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Leaving Certificate Engineering prescribed topic:

“Basic principles of operation and applications of fuel injection systems in petrol-powered cars.”

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Electronic Fuel Injection

Overview

In this study, “the basic principles of operation and applications of fuel injection systems in petrol-powered cars”, we will cover the two ways in which injection systems operate.

Indirect Injection and Direct Injection

Indirect injection systems are the most common fuel systems in vehicles today, however direct injection is the newest development in petrol systems and follows on in the development from indirect injection, therefore it is very important to fully understand indirect injection systems first.

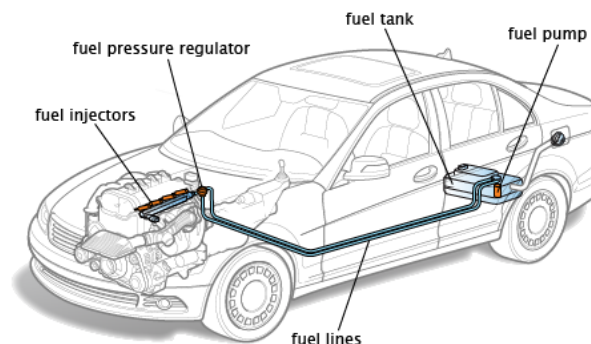
Section A

Indirect multi-point systems

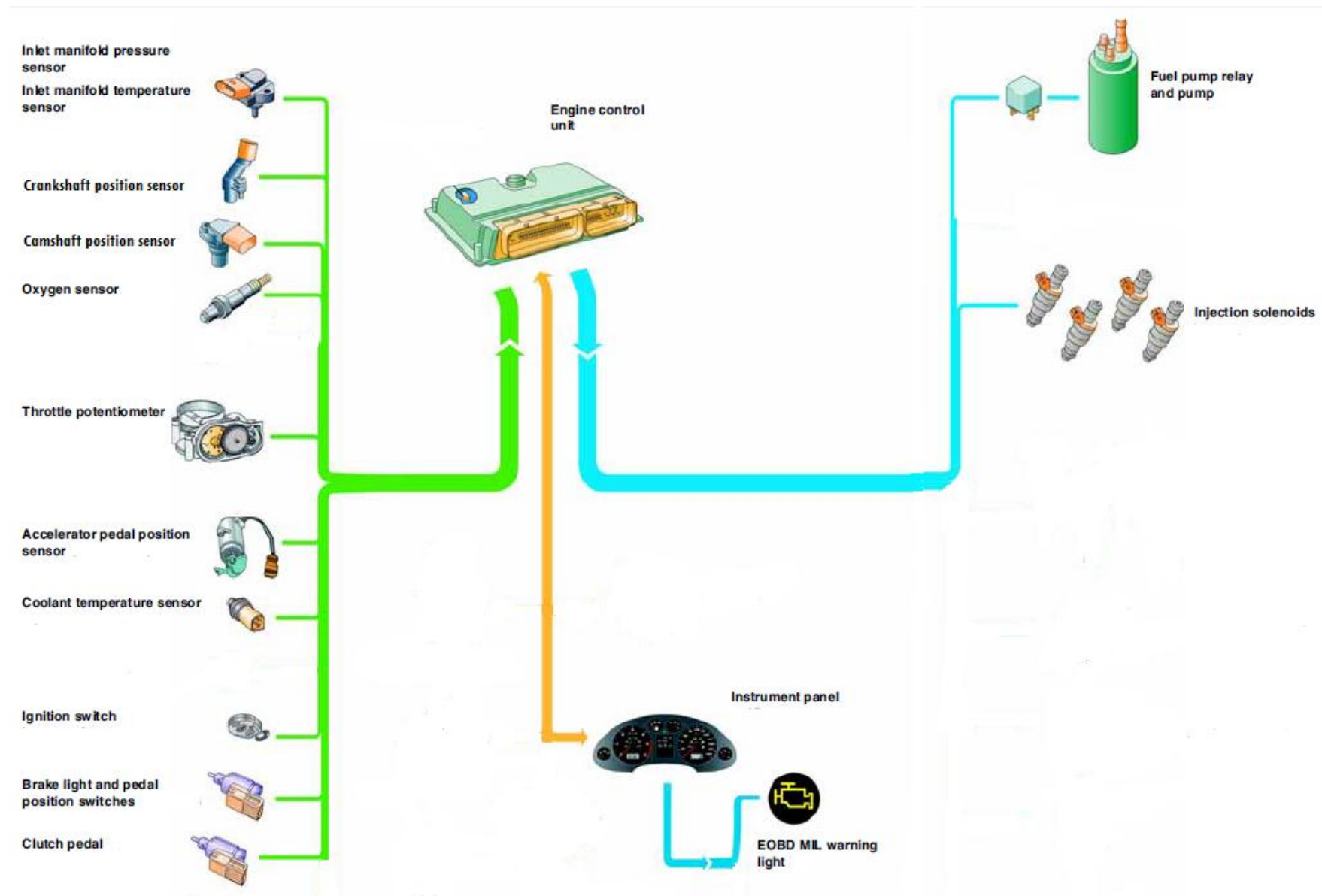
Indirect multi-point systems have electromechanically operated injectors opening for a predetermined length of time called the injector pulse width. The pulse width is determined by the engine's Electronic Control Module (ECM) and depends on the information from various engine sensors. The fuel is delivered from the tank through a filter, and a regulator controls its operating pressure. The fuel is delivered to the engine in precise quantities and is injected into the inlet manifold as the inlet valve opens and is drawn into the combustion chamber by the incoming air. The components that make up the system and their functions are as follows:

- The Manifold Absolute Pressure Sensor (MAP), this calculates the volume of air entering the cylinder.
- Lambda sensors is used calculates the amount of oxygen leaving the engine. The ECU can then determine whether the engine is getting too much fuel or too little fuel.
- Crankshaft position sensor is used to calculate the engine speed.
- Camshaft position sensor is used calculate which cylinder requires fuel injection.
- The Throttle position and Accelerator position sensors are used to calculate the driver's requirements. There is no longer a mechanical link between the accelerator and the throttle therefore the ECU must calculate how wide to open the throttle from these inputs.
- Coolant temperature sensor is used to adjust the fuel quantity when the engine is cold.
- The fuel pump delivers fuel from the tank to the fuel rail and the regulator maintains the fuel pressure on the rail under all driving conditions.

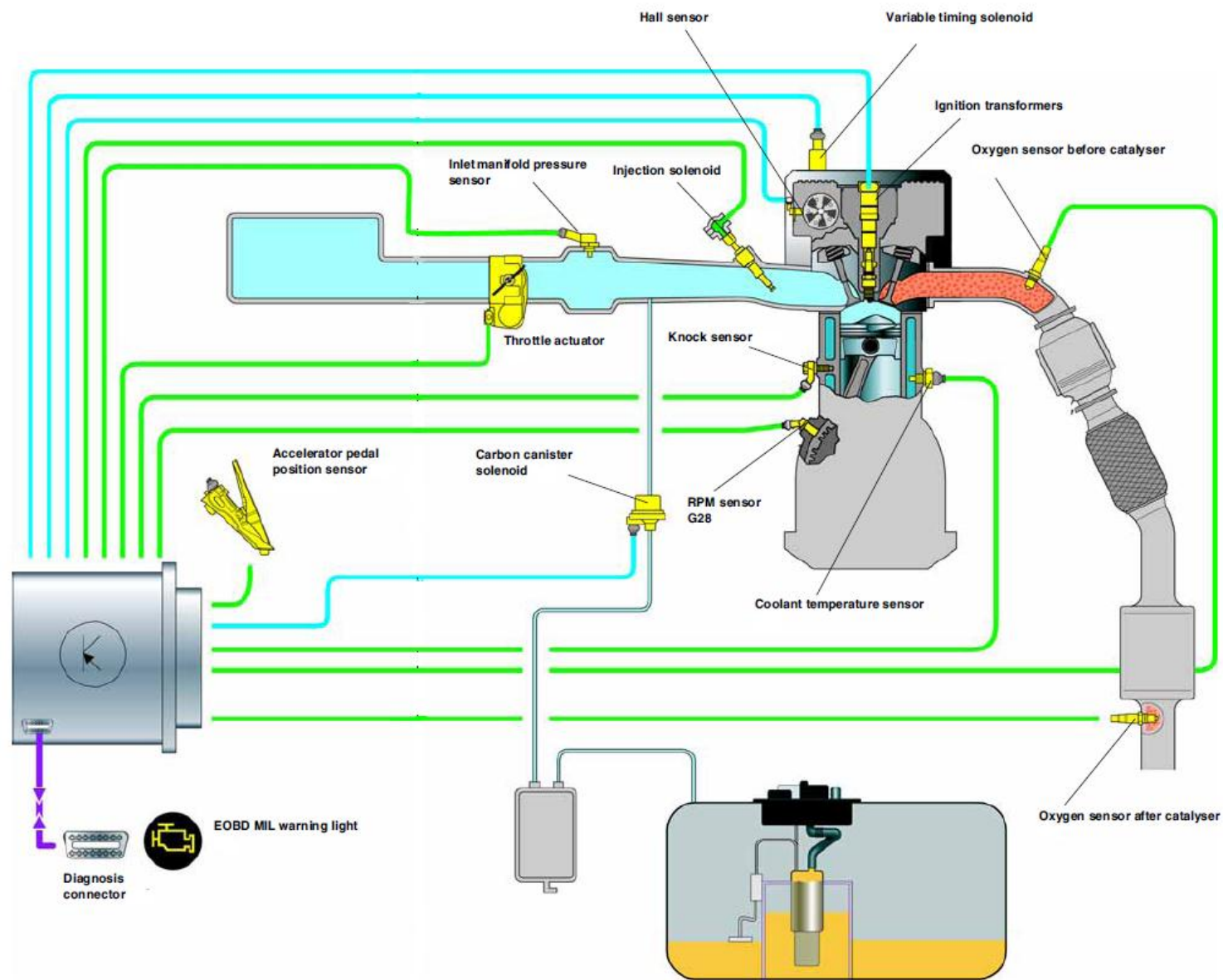
The sensors send information to the ECM which then calculates how long to open the injector for this is called injector pulse width. In the coming pages we will look in detail at these components.



Indirect injection system sensors and actuators



Indirect injection system overview



The Fuel Tank

This is the obvious place to start in any fuel system explanation. The tank is a sealed unit that allows the natural gassing of the fuel to aid delivery to the pump by slightly pressurising the system. When the filler cap is removed, pressure is heard to escape because the fuel filler caps are no longer vented.

The Fuel Pump

This type of high-pressure fuel pump (Figure 1) is called a roller cell pump, with the fuel entering the pump and being compressed by rotating cells which force it through the pump at a high pressure. The pump can produce a pressure of 8 bar with a delivery rate of approximately 4 to 5 litres per minute. Within the pump is a pressure relief valve that lifts off its seat at 8 bar to arrest the pressure if a blockage in the filter or fuel lines or elsewhere causes it to become obstructed. At the other end of the pump (output), there is a non-return valve which, when the voltage to the pump is removed, closes the return to the tank and maintains pressure within the system. The normal operating pressure within this system is approximately 2 bar, at which the current draw on the pump is 3 to 5 amps.

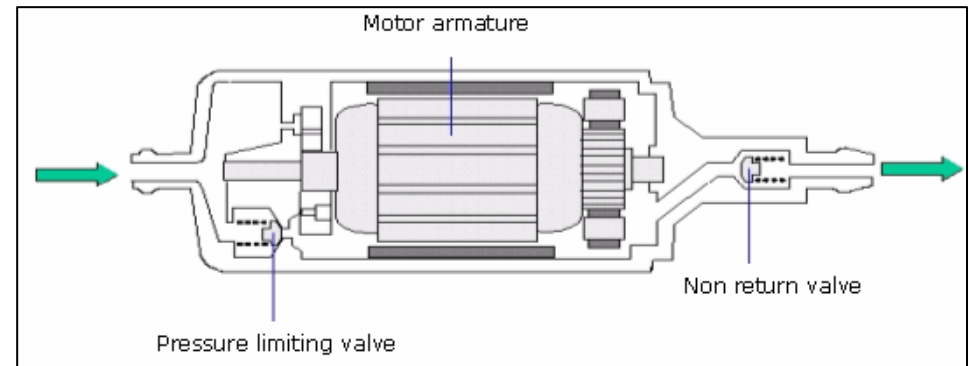


Figure 1 Fuel pump

The majority of fuel pumps fitted to today's motor vehicles are fitted within the vehicle's petrol tank and are referred to as 'submerged' fuel pumps. The pump is invariably located with the fuel sender unit and both units can sometimes be accessed through an inspection hole either in the boot floor or under the rear seat.

The advantage of the immersed pump is that it reduces the noise produced by the motor and the pump being immersed in the fuel keeps it cool. The pump is supplied with a 12V battery supply and is controlled by a fuel pump relay that is switched by the ECU. For quicker starting, the fuel pump may run on some models when the driver's door opens and when the fuel pressure is low in the system. For safety reasons if the vehicle is in an accident the power supply will be cut to the fuel pump. This can be done by an impact switch, which has to be reset, or through the air bag control unit, which usually is reset by an ignition on/off signal. These functions will vary from manufacturer to manufacturer.

The function of a fuel regulator

An electric fuel pump delivers the fuel and generates the injection pressure, which for manifold injection is typically about 3 to 4 bar. The function of the fuel regulator is to maintain fuel rail pressure. When engine speed is low there is less fuel injected into each cylinder so pressure in the rail increases. When engine speed is high there is more fuel injected into each cylinder so pressure in the rail decreases. The ECM need rail pressure to remain constant to be able to calculate how long to open the injectors for (pulses width).

System with fuel return

The fuel is drawn from the fuel tank (Figure 2) and passes through the fuel filter in to a high-pressure line, from where it flows to the engine-mounted fuel rail (7). The rail supplies the fuel to the fuel injectors (6). A mechanical pressure regulator (5) mounted on the rail keeps the differential pressure between the fuel injectors and the intake manifold constant, regardless of the absolute intake manifold pressure, i.e., the engine load. The pressure regulator can do this as it is controlled by the inlet manifold vacuum, the greater the vacuum the more fuel the regulator allows to escape back to the fuel tank. The excess fuel heated in the engine compartment causes the fuel temperature in the tank to rise. Fuel vapours are formed in the tank as a function of fuel temperature. Ensuring adherence to environmental protection regulations, the vapours are routed through a tank ventilation system for intermediate storage in a carbon canister until they can be returned through the intake manifold for combustion in the engine (evaporative emissions control system).

Fuel regulator vacuum controlled system with fuel return

1. Fuel tank
2. Electric fuel pump
3. Fuel filter
4. High-pressure line
5. Pressure regulator controlled by inlet manifold vacuum
6. Fuel injectors
7. Fuel rail
8. Return line

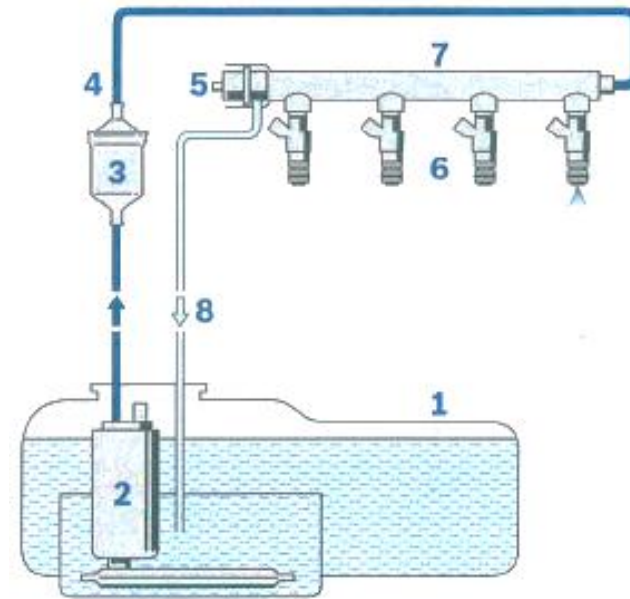


Figure 2 Fuel regulator vacuum controlled system with fuel return

Demand-controlled Electronic Returnless Fuel System

This version has all the required components fitted within the one unit of the submersible fuel pump. It contains a small particle filter (in addition to the strainer), pump, electronic pressure regulator, fuel level sensor and a sound isolation system. The electronic pressure regulator allows the pressure to be increased under acceleration conditions, and the pump's output can be adjusted to suit the engine's fuel demand. This prolongs the pump's life as it is no longer providing a larger than required output delivery.

The Electronic Control Module (ECM) supplies the required pressure information, while the fuel pump's output signal is supplied in the form of a digital square wave. Altering the square wave's duty cycle affects the pump's delivery output.

To compensate for the changing viscosity of the fuel with changing fuel temperature, a fuel rail temperature sensor is installed. A pulsation damper may also be fitted ahead of or inside the fuel rail.

Fuel regulator demand controlled system

- 1 Suction jet pump for tank filling
- 2 Electric fuel pump with fuel filter
- 3 Pressure-relief valve and pressure sensor
- 4 Control module for controlling electric fuel pump
- 5 High-pressure line
- 6 Fuel rail
- 7 Fuel injectors

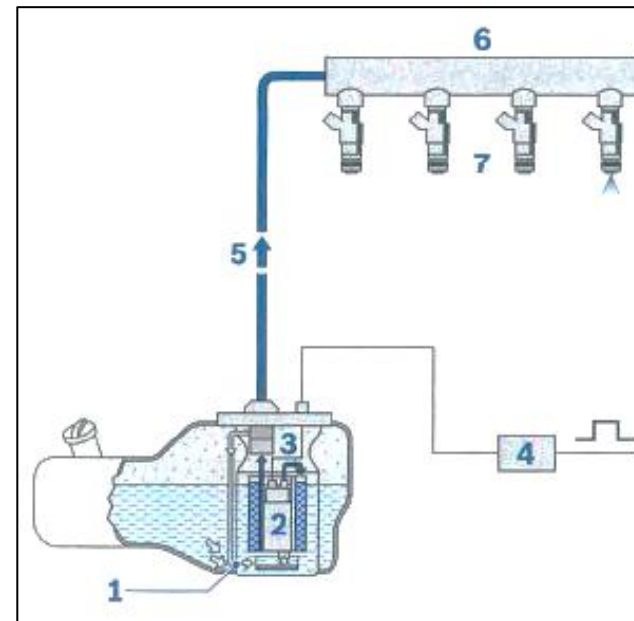


Figure 3 Fuel regulator demand controlled system

Injectors

The injector is an electromechanical device, which is fed by a 12 volt supply from the ECM.

The injector consists of a solenoid operated valve which is held in the closed position by a spring until the earth circuit is completed by the ECM. When the electromagnetic field lifts the needle off its seat, fuel is delivered to the engine. The total lift on the needle is approximately 0.15 mm and has a reaction time around 1 millisecond.

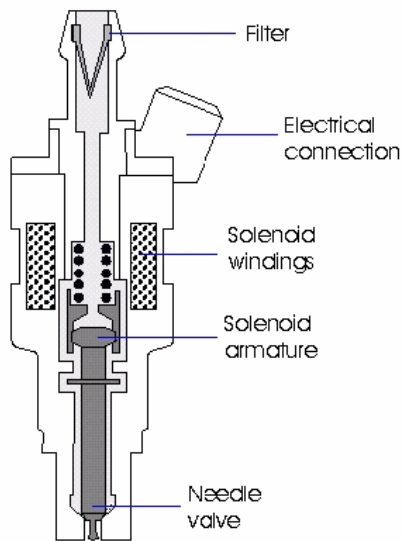


Figure 4 Cross section of an electronic fuel injector.

The injector is supplied with fuel from a common fuel rail. The injector pulse width depends on the input signals seen by the ECM from its various engine sensors, and varies to compensate for cold engine starting and warm-up periods, the initial wide pulse getting narrower as the engine warms to operating temperature. The pulse width also expands under acceleration and contracts under light load conditions.

The injector has constant voltage supply while the engine is running and the earth path is switched via the ECM. An example of a typical waveform is shown below in Figure 5.

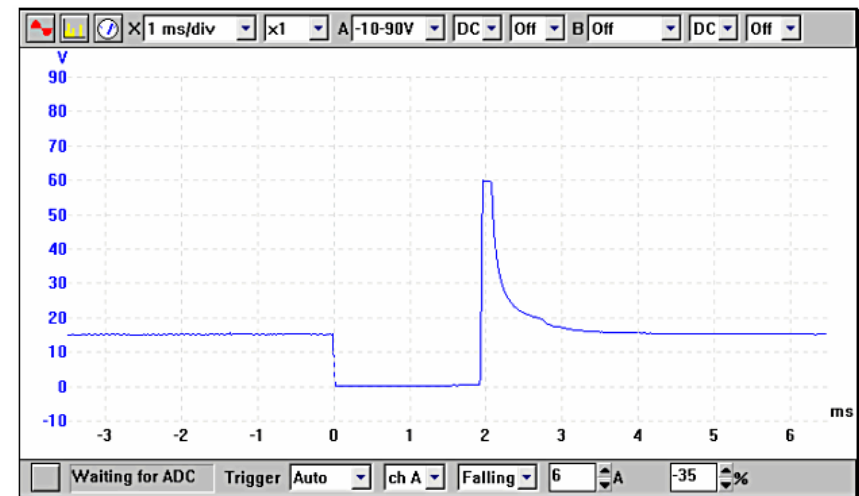


Figure 5 Injector voltage waveform

Each injector receives just 1 injection pulse per cycle, timed to coincide with the opening of the inlet valve. As a very rough guide the injector pulse widths

for an engine at normal operating temperature at idle speed are around 2.5 ms .

An electromechanical injector of course takes a short time to react, as it requires a level of magnetism to build before the pintle is lifted off its seat. This time is called the 'solenoid reaction time'. This delay is important to monitor and can sometimes occupy a third of the total pulse width. A good example of the delay in opening can be seen in the example waveform shown below in Figure 6.

The waveform is 'split' into two clearly defined areas. The first part of the waveform is responsible for the electromagnetic force lifting the pintle, in this example taking approximately 0.6ms. At this point the current can be seen to level off before rising again as the pintle is held open. With this level off and it can be seen that the amount of time that the injector is held open is not necessarily the same as the time measured. It is not however possible to calculate the time taken for the injector's spring to fully close the injector and cut off the fuel flow.

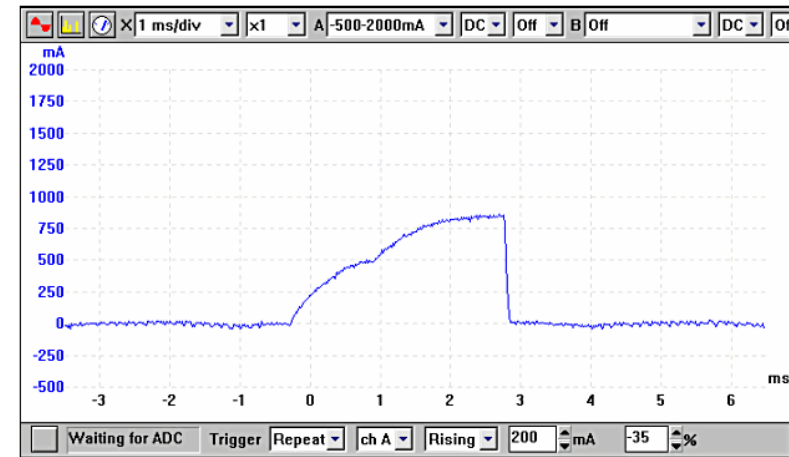


Figure 6 Injector current waveform

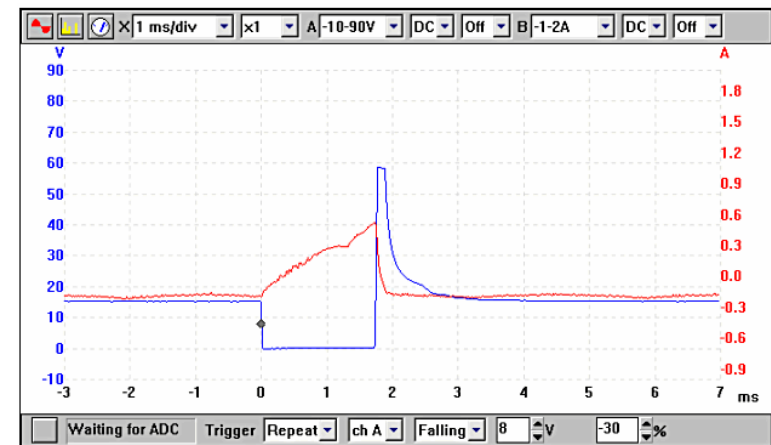


Figure 7 Injector current and voltage waveform

Sensors

Map Sensor

The Manifold Absolute Pressure Sensor or MAP is located in the intake manifold. This sensor is used to measure manifold pressure, which informs the ECU of the engine load, this information is needed to work out how much fuel to inject. In order to work out the air mass the ECU also needs to know the air temperature and the engine speed:

Lambda sensors

The exhaust gas oxygen sensor (EGO or O_2), or lambda sensor, is the key sensor in the engine fuel control feedback loop. The computer uses the O_2 sensor's input to balance the fuel mixture, leaning the mixture when the sensor reads rich and richening the mixture when the sensor reads lean.

Lambda sensors produce a voltage signal that varies with the amount of unburned oxygen in the exhaust. An oxygen sensor is essentially a battery that generates its own voltage. When hot (at least 250°C), the zirconium dioxide element in the sensor's tip produces a voltage that varies according to the amount of oxygen in the exhaust compared to the ambient oxygen level in the outside air. The greater the difference, the higher the sensor's output voltage.

Sensor output ranges from 0.2 Volts (lean) to 0.8 Volts (rich). A perfectly balanced or "stoichiometric" fuel mixture of 14.7 parts of air to 1 part of fuel gives an average reading of around 0.45 Volts.

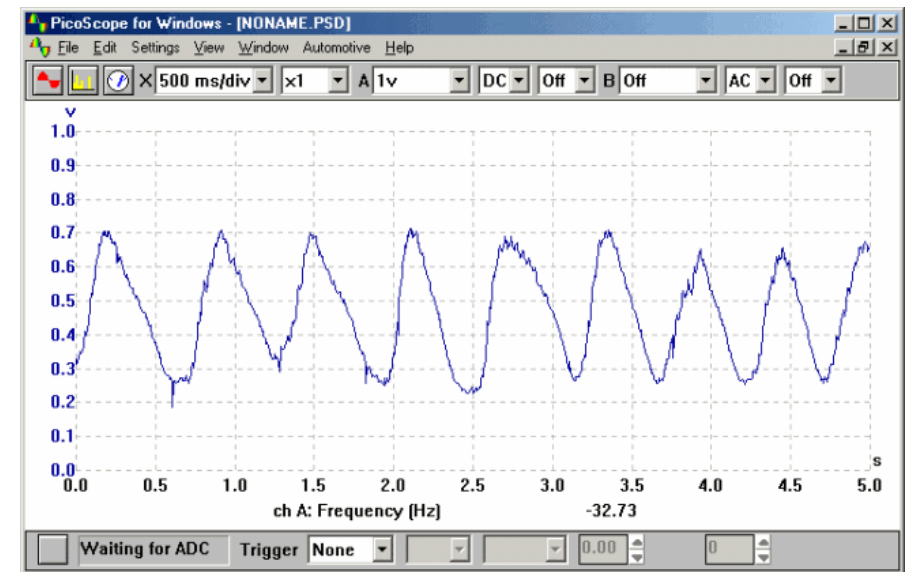


Figure 8 O_2 Sensor wave form

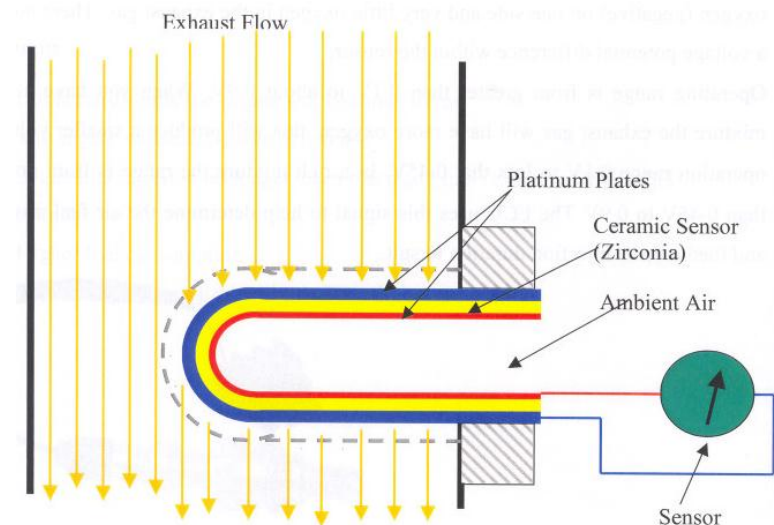


Figure 9 O_2 Sensor

Crankshaft Signals

Operation

A toothed wheel passes the magnet and windings located in the inductive sensor. The magnetic field around the windings is cut by the teeth as the trigger wheel passes the sensor. This induces an A/C signal in the windings. This A/C voltage is used to inform the ECU of engine speed and Top Dead Centre (TDC) for cylinder number 1 and 4.

The Voltage signal can be as little as 2-3 volts at idle and 50 volts at higher speeds. The gap between the sensor and trigger wheel has a large bearing on the signal. The magnetic strength also affects the signal strength .



Figure 11 Crankshaft position sensor and the reluctor teeth

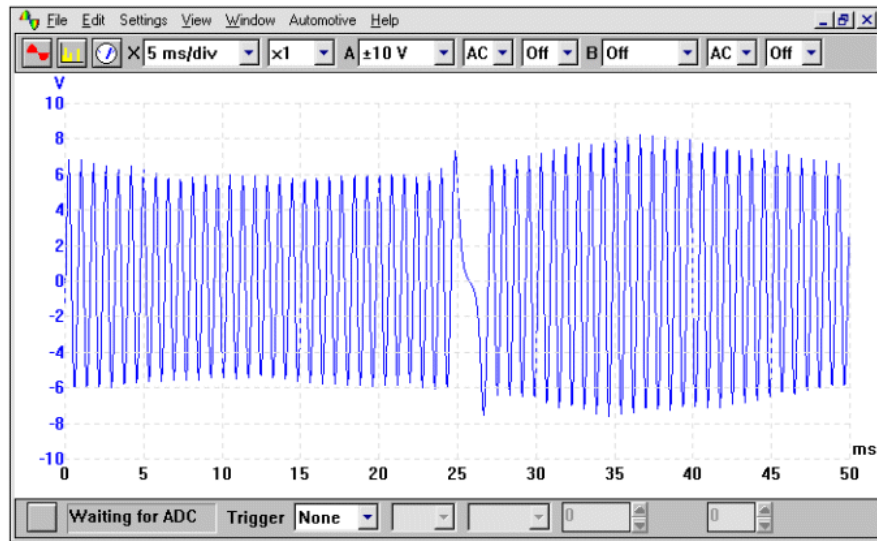


Figure 10 Inductive crankshaft sensor waveform.

Hall Sensor

This is a simple digital on/off switch; it produces a square wave on/off signal. The sensor is made up of a semiconductor or Hall IC chip. When the hall chip is exposed to magnetic lines of force, it produces a signal voltage. When the lines of magnetic force are not acting on the Hall IC chip, the voltage is zero.

Operation

The operation is similar to the inductive sensor. The rotating crankshaft interrupts the Hall IC voltage generating a square wave signal. The ECU then processes this information to work out engine speed and TDC of cylinder number 1 and 4.

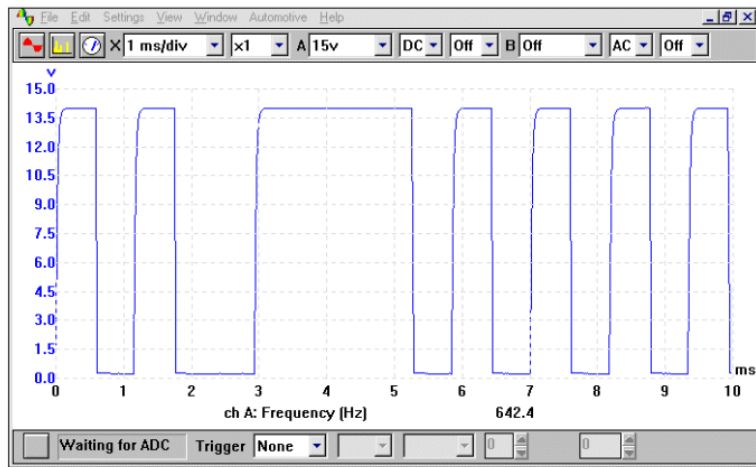


Figure 12 Hall crankshaft sensor waveform

Camshaft Position Sensor Inductive

The Camshaft sensor can be an inductive type sensor (AC sine wave) or a Hall Effect producing square wave on/off signal and is exactly the same as the crankshaft sensor explained earlier.

Each tooth produces a pulse signal, and as the camshaft speeds up more pulses are produced; the ECU determines the speed of the shaft by the number of pulses in one second. The signal is used for quicker cylinder 1 recognition. When the ECU receives a signal from the camshaft sender and the reference mark from the crankshaft simultaneously it knows that it is now on compression in cylinder number 1. It then counts the number of teeth on the crankshaft as each tooth represents a number of degrees of crankshaft

rotation and from this information the ECU can calculate the position of each piston.

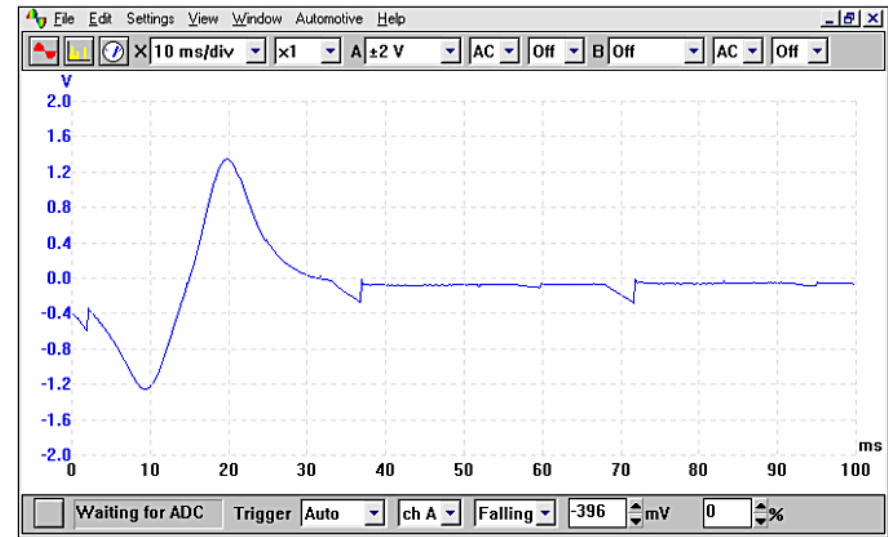


Figure 13 Inductive Camshaft Position Sensor waveform

Throttle Position Sensor

The throttle position sensor is mounted on the throttle body. It converts throttle valve movement into a voltage signal and as the throttle opens and closes the voltage increases/decreases. The sensor is a potentiometer, which is an arm that moves along a copper track varying the input voltage. The sensor is supplied with 5 volts. At idle the voltage can be between 0.5V to 1V, this will indicate idle state and the control unit will adapt idle conditions. Wide-open throttle will vary between 3.8V to 4.7V, this will indicate full load situation to the control unit.

Two readings are used in some throttle bodies potentiometers. This is for safety reasons. In order for the ECU to identify each different signal the signals are inversed. This is a closed loop system, since it sends feedback information on the position of the throttle butterfly.

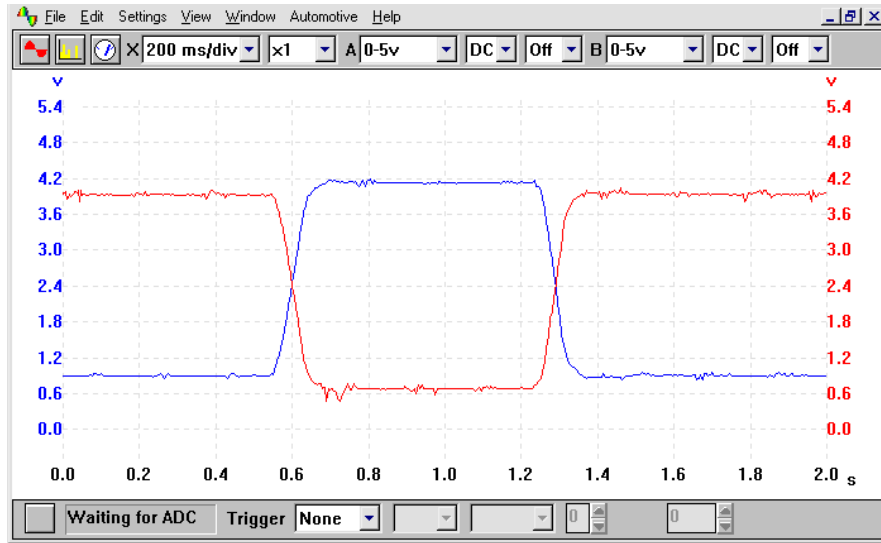


Figure 14 Throttle position sensor waveform

The waveform shown in the example trace shows the throttle moving from idle to WOT (Wide Open Throttle) and back once again to idle. The blue trace shows a conventional rising voltage as the throttle butterfly is opened, while the red trace is inverted. The combined signals allow the ECM to calculate a mean voltage output from the two signals allowing the throttle butterfly position to be calculated with greater accuracy.

The Accelerator position sensor

The Accelerator pedal has two potentiometers attached to it, achieving the accuracy required from the pedal's movement. The resistance 'felt' when the pedal is depressed is designed to give the same feel as a conventional throttle.

The waveform shown in figure 15 shows the throttle moving from idle to WOT (Wide Open Throttle) and back once again to idle. In the example, the blue trace shows a conventional increasing voltage as the pedal is depressed, while the red trace operates over a lower voltage. Combined signals allow the ECM to calculate a mean voltage output from the two signals. This allows the pedal position to be calculated with greater accuracy than when only a single voltage output is taken into consideration.

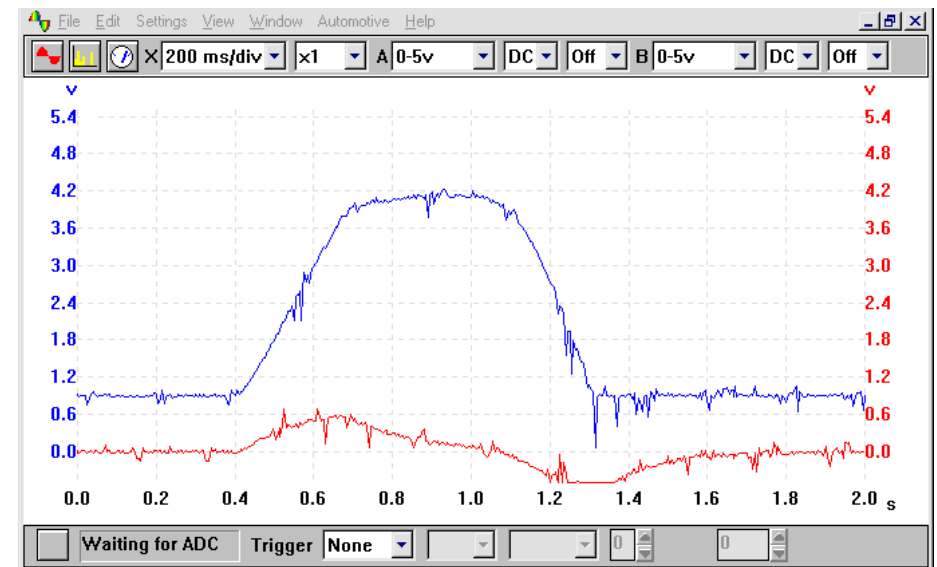


Figure 15 Accelerator position sensor waveform

Coolant Temperature Sensor

The coolant temperature sensor is a device that reports the engine's temperature back to the ECM. It is this signal that determines the engine's warm-up enrichment and its fast idle speed.

The Coolant Temperature Sensor (CTS) is a two-wire device with a voltage supply of approximately 5 volts. The sensor itself has the ability to alter its resistance with engine temperature change. The majority of sensors have a Negative Temperature Coefficient (NTC), which results in the resistance of the component decreasing as the temperature increases. The resistance change therefore alters the voltage seen at the sensor and can be monitored for any discrepancies across its operational range, figure 16.

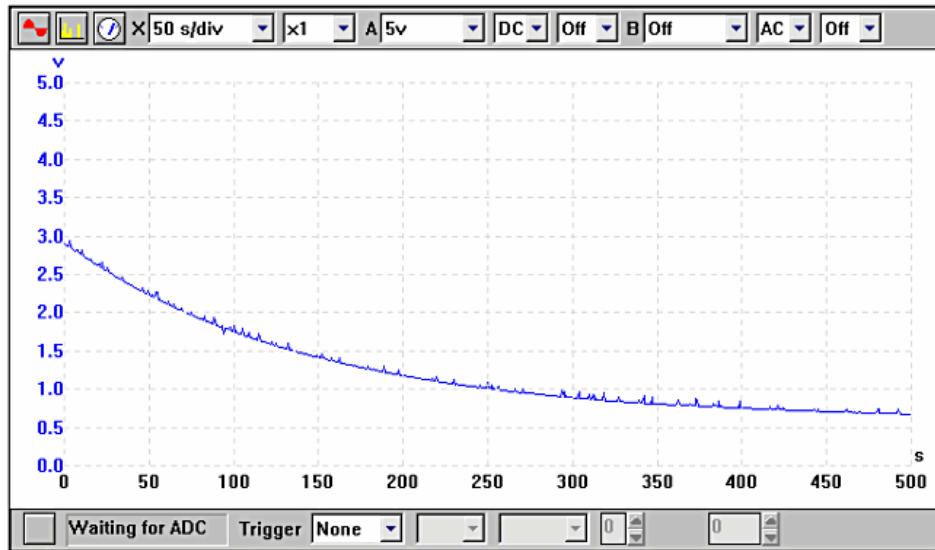


Figure 16 Coolant temperature sensor waveform

Section B

Direct injection

It is claimed that direct injection, when compared with an equivalent engine with indirect injection, provides a decrease in fuel consumption in the region of 15% to 20%, while engine power is slightly improved.

One other benefit is that direct injection systems require very rapid vaporisation of the petrol to enable it to mix quickly with the air. This rapid vaporisation is achieved through the use of high fuel pressures and a special injector nozzle design. Importantly, when a liquid vaporises, it has the effect of drawing heat from the surrounding air, i.e. it cools the surrounding air. Therefore, when fuel is injected into the cylinder, the vaporisation process reduces the temperature of the air in the cylinder, reducing the potential for combustion knock (which can occur if temperatures are too high).

This reduced tendency for combustion knock enables higher compression ratios of around 12:1 to be used (which would otherwise raise cylinder temperatures and cause combustion knock). Thus combustion efficiency is improved, giving more power as well as improved fuel consumption and emissions. In addition, the cooling effect on the air in the cylinder causes the air to become denser; the greater the air density or mass within the cylinder, the greater the power produced.

Mixture formation

Until very recently, the vast majority of petrol engines operated with the air

and petrol mixed outside the cylinder (i.e. indirect injection as discussed earlier). Although mixing can continue after the air and petrol are inside the cylinder, the initial mixing process starts in the intake manifold. With direct injection, the air is still drawn into the cylinder in the conventional manner, but the petrol is injected directly into the cylinder, so mixing occurs only within the cylinder.

One main advantage of mixing the air and petrol in the cylinder is that different mixture formation processes can be achieved using different injection timing. Essentially, there are two types of mixture formation used with direct injection systems: 'homogenous' and 'stratified'.

However it should be noted that in fact there is a 3rd type, the transition from stratified to homogenous and this is called 'homogenous lean'.

Homogenous mixture formation

A homogenous mixture is one where the fuel mixes with the air in such a way that the mix is uniform or unvarying throughout the whole volume of air/petrol mix (Figure 17). This means that the whole volume of mixture will have the same air:fuel ratio (no weak or rich pockets of mixture). Therefore, when ignition occurs, all of the mixture will ignite and burn (combust) with equal efficiency and the flame created by initial combustion will therefore spread through the whole mixture (flame prorogation).

In general, a homogenous mixture will operate at or around the stoichiometric air:fuel ratio of 14.7 parts of air to 1 part of petrol (by weight). This is the theoretical ideal ratio which will also provide low emissions of most pollutants.

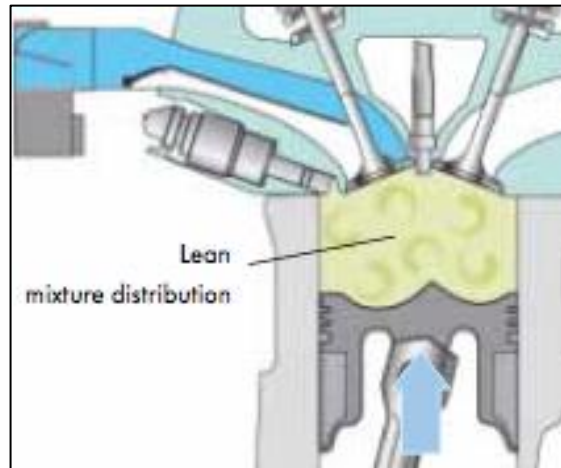


Figure 17 Homogenous mixture formation

It is possible to operate with weak mixtures of up to 20:1 (or slightly higher) before misfiring occurs. These weaker mixtures provide good economy and low emissions of most pollutants. In practice, maximum torque and power are usually achieved with slightly richer air:fuel ratios of around 12:1 but with higher emissions of some pollutants.

Since the early 1990s in Europe, emissions regulations have resulted in engines operating with air:fuel ratios that are generally close to the stoichiometric value for most operating conditions. This allowed catalytic converters to convert most of the pollutants into harmless gases. Operating at stoichiometric air:fuel ratios throughout the mixture effectively means that the mixture should be homogenous under all engine operating conditions.

Stratified mixture formation

With stratified mixture formation, a small isolated pocket or cloud of air:fuel mixture is created within the cylinder; the remainder of the air is effectively pure (Figure 18). In reality, it is possible to have a pocket of mixture with a

stoichiometric air:fuel ratio (which therefore burns normally), while the remaining air is either completely free of any petrol or has a very small amount of petrol mixed in, i.e. it is very weak.

This small pocket of mixture is directed by the airflow within the combustion chamber so that it is directly exposed to the spark plug. When the spark occurs, therefore, it is only this pocket or cloud of mixture that ignites and combusts.

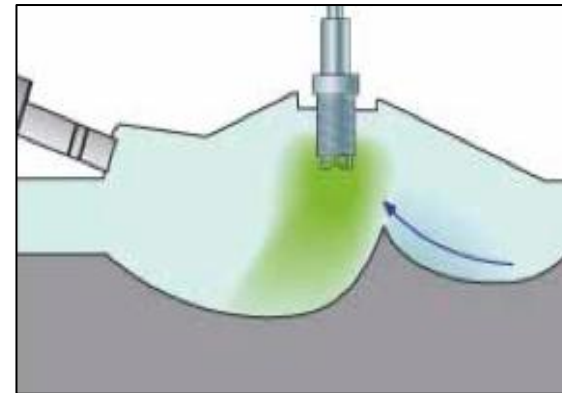


Figure 18 Stratified charge mode

The combustion of this isolated cloud of mixture is used to heat up all of the remaining air, thus producing expansion of the gas within the cylinder. If the remaining 'fresh air' does in fact contain a small quantity of petrol (forming a very weak mixture), it will combust slowly, which will in fact assist in the expansion of the gases.

It should, however, be noted that a stratified mixture formation will not produce as much energy or force within the cylinder as a fully homogenous mix of air and petrol, because only a small percentage of the full charge of air in the cylinder is used to generate the heat. With homogenous mixtures, the full charge of air is mixed with petrol, and therefore all of the mix combusts. It is

also possible to alter the air:fuel ratio for the small pocket of mixture so that this pocket also operates on a weaker mixture, but the mixture must be rich enough to achieve good combustion.

The important point to remember is that, although the small localised pocket of mixture has an air:fuel ratio that is rich enough to achieve combustion, the overall mixture within the cylinder has an excess of air because of the large volume of pure air in the rest of the cylinder. It is in fact possible to achieve a total air:fuel ratio of up to 40:1 (the total quantity of air compared with the total quantity of petrol).

The obvious advantage of stratified mixture formation is that the amount of fuel required is much smaller than for homogenous mixtures and therefore fuel consumption is much lower. However, a stratified mixture formation cannot produce the same power as a homogenous mixture, which means that stratified mixture formation is ideal for light load conditions and lower engine speeds, but, when engine speeds increase above mid-range (typically around 3000 rev/min) or increased engine torque and power are required, the engine must operate with a homogenous mixture (figure 19).

Injection timing

Most direct injection petrol engines operate with stratified and homogenous mixture formations depending on operating conditions. This is achieved by controlling the injection timing. Direct injection systems generally have two distinct timing periods, which provide different characteristics for mixing the air and fuel. One timing period is during the induction (intake) stroke; the other is

at the end of the compression stroke.

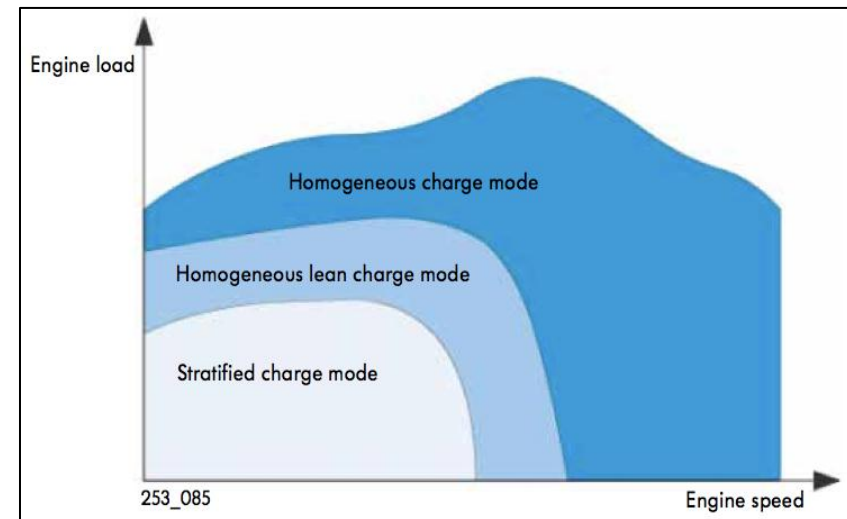


Figure 19 Torque and power requirements

Intake stroke injection timing

When petrol is injected during the intake stroke (while the air is being drawn into the cylinder), the fuel will mix with all of the air in the cylinder, resulting in complete mixing or homogenous mixture formation. Note that the intake ports can be designed to create swirl or controlled turbulence of the air entering the cylinder, which assists in mixing the petrol with the air. The mixture is typically at or close to the stoichiometric air:fuel ratio, thus enabling good power to be produced with reasonably low emission of pollutants. The high fuel injection pressures used and the design of the injector nozzle create good atomisation of the petrol, improving the mixing process, which continues during the intake and compression strokes.

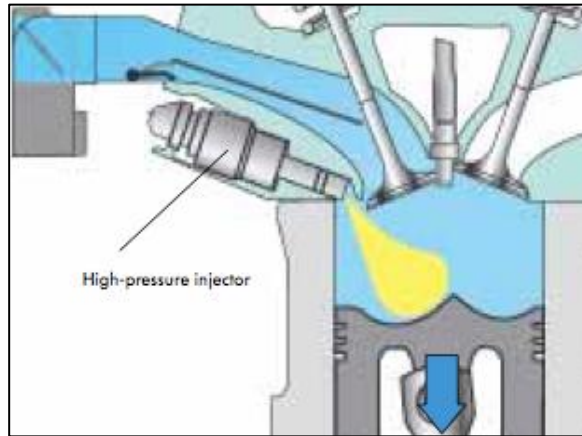


Figure 20 Fuel injection on Homogenous mode

Compression stroke injection timing

A relatively small amount of petrol is injected at the end of the compression stroke, just prior to ignition (Figure 22). The design of the combustion chamber includes an area (usually in the top of the piston crown) which promotes swirl or turbulence in a small, localised region. This allows the injected fuel to mix with a small pocket of air, forming a small pocket or cloud of mixed air and petrol. The small pocket of mixture is then directed to the spark plug tip, ensuring ignition of the mixture.

To create the small localised pocket of air: fuel mixture requires special piston and combustion chamber design. In addition, the location of the spark plug and injector in the cylinder are critical. One specific design features an additional flap (figure 31) in the intake tract (known as a charge motion valve). This is used in conjunction with a specially shaped piston crown and inlet manifold design to provide the required gas behaviour in stratified operation mode. This

characteristic behaviour is known as 'tumble'. The flap valve is actuated electronically via a stepper motor and is controlled by the ECU. The angle of this valve reduces the cross sectional area of the inlet manifold, thus increasing gas velocity and tumble imparted to the incoming air charge during stratified operation. During homogeneous operation this valve is fully open and has no effect.

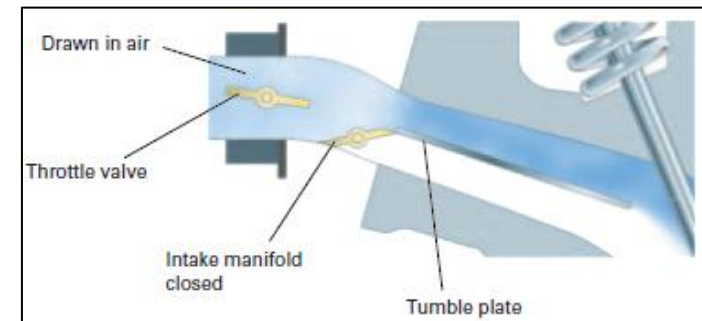


Figure 21 Charge motion valve

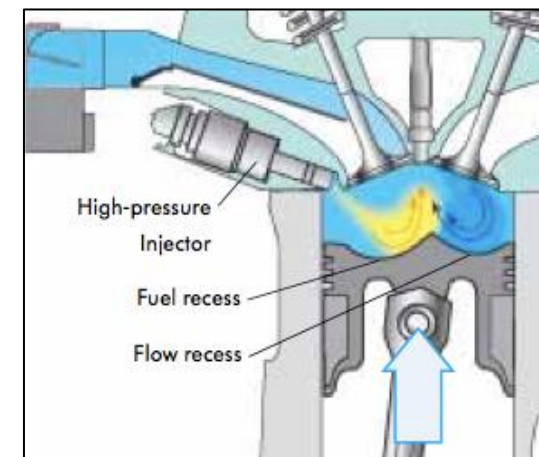


Figure 22 Fuel injection on stratified mode

Using both timing periods

Direct injection systems in petrol engines generally use both timing periods (intake stroke and compression stroke timing) independently, depending on the operating conditions. For light load driving and at idle, compression stroke injection timing means that very lean mixtures can be used (stratified mixture formation), which provides low power but good economy. When higher engine power is required or when the engine is operating at higher speeds, the injection timing changes to the intake stroke, providing a full charge of mixed air and petrol to the cylinder (homogenous mixture formation).

Because the injector timing is entirely controlled by the ECU, it is possible to time the injection to any point in the engine operating cycle. The exact time of injection during the intake stroke period and the compression stroke period can therefore be adjusted to suit the exact operating conditions, such as speed, temperature, etc.

There are also certain conditions under which injection takes place on both the intake and the compression strokes this is called homogeneous lean. A small quantity of fuel is delivered on the intake stroke, which produces a homogenous but weak mixture. Injection occurs again on the compression stroke to produce a normal stratified charge (which will have an air:fuel ratio that is close to stoichiometric). With this dual injection process, the stratified charge ignites and combusts normally which then creates combustion in the rest of the air (which has a weak homogenous mixture). This process produces more power or torque than when the system is operating with only a stratified mixture formation. This is used when the system is changing from stratified to

homogenous operation to provide a smooth transition.

Throttle control and mixture control to regulate power and torque

While direct injection has a number of advantages that on their own help to improve engine efficiency and reduce emissions, it is the fact that direct injection allows 'stratified mixture formation' to be used that provides the greatest benefit. With direct injection, there are effectively two types of mixture formation and combustion process that can be used at different times. However, getting the full benefit of both these processes, especially the stratified mixture formation, requires additional changes to engine design and engine control.

Filling the cylinder with air

Ideally, a cylinder should be fully charged with air at the end of the intake stroke (the largest possible volume of air), causing higher pressures at the end of the compression stroke. When combustion occurs, the heat produced causes the air to expand, but when a higher volume of air is compressed into the small combustion chamber, the expansion will be greater.

Ideally therefore there should be no restrictions that could prevent the cylinder from filling with air during the intake stroke. Unfortunately, petrol engines have traditionally had a throttle butterfly to regulate airflow into the cylinder as a means of controlling engine torque and power: when the engine is operating at light loads the throttle is almost fully closed, restricting the airflow into the cylinder. The cylinder is therefore only partially filled with air, resulting in low efficiency (low volumetric efficiency). Additionally, power is wasted by the

pumping action of the piston on the intake stroke, which is trying to draw air through the restriction.

To avoid this, the throttle should remain as far open as possible to enable improved volumetric efficiency with subsequent improvements during the combustion and expansion phases. This is in fact achievable with direct injection by holding the throttle open during light load conditions and then using an alternative means of controlling torque and power. The throttle is electrically operated using a stepper motor or similar device, which is in turn controlled by the system ECU

Controlling power by altering the air:fuel ratio

As explained earlier, when an engine has direct fuel injection, the stratified mixture formation process is used during light load operation. It is possible to alter the air:fuel ratio of the stratified charge (the small pocket of mixture), which will alter the energy produced during the combustion and expansion phases. So, if a weak stratified charge mixture is used, less energy will be produced compared with when the mixture is at the ideal air:fuel ratio (or slightly richer).

Therefore if the throttle is held in the open position (by controlling the stepper motor), a full charge of air will fill the cylinder on each intake stroke, but the energy produced on the power stroke will be regulated by the air:fuel ratio in the small pocket of mixture.

Note that when the engine is required to produce more power because the load is increasing (when accelerating), it must operate with a homogenous

mixture formation. The stratified mixture formation process operates with air:fuel ratios that are much too weak to enable good torque and power to be produced.

Injectors

Injectors used in direct injection systems operate in much the same way as for those in indirect injection systems: the injector is constructed with a solenoid that opens the injector valve by moving the needle off a seat, thus allowing fuel to flow through the valve. The opening time and opening duration of the solenoid are controlled by the ECU so that the required quantity of fuel is injected at exactly the correct time. Figure 33 shows an injector used on a direct injection system.

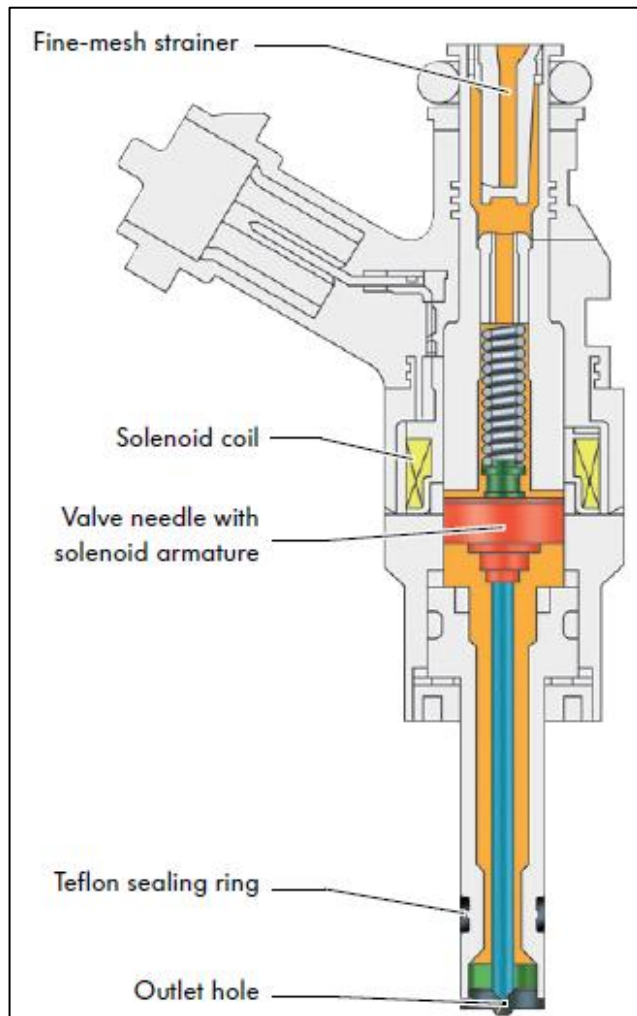


Figure 23 Fuel Injector

Injection pressure

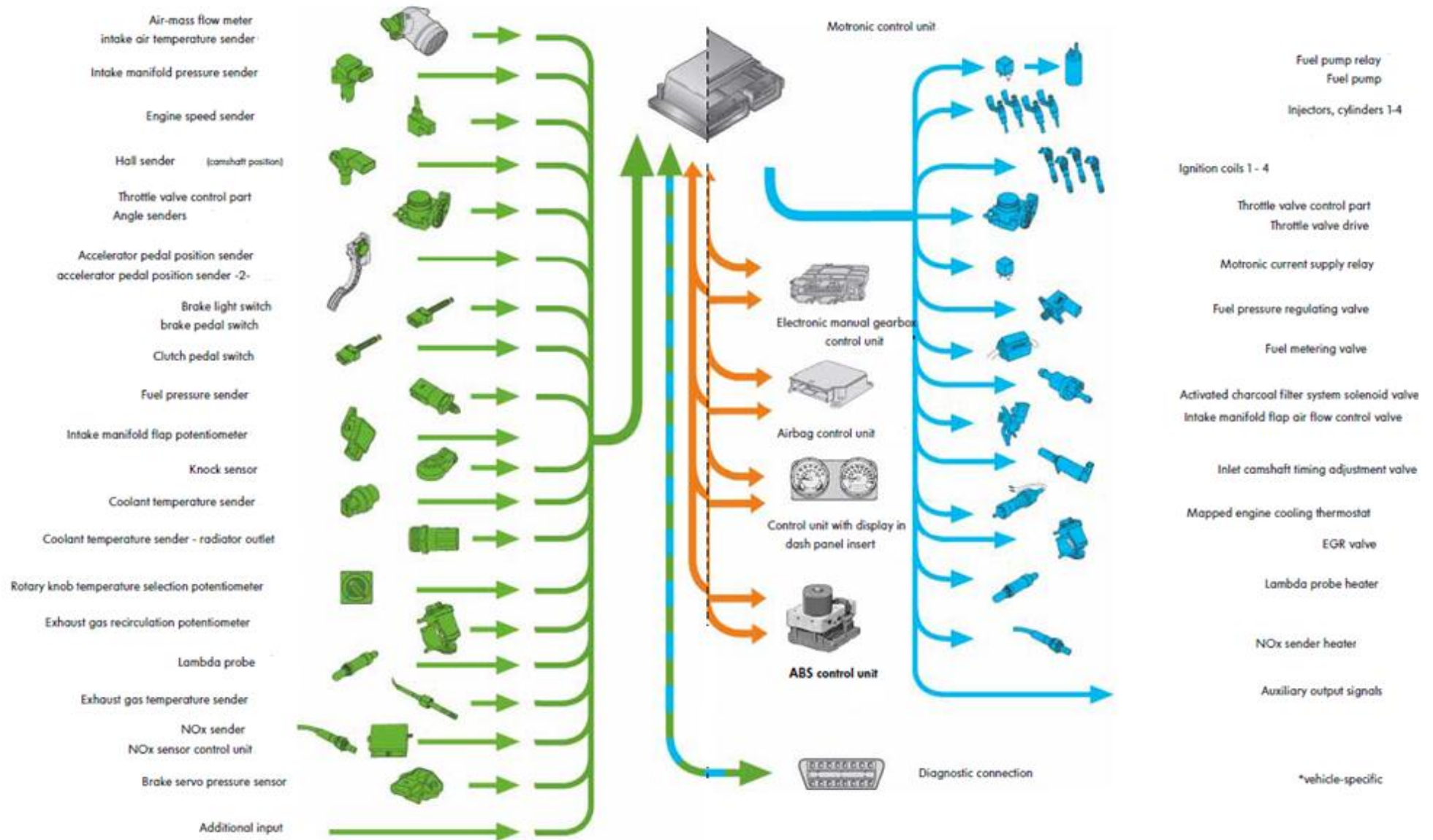
In direct injection systems, fuel can be injected at the end of the compression stroke, when cylinder pressures can reach 20 bar. To obtain the required atomisation of the fuel in this high pressure environment and to deliver the required quantity of fuel quickly, it is necessary to use a high fuel injection pressure. The pressure in the fuel rail (to which all the injectors are connected), is typically around 120 bar.

Throttle control

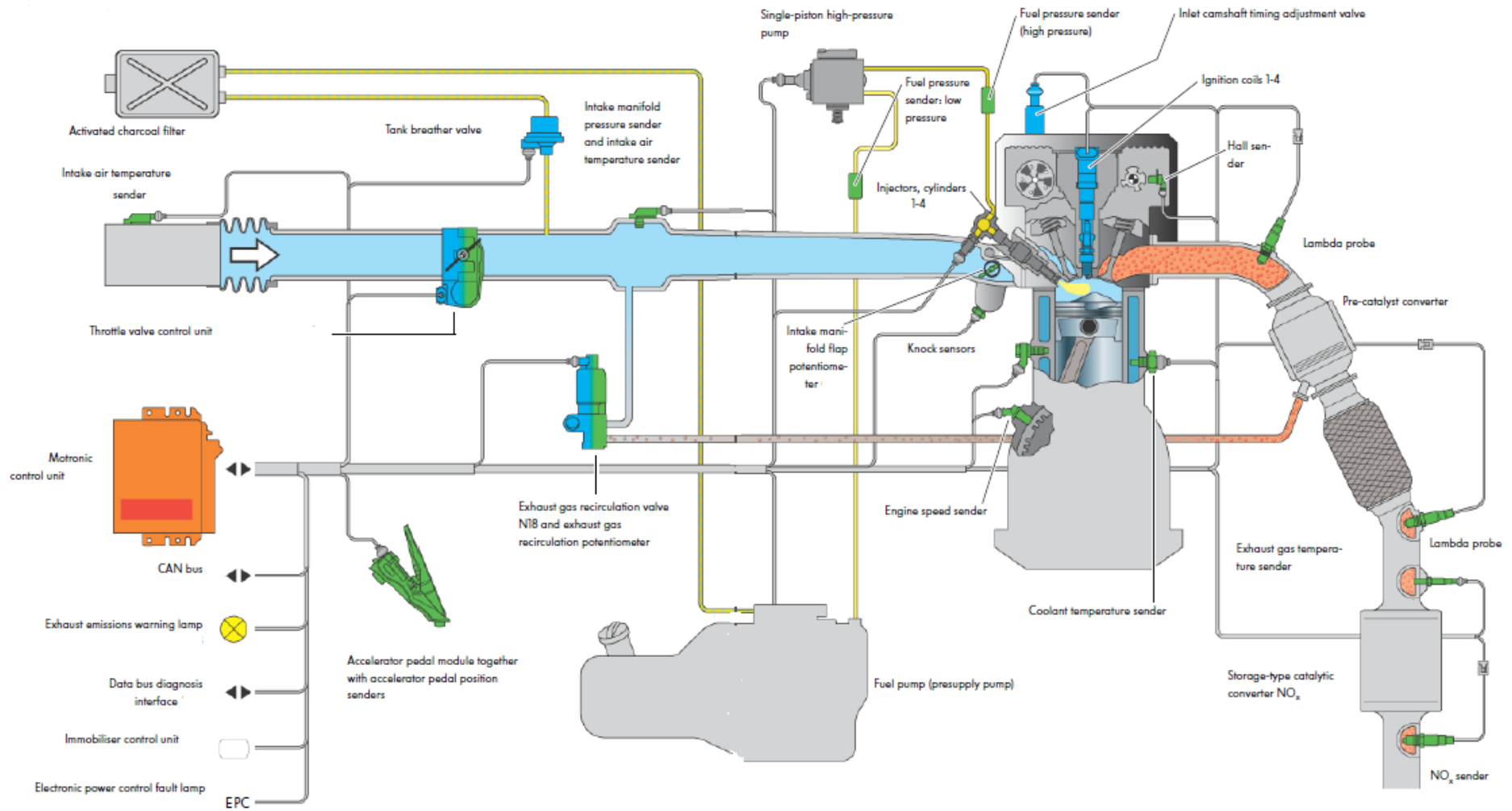
When the engine is operating with the stratified mixture formation process, the throttle is held open and engine torque is controlled using changes in the air:fuel ratio. The throttle must therefore not be directly connected to the throttle pedal, and is in fact controlled by the ECU, which sends control signals to a motor (usually a stepper motor), making the throttle open and close as required.

In effect, the driver selects a desired level of performance or engine operation in the usual way by moving the throttle pedal. The throttle pedal is connected to a potentiometer and, as the throttle pedal is moved, an analogue signal is sent to the ECU. The ECU can control the opening of the throttle depending on the driver input via the throttle pedal and on other factors such as temperature, engine speed, etc. However, when the system is operating using the stratified mixture formation process, the throttle is held open and engine power is controlled by changes in the air fuel ratio.

Direct injection system sensors and actuators



Direct injection system overview



References

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