1. Introduction

The fuel injection of petrol engines offers many advantages, such as higher performance, reduced fuel consumption, and lower emissions. These advantages are realized by direct injection of the fuel. A fuel injection system offers additional possibilities and degrees of freedom to the engine technical designer. It permits an optimal design of the air intake system of the engine. Further, it permits consideration of a multiplicity of factors which are necessary for an ideal adjustment of the output to the various operating conditions of the engine. The electronically controlled fuel injection offers special advantages regarding the control possibilities, since electronics can control the injection by measuring many engine parameters simultaneously.

The Jetronic system developed by Bosch, which was used on the 1967 VW 1600 in close co-operation with Volkswagen, is an electronically controlled gasoline fuel injection system, which is manufactured in volume and is well-proven in use. The VW 1600 equipped with Jetronic fulfills the stringent 1968 USA exhaust regulations. In the meantime, the fuel injection system was developed further and improved in different areas. It has been adapted to various four-cylinder and six cylinder engines of high specific performance. The reduction of emission of unburned exhaust constituents was reduced by refinement of the control methods and handling of the system.

2. Principle of the new Jetronic system

The Jetronic system was described already in detail. The new system is described here in entirety for completeness, whereby the features which are connected with the advancement are particularly emphasized. The principle of the new system is represented in fig. 1.

2.1 Fuel Cycle

An electric fuel pump propels the fuel and produces the injection pressure. The fuel is drawn from the tank through a filter as it flows to the pump. The filter can be arranged also in the pressurized part of the system, if the suction face of the pump is protected by a small pre-screener against rough dirt. At the end of the pressurized system an overflow pressure controller of high accuracy keeps the fuel pressure independent of the injected amount of fuel at a constant 2.0 atmospheres. The pump supplies 20 to 40 l/h, more fuel than the engine maximum injected quantity requires. The surplus fuel flows back from the pressure control valve by a second line into the tank. A third line leads directly from the pump to the tank return; it serves as the exhaust of the pump during hot starting. From the pressure pipe, branch lines lead to the individual injectors.

2.2 Air Intake System

The intake air arrives from the air cleaner (not represented in fig. 1) at a throttle valve of large diameter, feeding into the air plenum, from which to each cylinder its own intake runner leads. Form and volumes of the plenum as well as length and diameter of the intake runners have a substantial influence on the production of the engine torque as a function of engine speed.

An electromagnetically operated fuel injector is assigned to each cylinder. The fuel injectors are built depending upon design of the engine into the intake or into the cylinder head. The fuel jet is directed toward the plate of the intake valve. Moistening the wall of the intake runner by the fuel jet is avoided to a large extent. For the warming and noise isolation as well as for vacuum sealing fuel injectors are fitted with O-ring seals.

In order to achieve good response and low emissions, the fuel injectors must be attached as close as possible to the intake valves. However, due to the close proximity to the valve, during cold weather starting the fuel does not have a sufficient opportunity to mix with the combustion air. To improve cold weather starting (to – 30 C) with the new Jetronic systems, a particularly fine-spraying single solenoid valve was developed, which during cold weather starting directly squirts additional fuel behind the throttle valve into the plenum. Thus the additional fuel is very well atomized when starting and mixed with air, and the highly volatile parts evaporate on the way through the intake runners up to the cylinder.

2.3 Controlling the Amount of Fuel Using Manifold Pressure and Engine Speed

For each cylinder duty cycle, one fuel injection is needed. To reduce the requirements for electronic control, however, the injectors are combined in groups. With four-cylinder engines the cylinders are grouped by two, and with six-cylinder engines three valves are electrically parallel switched and squirt thus at the same time. The valve groupings are situated consecutively in the firing order.

The injectors are opened by current pulses, which the electronic controller supplies. The injecting pulse for the two groups of valves is determined by two control contacts built in the distributor, which are closed alternately at 180 degrees each camshaft revolution. This so-called impulse marks the beginning of the injector current pulses. For each duty cycle the amount of fuel injected is determined by the duration of the current pulses, which is calculated by the electronic controller, dependent on the state of the engine. The state of the engine is determined by sensors and transmitted to the controller in form of electrical quantities.

The amount of fuel for each injection must be related to the amount of air sucked into the cylinder. This is proportional to the absolute air pressure in the intake manifold and depends only in small measure to the engine speed in the first approximation. It offers itself to control the injection amount by the absolute intake manifold pressure with correction by the engine speed; this was carried out with the Jetronic.

In fig. 2 is the characteristic diagram for the fuel requirement per stroke of a six cylinder engine is represented, which was determined on the engine test stand. Over the engine speed <n> with the absolute manifold pressure <ps> as parameter, the injection current pulse duration <ti> was overlaid, which are proportional to the necessary injection amount for each stroke. At full load the pressure is no longer constant, due to a decreasing manifold pressure as a function of engine speed, shown by the numbering of the full load curve.

A vertical cut by the curve family at a constant engine speed shows how the fuel requirement depends on the manifold pressure; e.g. the pulse time T1 between 2.4 ms at 300 Torr, 6.0 ms at 700 Torr, and 7.3 ms at full load for an engine speed of 2000 rpm. The manifold pressure control in the electronic controller follows this dependency with large accuracy. The engine speed dependency is shown by an increase in the curve from 1000 to 5000 rpm, and a decrease in the curve above 5000 rpm.

The absolute manifold pressure controls the pulse time via the pressure sensor. Its inductance is a part of the mono-stable trigger stage of the controller which determines the basic injection pulse. The mono-stable trigger stage is activated twice for each camshaft revolution by the trigger impulses from the contact trigger points in the distributor. For each injection valve group the current is switched on at the same time. The mono-stable trigger stage switches off after a certain time, depending on the inductance of the pressure sensor coil, thereby closing the fuel injectors.

For the engine speed no additional input is necessary to the controller, since it is already present in form of the time delay between the successive trigger impulses from the contact trigger points in the distributor. For the engine speed influence on the injection duration, a voltage-dependent control signal is formed from the time delay. This control voltage influences the session of the mono-stable trigger stage according to the process required by the characteristic diagram.

2.4 Cold Starting and Automatic Warm-Up

During cold weather starting and the following warming-up phase the engine needs an enriched mixture. During starting, enrichment is accomplished by the cold start valve. During cranking, it sprays an amount of fuel from 100 to 200 cm^3/min, depending on engine size. The cold start valve is controlled by a thermal switch with a set point between 0 and + 15 C (depending on engine size). The thermal switch design can be either electronic or mechanical. The electronic thermal switch is part of the electronic controller and by the coolant temperature feeler is headed for. The mechanical bimetal thermal switch, some one additional installation place at the engine necessarily, is switched on electrically directly into the control line leading to the cold weather starting valve.

With engines that are likely to foul the spark plugs with a rich starting mixture, it is preferable to replace the thermal switch by a thermal-time switch which again is implemented with either electronic or mechanical switches. The thermal-time switch limits the duration of the operation of the cold start valve. The switch is designed so that at a coolant temperature of – 20 C, the cold start valve operates for between 5 to 20 s, depending upon motor type. With rising coolant temperature the operation time decreases, and with +20 C to + 40 C the valve does not operate.

The operation of the engine up to achieving the status, at operating temperature following to the cold weather starting, calls itself as a warming-up phase. During this operating condition the engine needs a considerable warming up enrichment. Immediately after a start with -20 C two to three times as much fuel must as in the status at operating temperature own-squirts to become depending upon motor type. The enrichment is abgeregelt during the warming-up phase with rising engine temperature constantly and disappears with achieving the operating temperature. The warming up quantity is injected also during starting. At low temperatures it is still added to the quantity hosed down by the cold weather starting valve. Above the switching temperature of the thermal switch it works during starting as start enrichment.

The enrichment is controlled over temperature sensors, which increase the session of the mono-stable trigger stage temperature-dependent. The temperature must be sensed at the engine in a place, which represents the temperatures relevant for the fuel preparation and the burn processes as well as possible. With the fuel injection system of a water-cooled engine represented in fig. 1

the warming up enrichment is controlled by the temperature sensor attached in the cooling water. With air-cooled engines the control takes place via a feeler at the cylinder head.

With the cold weather starting and with the following warm up apart from a richer air/fuel mixture also a larger amount of air in the no-load operation one needs. The additional amount of air is once necessary, in order to increase the idling speed, so that a perfect cyclic testing is achieved. Additionally the cold engine in the no-load operation must produce a substantially higher performance for the overcoming of the strongly increased friction. The added air is controlled by the throttle valve a going around bypass valve, the so-called slidegate valve. This consists of a valve, whose cross-section of the opening as a function of the engine temperature or the temperature of an electrical heating spiral is changed over a bimetal spiral or an extension off item.

2.5 Additional controls and corrections

For partial load-operate the engine the fuel will in such a way measure that the specific fuel consumption and the proportion of unburned exhaust constituents as down as possible are. With full load against it the amount of fuel is determined on the basis of the criterion of max. engine performance. As follows from fig. 2, therefore the pulse time rises between the 700-Torr-Kurve and the full load curve, related to the suction tube printing increase, more strongly than with partial load. This strong increase of the injection amount with full load, required by the characteristic diagram, is called full load enrichment. It could be achieved basically by an accordingly steeply running dependency of the inductance of the pressure probe on the suction tube printing between 700 torr and 760 torr. This procedures would have however disadvantage that with the operation of the vehicle in large heights, in which the atmospheric printing does not achieve values over 700 torr at all no full load enrichment became effective.

This disadvantage is avoided, if the full load enrichment is controlled not by the absolute suction tube printing, but by the vacuum tube pressure, i.e. by the differential pressure between suction tube printing and atmospheric pressure. With the past Jetronic system the enrichment is controlled by a push button switch, which the negative pressure in the suction tube affects. If the negative pressure in the intake manifold falls with opening the throttle cap under approximately 50 torr, then a contact in the push button switch is closed, whereby the session of the mono-stable trigger stage in the controller is increased. With the new Jetronic system this function is in the pressure probe with contained (paragraph 3,3), without indicating the disadvantage specified above.

The weight of the amount of air sucked in by the engine for each stroke, to which the appropriate amount of fuel is to be injected, depends not only on the intake manifold pressure and on the engine speed, but also on the temperature the intake air. At low outside temperatures air density is higher, so that the air/fuel mixture becomes here leaner, if the control does not consider the air temperature. Emission-controlled engines, which have a relatively lean mixture adjustment already at a temperature of +20 C, often misfire in the partial load range at outside temperatures between 0 and -20 C. To avoid this problem, a temperature sensor (fig. 1) is incorporated into the intake manifold or into the air cleaner. Accounting for the effect of air temperature increases the injection amount around 1 to 3 per cent per 10 deg. C increase.

In order to save and reduce the emission of unburned exhaust constituents for a given operating fuel cycle, while coasting, the fuel supply is completely locked off. The controller does not supply injection pulses in this operating condition, which is signaled by the throttle position switch. So that the engine does not remain being however when disengaging, the fuel shut-off position is disengaged for engine speeds between 1000 and 1500 rpm. The for this necessary number of revolutions switch is electronically executed and contained in the controller.

In order to use the advantages of the fuel shut-off position within a wide area, it is desirable to put the switching number of revolutions as deeply as possible. With engine not at operating temperature it would oppose that that the engine remains sometimes being. With the new Jetronic systems this difficulty is overcome by the fact that the switching number of revolutions depends on the temperature of the cooling water. It is situated with coolant temperatures under 0 C with approximately 1500 rpm and shifts with increasing coolant temperature on approximately 1000 rpm.

With the new Jetronic systems the throttle valve switch serves additionally as signal generator for an acceleration enrichment controlled of the throttle valve movement. For this purpose the new throttle valve switches are equipped with an additional contact record, which supplies a sequence of pulsed voltages when opening the throttle valve to the controller. These pulsed voltages cause an injecting of additional amounts of fuel during opening the throttle valve. The addition quantities are very small and hardly affect the fuel consumption.

In contrast to the carburetor an acceleration enrichment is not necessarily necessary for a fuel injection system. It brings however a set of advantages with itself. On the one hand it bridges the very small, but nevertheless available response lag of the pneumatically headed for pressure probe, so that the engine of each accelerator pedal movement follows completely delay-free. Further the acceleration enrichment enables a still leaner mixture adjustment in the partial load range without the danger of ignition misfires with accelerating, whereby a further sinking the hydrocarbon emission one ore-hurries. Finally one gets along with a fuel injection system with acceleration enrichment with a smaller mixture enrichment with cold engine, whereby the emission of unburned exhaust constituents and the danger of fouling the spark plugs are lowered.

The opening and closing time of the electromagnetic fuel injectors depend on the operation voltage. With increasing operating voltage the opening and closing time decreases, so that at the same duration of the current pulse the fuel injector is opened longer and thus a larger amount of fuel is sprayed. Since a stabilization of supply voltage would be very complex, the influence of the voltage on the injection amount is compensated by a dependency moving in opposite directions of the pulse time on the voltage in the electronic controller.

The fuel pump is switched on not over the ignition switch, but by the pump controlling device in the electronic controller. The pump controlling device prevents an operation of the pump with switched on ignition, as long as the engine is. Thus in the case one is not avoided due to pollution quite closely to close fuel injector a penetration of fuel into the cylinder concerned.

3.1 Electronic Control Unit

The electronic controller is structured in the conventional technique of printed circuits. It contains depending upon execution 250 to 300 elements, of it about 30 transistors and 40 diodes. The main printed circuit board covers those circuit sections, which are independent of the respective motor type and which differ if necessary by different alignment restatuses. A small addition disk contains the circuits adapted particularly to the engine.

Fig. 3 shows the controller with removed cover, more cut addition-flatly and partly cut cooling fins. The two power transistors of the output stages and a power diode are installed on a vertically arranged cooling angle. The partly cut radiator box contains of high speed resistances, which are switched into series with the fuel injectors, in order to obtain a faster current rise. The wiring harness, which connects the controller with the remaining electrical units, ends to 25 in a poligen multiple plug, which is put on a counterpart connected firmly with the printed circuit board. After loosening of a strain relief clip a plastic slide, which forms a side panel of the controller, can be taken off.

Fig. 5 shows the block diagram of the controller and the electromechanical units connected with it. The circuit sections of the main control and their connections are strengthened drawn. The trigger impulses of the distributors of arranged release contacts arrive at the control multivibrator and bring these in position ON. They arrive further at the number of revolutions correction, which for its part influences the session control multivibrator. Finally those head for trigger impulse still circuit logic, a bistabile level, which passes the control pulses on produced by the control multivibrator either to one or to the other output stage, whereby in the change the groups of valves 1 and 2 are excited in each case. The duration of the impulses produced by the control multivibrator essentially depends on the inductance of the pressure probe; further it is influenced by the temperature sensor I over a resistance network, in order to consider the temperature of the intake air.

The number of revolutions switch for fuel shut-off position receives the number of revolutions information from the impulse clearing in the distributor. The idle position of the throttle valve is signaled by the spare contact of the throttle valve owner. The temperature dependence of the switching number of revolutions is controlled by the temperature sensor II (cooling water). The number of revolutions switch suppresses the impulses produced by the control multivibrator with closed throttle valve, if the engine speed is situated above the switching number of revolutions.

The second contact record in the throttle valve switch supplies when opening the throttle valve trigger impulses to the transition enrichment, which control pulse of 2 to 3 ms produces duration. These additional control pulses arrive over circuit logic depending upon position of this bistabile step over one of the two output stages at one of the two groups of valves.

The pump controlling device switches the fuel pump on, if either while starting of the starter switch a signal comes or if the engine speed is situated above a border number of revolutions from 100 to 300 rpm. The number of revolutions information is won by an integrating circuit from the trigger impulses of the distributor.

The cold weather starting valve is excited, if during starting a signal of the starter switch is present and if the temperature of the cooling water is situated at the same time below the switching temperature of the thermal relay. The thermal relay can be replaced by a thermal time switch. This consists of an electronic timer, which is brought at the beginning of the starting procedure by the signal by the starter switch in position ON and whose session is controlled by the temperature sensor II. The temperature sensor II (cooling water) causes over the warming up enrichment, resistance and diode network, a temperature-dependent enlargement of the duration of the impulses control multivibrator.

3.2 Contact Trigger Points

The contact trigger points consist of two switches, which are built in the lower part of the distributor housing. The switches are operated by a cam on the distributor shaft. The contact material and current load of the switches are selected for maintenance-free operation over the entire life span of the distributor. The overall height of the distributor is increased by the contact trigger points by about 5 to 10 mm.

3.3 Pressure Sensor

The pressure sensor is represented schematically in fig. 6. It consists of two aneroid cells which shift the armature of a coil, changing its inductance. The coil serves a component of the mono-stable control multivibrator in the electronic controller, which determines the duration of the current pulses. The manifold pressure is converted directly into the appropriate pulse time. The measuring system is built in a die-cast metal housing, which is connected by a hose to the manifold pressure of the engine. The pressure probe of the new Jetronic system contains an additional metal diaphragm, which shifts (in the picture) left stocks of the diaphragm boxes dependent on the negative pressure.

The coil is enclosed by an ice set in form of a double u, which indicates two drillings for the adjustable anchor. The anchor moves without friction, held by two leaf springs. Its magnetically effective section consists of a cylinder, ending in a small cone. Air gap of the iron set (on the right in the picture) is constant; the other one changes, if the anchor with its cone dives more or less far into the left drilling of the core.

The left-most chamber, which is formed by the metal diaphragm and the housing bottom, is vented to the atmosphere; in the rest of pressure sensor the manifold pressure of the engine prevails. Under part-load, the diaphragm is pressed against the part-load stop, due to the high negative pressure overcoming the pre-loading of the coil spring (on the right in the picture). With increasing load, i.e. with increasing manifold pressure, the aneroid cells are squeezed together, which moves the armature further into the core, increasing the inductance and extending the pulse time so that the injection amount is increased. During the transition to the full-load, if the negative pressure differential becomes smaller than 100 Torr, the pre-loading of the coil spring outweighs the pressure against the diaphragm, and the diaphragm moves to the left and contacts the full-load stop when the pressure differential drops to 50 Torr. This movement is superimposed on the movement of the diaphragm boxes and causes an additional movement of the armature, lengthening the pulse time.

In order to prevent a vibration stimulation of the measuring system with the pulsating pressure in the manifold of the engine, a throttle drilling of small cross section is attached for the absorption at the pipe union for the pressure oil hose. So that nevertheless the engine responds when rapid opening the throttle valve, when rapid rising of the manifold pressure a valve of large cross section is automatically opened.

3.4 Throttle Valve Switch

Fig. 7 shows the throttle valve switch in the plan view with cut cover. The throttle idle micro-switch of forming contacts a by the lever c connected rigidly with the throttle valve wave with closed throttle valve are operated. The disk b is concentrically arranged to the hub of the lever c. One wave feather/spring between the disk and the housing bottom provides for a defined friction opposite the housing. When opening the throttle valve (in the picture against the clockwise direction) the disk b is held by the friction first, the lever c moves against the contact record d drags switch and closes this. After a small overflow route for the contact record dashed a drawn driver of the lever c carries the disk forward b. Thus the two slide with the disk b firmly connected pickup shoe on the contact plate e. With closed contact record d the teeth of the two edge contacts in the change are connected electrically with the continuous pickup shoe path. Switching a comb on the other hand has the advantage in relation to easy switching on and off that during uncertain contacting or bouncing the contact no additional enrichment impulses in the controller are released.

3.5 Temperature Sensors

The temperature sensors are temperature-dependent resistors (NTC resistors), mounted in injected plastic into hollow screw mountings. Fig. 4 shows two different versions of the temperature sensors.

3.6 Fuel Injector

The fuel injector is represented in fig. 8 on average. It essentially consists of a valve body and the nozzle needle with put armature. The valve body contains on the right of the magnet coil and on the left of the guidance for the nozzle needle. If the magnet coil is dead, then the nozzle needle is pressed by a coil spring on its sealing seat, which is at the left end of the valve. If the magnet is energized, then the nozzle needle is taken off around approximately 0.15 mm from its seat, and the fuel can withdraw by a calibrated annular gap. The front end of the nozzle needle contains a spraying tap with polished section for atomization the fuel. The closing time of the valve is approximately 1 ms.

3.7 Cold Start Valve

Against the cold weather starting valve no high demands are made regarding the suit and declivity time. But to an extremely fine atomization of the fuel great importance is attached. Therefore a single solenoid valve particularly suitable for these purposes was developed, which is represented in fig. 9 on average. The mobile anchor of the magnetic circuit is pressed in a state of rest by the coil spring with that you doing approximately the valve seat and locks this off. With tightened anchor the valve seat is released. The fuel moves by laterally the angeflachten anchor and arrives by a crosswise and a longitudinal drilling of the section of the magnetic circuit designed as nozzle holders at the guide vane. In the guide vane the fuel by two tangential intake drillings in rotation shift and leaves the nozzle finely sputtered on the coat of a cone of approximately + / - 45 degrees.

3.8 Auxiliary Air Regulator

The auxiliary air valve for the VW 1600 is a rotary valve operated by a bimetal spiral, immersed in the engine oil in the crank case. For water-cooled engines a new auxiliary air valve was developed, shown in fig. 10. A grow-filled expansion item shifts a pilot piston in a sleeve with rising coolant temperature against a strong reset spring. The control window at the air inlet is reduced with rising temperature and is completely closed with 60 to 70 C coolant temperature. Form of the control window is selected in such a way the cross-section of the opening as a function of the temperature that with each start temperature the desired idling speed adjusts.

The addition air slidegate valve can be flanged on to the cylinder head or at the connecting piececonnecting piece connecting pieces of the cooling water cycle, whereby the expansion item is flowed around by the cooling water. With cultivation difficulties at the engine the possibility exists of assembling the addition air slidegate valve with a separate housing which is over hose lines with the cooling water cycle in connection.

3.9 Fuel Pump

As fuel pump a role vane pump is used, which is propelled by a permanent-moved electric motor. Depending upon fuel requirement of the combustion engine pumps with mechanical handling capacities of 60 are l/h, to 90 l/h and 120 l/h at the disposal. The electrically taken up performance is situated dependent on the mechanical handling capacity between 30 and 50 Watts.

The actual pump consists of a cylindrical cavity, in which a rotary runner disk contains five pocket-clamp recesses at its scope, in which a metal role is in each case. The roles are pressed with the rotation of the runner disk by the centrifugal energy outward and work as circulating seal. A pump effect comes off thereby that by the circulating sealing roles at the fuel entrance a periodically becoming larger and at the fuel withdrawal a periodically becoming smaller volume develops.

During a first execution of the fuel pump electric motor and pump were separate units, which were connected by a flexible clutch. In the meantime a new version was developed and taken up to the production, with which the runner disk of the pump sits on the wave of the electric motor. The pump is not sealed against the electric motor, the electric motor is filled with fuel. The new pump (fig. 4) is substantially shorter and consists of few sections.

3.10 Fuel Pressure Regulator

The pressure control valve consists of a two-piece metal housing, into which a diaphragm is rolled in. The fuel occurs one or more radial connecting pieces by and presses on the diaphragm, which is loaded with a linked up coil spring on the opposite side. The diaphragm releases the opening with the exceeding of the adjusted printing to an axially arranged bypass. The fuel printing is stopped by adjusting the pre-loading of the coil spring.

3.11 Fuel Filter

The filter contains a paper element with a average pore size of 20 micrometers. It is appropriate and as a whole is changed for a run time of approximately 20,000 km. Depending upon mechanical handling capacity of the pump different sizes are available. For an installation on the suction face of the pump a filter with plastic housing is used. With printing-lateral installation the housing consists of Aluminum.

4. Development tendencies

4.1 Advancement of the Jetronic System

With that managing described fuel injection system a technical status was achieved, which leaves desires open regarding the request existing from the engine page hardly still. The system enters and processes all substantial which are applicable measured variables, which indicate the various operating conditions of an engine, and them could consider still further measured variables if necessary. During the advancement must be preferably aimed at therefore the improvement and simplification of the fuel injection system and fewer the modification of interaction between engine and injection system.

On the electronic controller as of the scope and from the cost page it appears most important unit of the fuel injection system that by introduction of integrated circuits a number of important advantages can be obtained. Apart from a noticeable decrease of the costs, a smaller size and smaller self-heating is to be counted on a still higher reliability.

The Jetronic system was conceived as building block principle. It consists of a set of units, whose installation at the engine or in the vehicle can be selected to a large extent freely. Hence it follows that the units are to a large extent independent in their shaping of the respective application or could be at least. After a larger number of motor types was now already equipped with Jetronic systems, extensive experiences are present, which will lead after appropriate analysis to units, which are as universally as possible usable. These universally usable units will then lead themselves with the use the Jetronic systems already drawing with a multiplicity of motor types to economic numbers of items, which will affect the costs of the systems favorably.

4.2 Fuel injection and exhaust emission control

The electronically controlled fuel injection is a substantial aid with the reduction of the concentration of unburned exhaust constituents. Mid the new Jetronic systems is usually without difficulties possible it to keep those from 1970 on in the USA valid intensified exhaust regulations. With the attempt further to lower, one states the waste gas emission regarding the still sharper regulations planned in the USA that for the degree of the decontamination from the engine certain limits are law, which cannot be influenced by the fuel injection. After the available experiences it is not generally with Jetronic systems a problem to keep the limit values for the emission of Carbon monoxide (CO), required by the legislator. On the other hand it is not in every case easily possible to lower the emission of unburned hydrocarbons (HC) sufficient far.

To the looking at clearing of problems the process in principle of the concentrations of Carbon monoxide (CO), the nitrogen oxides (NOx) and the unburned hydrocarbons (HC) over the aerodynamic force material relation or the air number is represented lambda in fig. 11. The curves apply to a stationary operating point in the partial load range. For a certain engine the scales for aerodynamic force material relation or air number lambda a third scale moving in opposite directions with the injection amount per stroke or the pulse time can be assigned. The inject-long permits a variation to the mixture adjustment with the selection along the abscissa.

The CO concentration decreases first with increasing air number, achieved above lambda = 1, to the stoichiometric relation, already a very low value, which is generally below 0,25 %, and maintains this value of air number rising also further. The concentration of unburned hydrocarbons indicates a narrow minimum within the range between lambda = 1.0 and lambda = 1.2 and rises with a further emaciation of the mixture again steeply, whereby the taken off line in fig. 11

represents an average value for European engines. Measurements of some large volume American eight cylinder engines resulted in rerises in the case of substantially higher air numbers (broken line). The steep re+rise is connected with burn misfires beginning, which are already caused by that to lean air/fuel mixture. The burn misfires have a jerky run of the engine to the consequence and to determine the so-called run border. This is situated like the rise of the hydrocarbon concentration dependent on the motor type with differentiate-light air numbers and depends obviously on a number of constructional features of the engine.

The amount of fuel is determined usually in such a way that the engine in the hydrocarbon minimum is operated, if still another sufficient safety margin borders to run will self-hold can. A smaller than the HC concentration occurring in the minimum cannot be achieved however by variation of the characteristics of the fuel injection system. The minimum value is determined by the parameters of the engine. Important measured variables are the combustion chamber form, the relation of surface to volumes in the compression space, the height of compression ratio, the control times of the cam shaft, the formation of the piston rings, the type of the crank case exhaust and the pre-ignition. Regarding a further decrease of the maximum admissible HC concentration in the exhaust gas it is necessary to make also with application of the fuel injection certain modifications at the engines in order to lower the level of the HC of minimum further.

A further, still more heavily weighing problem results from the limitation of the nitrogen oxide concentration in the exhaust gas, requested in the State of California of 1971. This indicates process over the air number with stationary operation of the engine in fig. 11 in principle the racks lambda. Fuel injection engines are usually operated in the partial load range in the proximity of the air number lambda = 1.1.

With this air number the concentration of the nitrogen oxides achieves approximately their maximum. An effective lowering of the concentration can be achieved by an extremely lean operation of the engine, if those does not border run yet is exceeded. First attempts at motor types with for this favorable run border with extremely lean air/fuel mixture considerable reductions of the nitrogen oxide concentration resulted in.

Here pointed out the way of a lowering of the nitrogen oxide concentration by extremely lean adjustment air/fuel mixtures presupposes that the engines are developed further mid the target to shift their run border toward to the lean mixture. Further an extremely even fuel and air distribution are necessary on the individual cylinders as well as a very precise fuel measuring. The latter prerequisites are to be fulfilled with fuel injection systems without all too large difficulties.