FUEL INJECTION

Advantages of fuel injection

The major advantage of any type of fuel injection system is accurate control of the fuel quantity injected into the engine. The basic principle of fuel injection is that if petrol is supplied to an injector (electrically controlled valve), at a constant differential pressure, then the amount of fuel injected will be directly proportional to the injector open time.

Most systems are now electronically controlled even if containing some mechanical metering components. This allows the operation of the injection system to be very closely matched to the requirements of the engine. This matching process is carried out during development on test beds and dynamometers, as well as development in the car. The ideal operating data for a large number of engine operating conditions are stored in a read only memory in the ECU. Close control of the fuel quantity injected allows the optimum setting for mixture strength when all operating factors are taken into account (see the air–fuel ratio section).

Further advantages of electronic fuel injection control are that overrun cut off can easily be implemented, fuel can be cut at the engine's rpm limit and information on fuel used can be supplied to a trip computer.

Fuel injection systems can be classified into two main categories:

- Single-point injection
- Multipoint injection

System overview

Figure 17 shows a typical control layout for a fuel injection system. Depending on the sophistication of the system, idle speed and idle mixture adjustment can be either mechanically or electronically controlled.

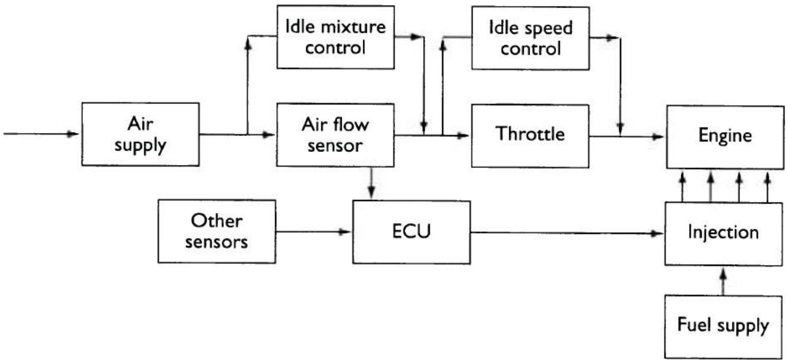

Figure 17. Typical control layout for a fuel injection system

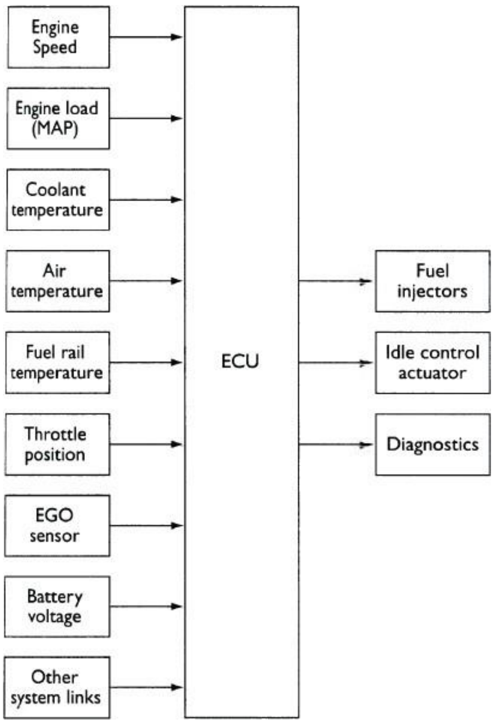

Figure 18. Block diagram of inputs and outputs common to most fuel injection systems

Figure 18 shows a block diagram of inputs and outputs common to most fuel injection systems. Note that the two most important input sensors to the system are speed and load. The basic fuelling requirement is determined from these inputs in a similar way to the determination of ignition timing.

This information forms part of a read only memory (ROM) chip in the ECU. When the ECU has determined the look-up value of the fuel required (injector open time), corrections to this figure can be added for battery voltage, temperature, throttle change or position and fuel cut off.

Idle speed, and fast idle, are also controlled by the ECU and a suitable actuator. It is also possible to have a form of closed loop control with electronic fuel injection. This involves a lambda sensor to monitor exhaust gas oxygen content. This allows very accurate control of the mixture strength, as the oxygen content of the exhaust is proportional to the air—fuel ratio. The signal from the lambda sensor is used to adjust the injector open time.

Components of a fuel injection system

The following components, with some additions, are typical of the Bosch `L' Jetronic systems. This system is not now used as almost all cars have full engine management (i.e. combined ignition and fuel control systems). However, it is a good example to use as an introduction to the subject. The various components are only discussed briefly, as most are included in other sections in more detail.

Flap type air flow sensor
A Bosch vane-type sensor is shown which moves due to the air being forced into the engine. The information provided to the ECU is air quantity and engine load.

Engine speed sensor
Most injection systems, which are not combined directly with the ignition, take a signal from the coil negative terminal. This provides speed data but also engine position to some extent. A resistor in series is often used to prevent high voltage surges reaching the ECU.

Temperature sensor
A simple thermistor provides engine coolant temperature information.

Throttle position sensor
Various sensors are shown consisting of the two-switch types, which only provide information that the throttle is at idle, full load or anywhere else in between; and potentiometer types, which give more detailed information.

Lambda sensor

This device provides information to the ECU on exhaust gas oxygen content. From this information, corrections can be applied to ensure the engine is kept at or very near to stoichiometry. Also shown in this figure is a combustion chamber pressure sensor.

Idle or fast idle control actuator

Bimetal or stepper motor actuators are used but the one shown is a pulsed actuator. The air that it allows through is set by its open/close ratio.

Fuel injector(s)

Two types are shown — the pintle and disc injectors. They are simple solenoid-operated valves designed to operate very quickly and produce a finely atomized spray pattern.

Injector resistors

These resistors were used on some systems when the injector coil resistance was very low. A lower inductive reactance in the circuit allows faster operation of the injectors. Most systems now limit injector maximum current in the ECU in much the same way as for low resistance ignition on coils.

Fuel pump

The pump ensures a constant supply of fuel to the fuel rail. The volume in the rail acts as a swamp to prevent pressure fluctuations as the injectors operate. The pump must be able to maintain a pressure of about 3 bar.

Fuel pressure regulator

This device ensures a constant differential pressure across the injectors. It is a mechanical device and has a connection to the inlet manifold.

Cold start injector and thermo-time switch

An extra injector was used on earlier systems as a form of choke. This worked in conjunction with the thermo-time switch to control the amount of cold enrichment. Both engine temperature and a heating winding heat it. This technique has been replaced on newer systems, which enrich the mixture by increasing the number of injector pulses or the pulse length.

Combination relay

This takes many forms on different systems but is basically two relays, one to control the fuel pump and one to power the rest of the injection system. The relay is often controlled by the ECU or will only operate when ignition pulses are sensed as a safety feature. This will only allow the fuel pump to operate when the engine is being cranked or is running.

Electronic control unit

Earlier ECUs were analogue in operation. All ECUs now in use employ digital processing.

DIESEL FUEL INJECTION

Diesel engines have the fuel injected into the combustion chamber where it is ignited by heat in the air charge. This is known as compression ignition (CI) because no spark is required. The high temperature needed to ignite the fuel is obtained by a high compression of the air charge. Diesel fuel is injected under high pressure from an injector nozzle, into the combustion chambers. The fuel is pressurised in a diesel injection pump. It is supplied and distributed to the injectors through high pressure fuel pipes or directly from a rail and/ or an injector. The high pressure generation is from a direct acting cam or a separate pump.

The air flow into a diesel engine is usually unobstructed by a throttle plate so a large air charge is always provided. Throttle plates may be used to provide control for emission devices. Engine speed is controlled by the amount of fuel injected. The engine is stopped by cutting off the fuel delivery. For all engine operating conditions a surplus amount of air is needed for complete combustion of the fuel.

Small high speed diesel engine compression ratios are about 20:1 for direct injection systems. This compression ratio is capable of raising the air charge to temperatures of between 500 °C and 800 °C. Very rapid combustion of the fuel therefore occurs when it is injected into the hot air charge.

The combustion process in a diesel engine follows three phases. These are ignition delay, flame spread and controlled combustion. In addition, an injection lag occurs in the high-pressure pipes, of earlier systems, as the pressure builds up just before injection.

The most important phase of controlled combustion is when fuel is being injected into a burning mixture. This must be at a rate that maintains an even combustion pressure onto the piston throughout the critical crankshaft rotational angles. This gives maximum torque and efficient fuel usage, because temperatures remain controlled and the heat lost to the exhaust is minimised. The low temperatures also help to keep nitrogen oxide emissions (NOx) to a minimum.

The speed of flame spread in a diesel engine is affected by the air charge temperature and the atomisation of the fuel. These characteristics are shared with the delay period. A sufficiently high air charge temperature, of at least 450 °C, is a minimum requirement for optimum ignition and combustion.

The delay phase or ignition lag for diesel fuel combustion lasts a few milli-seconds. It occurs immediately on injection as the fuel is heated up to the self-ignition temperature. The length of the delay is dependent on the compressed air charge temperature and the grade of fuel. The air charge temperature is also affected by the intake air temperature and the engine temperature.

A long delay period allows a high volume of fuel to be injected before ignition and flame spread occurs. In this situation diesel knock is at its most severe. When a diesel engine is cold, there may be insufficient heat in the air charge to bring the fuel up to the self-ignition temperature. When ignition is slow, heavy knocking occurs.

To aid starting and to reduce diesel knock, cold start devices may be used. For indirect injection engines, starting at lower-than-normal operating temperatures requires additional combustion chamber heating. For direct injection engines, cold start devices are only required in frosty weather.

An initial delay, known as injection lag, occurs in the high-pressure fuel lines of rotary pumped systems. This occurs between the start of the pressure rise and the point when pressure is sufficient to overcome the compression spring force in the injectors.

Ignition of the fuel occurs in the combustion chamber at the time of injection into the heated air charge. The injection point and the ignition timing are therefore effectively the same thing. Diesel engine injection timing is equivalent to the ignition timing for petrol engines. Injection timing must fall within a narrow angle of crankshaft rotation. It is advanced and retarded for engine speed and load conditions. Injection timing is set by accurate positioning of the fuel injection pump. Incorrect timing leads to power loss. An increase in the production of nitrogen oxides (NOx) when too far advanced or an increase in the hydrocarbon (HC) emissions, when too far retarded also occurs.

Particulate emissions result from incomplete combustion of fuel. Particulates are seen as black carbon smoke in the exhaust under heavy load or when fuel delivery and/or timing is incorrect. White smoke may also be visible at other times, such as when the injection pump timing is incorrect. It also occurs when compression pressures are low or when coolant has leaked into the combustion chambers.

Recent developments in electronic diesel fuel injection control have made it possible to produce small direct injection engines. Diesel engines are built to withstand the internal stresses, which are greater than other engines. Diesel engines are particularly suitable for turbocharging, which improves power and torque outputs.

EGR is used to reduce nitrogen oxide (NOx) emissions on petrol engines; this is also true for diesel engines (Figure 19). Additionally, a small quantity of hot exhaust gas in the air charge of a cold engine helps to reduce the delay period and the incidence of cold engine diesel knock.

Many diesel engined vehicles are now fitted with oxidation catalytic converters that work in conjunction with other emission components to reduce hydrocarbon and particulate emissions.

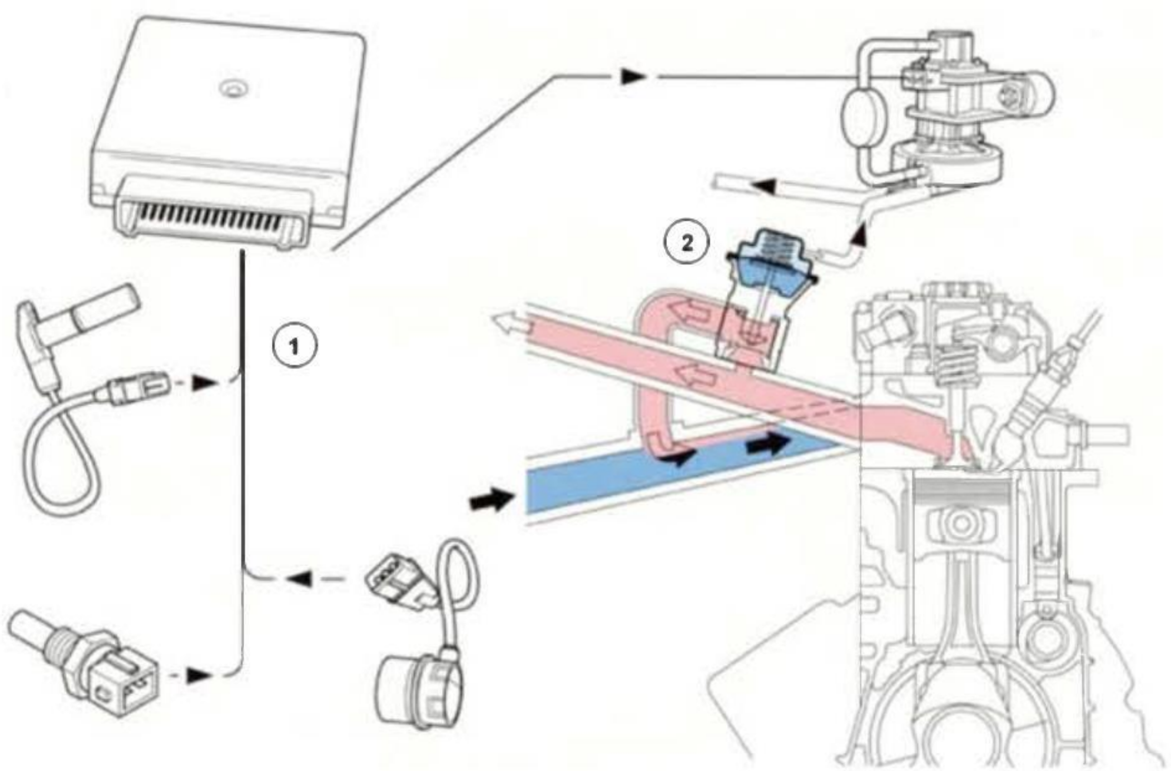

Figure 19. Diesel exhaust gas recirculation (EGR): 1 -ECU and sensors, 2-EGR actuator and control valve

The fuel systems for traditional direct and indirect injection are similar and vary only in injection pressures and injector types. Until more recently, all light high speed diesel engines used rotary diesel fuel injection pumps. These pumps producing injection pressures of over 100 bar for indirect engines. However, these can rise up to 1000 bar at the pump outlet, for turbocharged direct injection engines.

Injectors operate with a pulsing action at high pressure to break the fuel down into finely atomised parts. Atomisation is critical to good fuel distribution in the compressed air charge. The air charge pressure may be in excess of 60 bar. The pressure differential, between the fuel injection pressure and air charge pressure, must be sufficient to overcome the resistance during injection. This will also give good fuel atomisation and a shorter injection time.

The main components of a diesel fuel system provide for either the low pressure or the high-pressure functions. The low-pressure components are the fuel tank, the fuel feed and return pipes and hoses, a renewable fuel filter with a water trap and drain tap, and a priming or lift pump. The high-pressure components are the fuel injector pump, the high-pressure pipes and the injectors. Other components provide for cold engine starting. Electronically controlled systems include sensors, an electronic diesel control (EDC) module and actuators in the injection pump.

All diesel fuel entering the injection pump and injectors must be fully filtered. The internal components of the pump and injectors are manufactured to very fine tolerances. Even very small particles of dirt could be damaging to these components.

The most common rotary injection pumps are axial-piston designs having a roller ring and cam plate attached to an axial piston or plunger in the distributor head to generate the high pressure. The latest versions have full electronic control.

The high pressure pipes are of double thickness steel construction and are all of the same length. This is so that the internal pressure rise characteristics are identical for all cylinders. The high pressure connections are made by rolled flanges on the pipe ends and threaded unions securing the rolled flanges to convex, or occasionally concave, seats in the delivery valves and injectors.

The fuel injectors are fitted into the cylinder head with the nozzle tip projecting into the pre-combustion (IDI) or combustion chamber (DI). The injectors for indirect combustion are of a pintle or 'pintaux' design (similar to petrol injectors in many ways) and produce a conical spray pattern on injection. The injectors for direct injection (DI) are of a pencil type multi-hole design that produces a broad distribution of fuel on injection.

Fuel injectors are held closed by a compression spring. They are opened by hydraulic pressure when it is sufficient to overcome the spring force on the injector needle. The hydraulic pressure is applied to a face on the needle where it sits in a pressure chamber. The fuel pressure needed is in excess of 100 bar (1500 psi). This pressure lifts the needle and opens the nozzle, so that fuel is injected in a fine spray pattern into the combustion chamber

Electronic control of diesel injection

The advent of electronic control over the diesel injection pump has allowed many advances over the purely mechanical system. The production of high pressure and injection is, however, still mechanical with all current systems. The following advantages are apparent over the non-electronic control system.

- More precise control of fuel quantity injected.
- Better control of start of injection.
- Idle speed control.
- Control of exhaust gas recirculation.
- Drive by wire system (potentiometer on throttle pedal).
- An anti-surge function.
- Output to data acquisition systems etc.
- Temperature compensation.
- Cruise control.

A distributor-type injection pump can be used with electronic control. Because fuel must be injected at high pressure, the hydraulic head, pressure pump and drive elements are still used. An electromagnetic moving iron actuator adjusts the position of the control collar, which in turn controls the delivery stroke and therefore the injected quantity of fuel. Fuel pressure is applied to a roller ring and this controls the start of injection. A solenoid-operated valve controls the supply to the roller ring. These actuators together allow control of the start of injection and injection quantity.

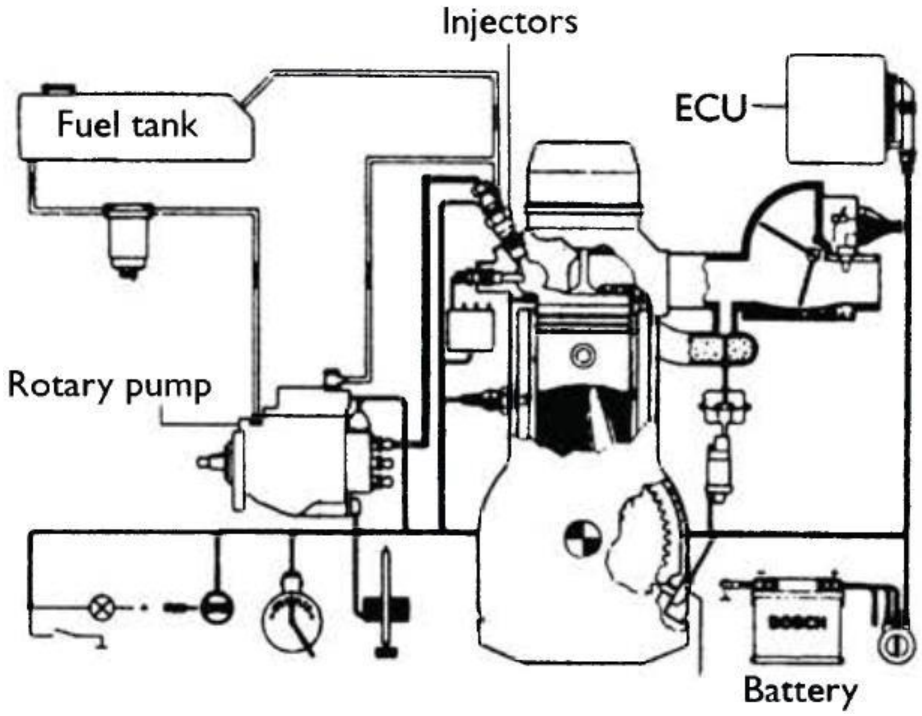

Figure 20. Layout of an electrical diesel control system

Ideal values for fuel quantity and timing are stored in memory maps in the electronic control unit. The injected fuel quantity is calculated from the accelerator position and the engine speed. The start of injection is determined from the following:

- Fuel quantity.
- Engine speed.
- Engine temperature.
- Air pressure.

The ECU is able to compare start of injection with actual delivery from a signal produced by the needle motion sensor in the injector.

Control of exhaust gas recirculation is by a simple solenoid valve. This is con-trolled as a function of engine speed, temperature and injected quantity. The ECU is also in control of the stop solenoid and glow plugs via a suitable relay. Figure 20 is the complete layout of an electronic diesel control system.