outclassed its competition).

Since VW has made more vehicles with this system (which the company calls CIS-E for "Continuous Injection System-Electronic) than everybody else put together, I'll give you the gospel according to Wolfsburg and use the Fox as my example. Although I'm being very model-specific here, a lot of what I say will give you a better understanding of K-Jetronic in general.

Flow

The little Volks has a fuel supply system with a small in-tank transfer pump that sends gasoline up to a reservoir. From there, the main roller-cell electric pump (which should never be allowed to run dry) picks it up and pushes it into an accumulator, which protects the metal diaphragm in the fuel distributor from the shock of the pump turning on, and maintains residual pressure after the engine is shut down to help avoid vapor lock.

After passing though a big, lifetime filter mounted on the same bracket as the pump and accumulator, the flow reaches the fuel distributor, and here's where you'll find the main differences between KE and other CIS's. As you know if you read the previous section, the basic principle of Bosch continuous injection is that a metal disc floating in a cone moves in accordance with the amount of air entering the engine, and the disc's lever is connected to a control plunger that rises in a barrel progressively uncovering fuel-metering slits. The more air being taken in, the more the disc moves, and the more gasoline is delivered. This much remains the same.

Mixmaster

Differential pressure valves still serve to maintain the pressure drop at the metering slits regardless of how much fuel is flowing through them, and here's where KE's closed-loop mix control comes in. An electro-magnetic differential pressure regulator (a small plastic box screwed to the side of the fuel distributor -- its presence will let you know the system is KE) opens and closes as commanded by the ECU, varying pressure in the lower chamber of the fuel distributor. When the computer gets a lean signal from the oxygen sensor, it sends additional current to the pressure regulator, increasing differential pressure, hence fuel flow, so the blend richens. And vice versa. Although the whole differential pressure versus fuel flow concept is a little hard to grasp, what I've just said is really all you need to know for diagnosis.

The injectors themselves, by the way, are of the air-shrouded variety that provide a very finely atomized spray. Air flow through passages in the cylinder head really breaks up those droplets.

Instead of the combo of a control pressure regulator and a pressure relief valve, KE-Jet has only a diaphragm-type pressure regulator, which maintains about 78 psi in the system by venting the excess back to the tank, and also keeps residual pressure available after the engine's shut down.

A cold start valve sprays extra gas into the intake manifold when it gets voltage from the thermo-time switch, just like previous systems. Also similar is the auxiliary air regulator, which is plumbed across the throttle plate to let in extra air for fast idle.

With that operational explanation taken care of, I'll look at service. As with every other modern engine control or fuel injection system, don't assume a driveability or performance problem is due to KE-Jet until you've checked for ignition problems, vacuum leaks, poor compression, etc. If it's not tampered with, this set-up should stay in calibration and last just about forever. But that's not to say you'll never run into any problems with it.

Closed loop?

The first thing to find out is if the closed-loop mode is ever being entered, and for that you'll need a milli-amp meter and either a special VW wiring adapter (I'd be surprised if you bought such a thing) or some home-made leads. With the ignition off, unplug the two-terminal connector from the differential pressure regulator. Those Bosch plugs can be difficult if you're not used to them -- pry off the metal clip completely with a small screwdriver, then separate the connection. Using very narrow spade terminals, crimp a male to one end of a six-inch wire, and a female to the other. Attach a similar pair of spades to the leads of your meter (I found that an ordinary analog multi-meter worked fine). Since a short here can blow the electronics, I wrapped the spades with electrical tape to make sure they wouldn't make contact with each other.

Now, connect the male end of your jumper to one side of the plug, the female end to the corresponding spade of the differential pressure regulator, then attach your meter in series across the other terminals, and set it to the milli-amp scale. Start the engine, let it get warm, and make sure all electrical accessories are off. Once normal operating temp is reached (remember, any oxygen sensor has to be warm to work, so you may need to hold rpm at 2,500 or so for a while to heat it up) look for a reading of 10 mA + or - 6, and it should fluctuate over a 1-3 milli-amp range. That fluctuation is the tip-off that closed-loop operation is occurring -- in open loop, the ECU sends a fixed 10mA signal, which won't cause any drivability problems, but will increase emissions.

A CO test should ideally go along with this. If you happen to access to an exhaust analyzer, pick up the sample at the convenient tube you'll find in front of the manifold (it has a blue rubber cap), make sure the timing is at 6 degrees BTDC and the idle speed is 900 rpm, then look for 0.3% to 1.2%. Altering the mixture requires drilling out a plug between the air sensor and the fuel distributor, then inserting a long metric allen wrench, but normally there'll be no reason to fool with this.

Garbage in . . .

If the computer isn't sending a proper signal to the differential pressure regulator, check the inputs. First, the coolant temperature sensor, which is of the NTC (Negative Temperature Coefficient) type that loses resistance as it gets hot. At 32 degrees F., there should be 6K ohms across its terminals, at 68 degrees 2.5K ohms, and at 176 degrees a mere 300 ohms. Next, measure oxygen sensor voltage, which should range between about 1/10 and one volt.

A good, straightforward test is to unplug the temperature sensor connector and bridge its leads with a jumper (no resistance, so the computer will think the engine's warmed up), then separate the oxygen sensor lead from the green wire, and observe the milli-amp reading at the differential pressure regulator as before. You should get 9-11 mA. Now, ground the green wire. Within 20 seconds, expect the meter to show 19-22 mA. No? Then check the wiring from the ECU to the oxygen sensor. If that's okay, the computer's probably bad, which is an unusual, but expensive, occurrence.

A complete lack of current to the differential pressure regulator won't make the car undriveable, but there may be a little roughness because the mixture will be lean. My VW Service Training contact warned me about a common cause of this electrical failure: "The 10 amp system fuse is auxiliary, mounted on the outside of the fuse and relay panel," he said. "People think it's a spare fuse and take it out to use it elsewhere. I've fixed cars that have been worked on for days simply by installing a fuse."

Won't hold

Hot restarting trouble can usually be traced to a loss of residual pressure in the injector lines that promotes percolation -- you'll have to crank for quite a while to purge all those bubbles. To check, attach a pressure gauge to the fuel line that goes to the cold start valve, run the engine, shut it off, and watch the needle. If it doesn't hold at about 38 psi for at least 10 minutes, the check valve in the pressure regulator is probably leaking.

The KE-Jet control plunger inside the fuel distributor seats on an O-ring, so a small amount of clearance between the air sensor lever and the plunger (engine off) is required or residual pressure will be lost. If you're used to other CIS's and you notice this clearance, you may jump to the unfortunate conclusion that the sensor plate is out of adjustment and get yourself in trouble. That little bit of free-play is supposed to be there. To see if it is, make sure there's pressure in the system (you can run the fuel pump by removing the pump's electrical relay and bridging panel terminals #30 and #87 for about five seconds), then try to lift the sensor plate using a magnet on its 10 mm center bolt. You should feel somewhere between just noticeable clearance and .080 in. (that's 5/64 in., or 2mm) of movement. While you're there, you might as well raise the plate through its full range to find out if it's binding, which condition can be corrected by loosening the bolt, centering the plate so a .004 in. feeler gauge can go all the way around it, and retightening the bolt (four ft. lbs. will do, and thread locking compound is a good idea here).

Coping with cold

When you encounter a hard- or no-start-while-cold problem, think about the thermo-time switch and the cold start valve. The points in the switch open at 86 degrees F., so make sure the engine's below that temperature, then remove the connector from the cold start valve, ground terminal #4 of the ignition coil, and put a test light across the connector's terminals. Run the starter and the light should glow for between one and eight seconds, then wink out.

To test the fuel delivery of the valve itself, remove the two Allen head screws that hold it to the intake manifold, detach the valve and aim its business end into a suitable container, energize the fuel pump as explained above, then connect a jumper from the positive battery post to one of the valve's terminals, and another jumper to ground (be careful not to make any sparks!). You should see a steady cone-shaped spray pattern. Disconnect the wires and no drops should appear at the valve tip for at least a minute.

If the powerplant tends to stall when cold because there's no fast idle, examine the auxiliary air regulator. With the coolant below 80 degrees F., unplug the regulator's electrical connector, start the engine and let it idle. Pinch either hose that's routed to the regulator and idle speed should decrease slightly. Let the engine reach normal operating temperature, plug the connector back in, and pinch again. You should hear no change in rpm. In cases where fast idle never kicks out, see that current is reaching the heating element in the regulator (that's what warms the bimetal and shuts off the flow of air) by using a test light across the connector terminals with the key on. No light means there's an open somewhere between the fuel pump relay and the plug.