Review on Direct Petrol Injection in SI engines without using Conventional Carburetor system

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Abstract-A carburetor is a part of a SI engine that converts liquid fuel into vapour. This is mixed with a certain amount of air that allows combustion in the engine. Using carburetor it is difficult to send uniform air-fuel mixture in each cylinder of a multi cylinder engine. In a multi cylinder engine, when the petrol-air mixture moves from first cylinder to the last cylinder, the petrol air mixture becomes weakest at the last cylinder because of the different inertia effects of petrol and air. Thus, the central cylinders which are very closed to the carburetor get the richer mixture. Thus the various cylinders receive the air petrol mixture in varying quantities and richness. This problem is called mal-distribution. Moreover, due to improper burning of fuel in a conventional carburetor engine a substantial amount of fuel is wasted and emerges out through the exhaust and thus gives less efficiency and more exhaust emissions. In modern automotive technology, the system uses electronic control system to control and monitor the essential parameters like mass air flow rate, fuel pressure, engine temperature , engine speed, air-fuel mixture etc. The mal-distribution problem is also solved by introducing automatic fuel injection system (Single Point Fuel Injection(SPFI) or Multi Point Fuel Injection(MPFI)) which not only calculates the desired air-fuel mixture continuously but also provides the same amount of petrol injected at each cylinder (in case of MPFI). Although most of the cars in India are incorporated with Microprocessor based Electronic Fuel Injection (EFI) system which are developed by foreign companies, but such novel system is yet to be developed indigenously with further improvement in performance by controlling more variables using suitable sensors, and modifying selection of petrol injection in a particular stroke of a SI engine.

Key words: Carburetor, IC Engine, Stoichiometric Mixture, Equivalence Ratio, Volumetric Efficiency, Compression Ratio, EFI, Sensors, ECU.

1. INTRODUCTION

The internal combustion engine is an engine in which the combustion of a fuel (e.g., petrol or diesel) occurs with an oxidizer (usually air) in a combustion chamber. Modern cars have engines that have four, six or eight cylinders. In an internal combustion engine the expansion of the high temperature and pressure gases, which are produced by the combustion, directly applies force to the pistons of the engine which are connected to the crankshaft by a connecting rod. The crankshaft translates the up and down movement of the pistons into the rotational motion that moves the car.

Most automobile engines today operate using a four stroke (suction, compression, expansion and exhaust) cycle.

In old automobiles, proper mixing of air and fuel (Petrol) for an Internal Combustion Engine is made by using a device called carburetor which is attached to the intake manifold of the IC Engine. The carburetor works on Bernoulli's principle: faster the air moves, the lower is its static pressure, and the higher is its dynamic pressure. The throttle (accelerator) linkage does not directly control the flow of liquid fuel. Instead, it actuates carburetor mechanisms which meter the flow of air being pulled into the engine. The speed of this flow, and therefore its pressure, determines the amount of fuel drawn into the airstream. Under all engine operating conditions, the carburetor must:

- Measure the airflow of the engine
- Deliver the correct amount of fuel to keep the fuel/air mixture in the proper range (adjusting for factors such as temperature)
- Mix the two finely and evenly

This job would be simple if air and gasoline (petrol) were ideal fluids; in practice, however, their deviations from ideal behavior due to viscosity, fluid drag, inertia, etc. require a great deal of complexity to compensate for exceptionally high or low engine speeds. A carburetor must provide the proper fuel/air mixture across a wide range of ambient temperatures, atmospheric pressures, engine speeds and loads, and centrifugal forces.

As mentioned earlier, using carburetor it is very difficult to send uniform air-fuel mixture in each cylinder of a multi cylinder engine. In a multi cylinder engine, when the petrol-air mixture moves from first cylinder to the last cylinder, the petrol air

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mixture becomes weakest at the last cylinder because of the different inertia effects of petrol and air. Thus, the central cylinders which are much closed to the carburetor get the richer mixture. Thus the various cylinders receive the air petrol mixture in varying quantities and richness. This problem is called mal-distribution. Moreover in a conventional carburetor engine a substantial amount of fuel is wasted (due to not burning properly) and emerges out through the exhaust and thus gives less efficiency and more exhaust emissions. Due to the above disadvantage as well as stringent regulations imposed by the Pollution Control Boards of different countries towards emission of gases, the use of carburetor was being phased out from early 1980s and electronic fuel injection system has been in use which takes care of all the essential parameters for best power outputs including control of emission of gases . The mal-distribution problem is solved by developing a fuel injection system which provides the same amount of petrol injected at each cylinder (in case of multi point fuel injection). The evaluation of Catalytic Converters put further pound on the Carburetor technology as the Catalytic Converters traps the excess residual Oxygen molecules emitted from the combustion chamber resulting early clogging of the Catalytic Converter. The emission of the excess residual Oxygen molecules was needed to be checked badly and unfortunately the technology of the Carburetor was inefficient to regulate the Oxygen content from both the intake air and the residual gases. To curb this need of relatively cleaner emission from the internal combustion engines Fuel Injection System was developed.

2. MECHANICAL FUEL INJECTION SYSTEM

Fuel Injection system as the name suggests is mainly consists of an Injector or a valve with a small nozzle at the extreme end which is responsible to supply the fuel to the combustion chamber with force resulting the Atomization of the fuel (breaking of the fuel particles into much smaller molecules), this force is generated from the fuel pump which is generally placed inside the fuel tank, the atomized fuel is easier to burn when combined with the radical oxygen molecules of the air intake creating an optimum fuel and air ratio hence resulting into increased fuel efficiency with remarkably cleaner emission.

2.1 Review on mechanical injection:

One of the first commercial gasoline injection systems was a mechanical system developed by Bosch and introduced in 1952. This system used a normal gasoline fuel pump, to provide fuel to a mechanically driven injection pump, which had separate plungers per injector to deliver a very high injection pressure directly into the combustion chamber.

Chevrolet introduced a mechanical fuel injection system, made by General Motors, in 1956 for its 283 V8 engine. This system directed the inducted engine air across a "spoon shaped" plunger that moved in proportion to the air volume. The plunger connected to the fuel metering system that mechanically dispensed fuel to the cylinders via distribution tubes. This system was not a "pulse" or intermittent injection, but rather a constant flow system, metering fuel to all cylinders simultaneously from a central "spider" of injection lines. The fuel meter was used to adjust the amount of flow according to engine speed and load, and included a fuel reservoir, which was similar to a carburetor's float chamber. With its own high-pressure fuel pump, the system supplied the necessary pressure for injection. This was a "port" injection where the injectors were located in the intake manifold, very near to the intake valve. The engine was rated at 315hp (235 kW).

3. ELECTRONIC FUEL INJECTION SYSTEM

Although, during the period from 1960 to late 1970s many developments were made by foreign companies towards fuel induction by carburetor but failed to comply with the emissions regulations and as such needed further research for improvement and as a result a more efficient system called Electronic Fuel Injection System (EFI) has been developed. The EFI System consists of following parts:

3.1 Engine Control Unit (ECU)

Initially, the ECU was made by designing proper electronic circuits using discrete electronic components for the purpose of controlling mainly the air fuel mixture by controlling the throttle position at the intake manifold, which had its obvious disadvantages like problem during cold start, uncontrolled exhaust gases etc. But after the advent of microprocessor during the late 1970s, a radical change in the electronic design took place. Modern ECU is a small but very efficient microcontroller chip responsible for calculating and monitoring the different activities of the engine with the help of various sensors installed at different parts of a vehicle and suitable programme. On the basis of the information collected from the sensors the ECU controls the Fuel Injector’s timing to release the fuel. The ECU also regulates the duration of the opening of the injector valve (Fig.1) which in turn affect the volume of fuel injected in the different cylinders.

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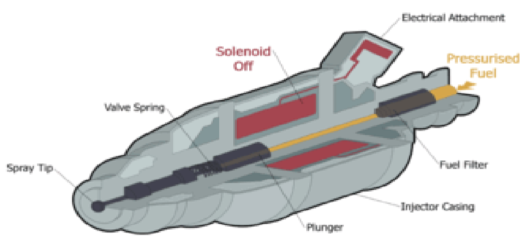

Fig.1: Fuel Injector

The major functions of ECU are as follows:

i) Control of Air/Fuel ratio

One specific air/fuel ratio is highly significant in electronic fuel control systems, namely, the *stoichiometric mixture*. The stoichiometric (i.e., chemically correct) mixture corresponds to an air and fuel combination such that if combustion were perfect all of the hydrogen and carbon in the fuel would be converted by the burning process to H_2O and CO_2. For gasoline the stoichiometric mixture ratio is 14.7:1.

Stoichiometry is sufficiently important that the fuel and air mixture is often represented by a ratio called the *equivalence ratio,* which is given the specific designation λ. The equivalence ratio is defined as follows:

$$\lambda = \frac{\text{(actual air/fuel ratio)}}{\text{(air/fuel ratio at stoichiometry)}}$$

A relatively low air/fuel ratio, below 14.7 (corresponding to $\lambda < 1$), is called a *rich* mixture; an air/fuel ratio above 14.7 (corresponding to $\lambda > 1$) is called a *lean* mixture. Emission control is strongly affected by air/fuel ratio, or by λ.

Stoichiometric mode is used for moderate load conditions. Fuel is injected during intake stroke, creating a homogeneous air-fuel mixture in the cylinder.

Lean or sratified mixture is used for light-load running conditions, at constant and reducing load speed, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke.

Ritch mixture is used for cold start (when engine is not properly warmed up), rapid acceleration and heavy loads (when climbing on a comparatively stiff road). The air-fuel mixture is homogeneous and the ratio is slightly ritcher than stoichiometric, which helps to prevent knocking. The fuel is injected during the intake stroke.

For an engine with fuel injection, an engine control unit (ECU) will determine the quantity of fuel to inject based on a number of parameters. If the Throttle position sensor is showing the throttle pedal is pressed further down, the Mass air flow sensor will measure the amount of additional air being sucked into the engine and the ECU will inject fixed quantity of fuel into the engine (most of the engine fuel inlet quantity is fixed). If the Engine coolant temperature sensor is showing the engine has not warmed up yet, more fuel will be injected (causing the engine to run slightly 'rich' until the engine warms up). Mixture control on computer controlled carburetors works similarly but with a mixture control solenoid or stepper motor incorporated in the float bowl of the carburetor.

ii) Control of ignition timing

A spark ignition engine requires a spark to initiate combustion in the combustion chamber. An ECU can adjust the exact timing of the spark (called ignition timing) to provide better power and economy. If the ECU detects knock, a condition which is potentially destructive to engines, and "judges" it to be the result of the ignition timing being too early in the compression stroke, it will delay (retard) the timing of the spark to prevent this. Since knock tends to occur more easily at lower rpm, the ECU controlling an automatic transmission will often downshift into a lower gear as a first attempt to alleviate knock.

iii) Control of idle speed

Most engine systems have idle speed control built into the ECU. The engine RPM is monitored by the crankshaft position sensor which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor. Early carburetor-based systems used a programmable throttle stop using a bidirectional DC motor. Early TBI systems used an idle air control stepper motor. Effective idle speed control must anticipate the engine load at idle. Changes in this idle load may come from HVAC systems, power steering systems, power brake systems, and electrical charging and supply systems. Engine temperature and transmission status, and lift and duration of camshaft also may change the engine load and/or the idle speed value desired.

A full authority throttle control system may be used to control idle speed, provide cruise control functions and top speed limitation.

iv) Control of variable valve timing

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Some engines have Variable Valve Timing. In such an engine, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at higher speed than at lower speed. This can optimize the flow of air into the cylinder, increasing power and economy.

v) Control of Emission

The exhaust emissions are much more clean because the more precious and accurate fuel metering reduces the concentration of toxic combustion byproducts like CO, Hydrocarbons, C_nH_m, Nitrogen Oxides, Sulphur Oxides and Smoke, leaving the engine. The emission quality is further improved by the use of Catalytic Converter. An **Oxygen Sensor** is attached to the Catalytic Converter and responsible to monitor the volume of Oxygen in the exhaust, on the basis of the data sent, the ECU decides how rich or lean fuel and air mixture should be.

Moreover, the undesirable exhaust gas emission of NO_x is significantly reduced while maintaining a relatively high level of torque by recirculating a precisely controlled amount of exhaust gas into the intake. which is called E***xhaust Gas Recirculation*** **(EGR)**. The mechanism by which EGR affects NO_x production is related to the peak combustion temperature. Roughly, the NO_x generation rate increases with increasing peak combustion temperature if all other variables remain fixed. Increasing EGR tends to lower this temperature; therefore, it tends to lower NOx generation.

Fig.2a below shows the block diagram of a modern Control System with ECU (Engine Control Unit)

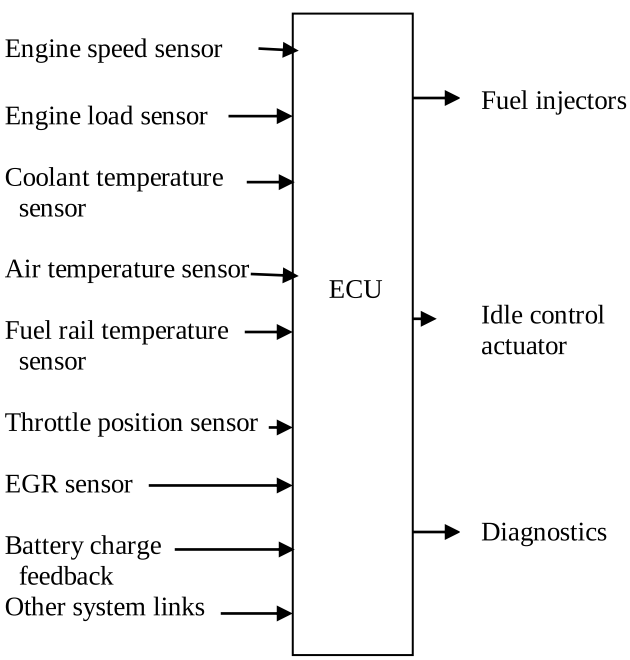
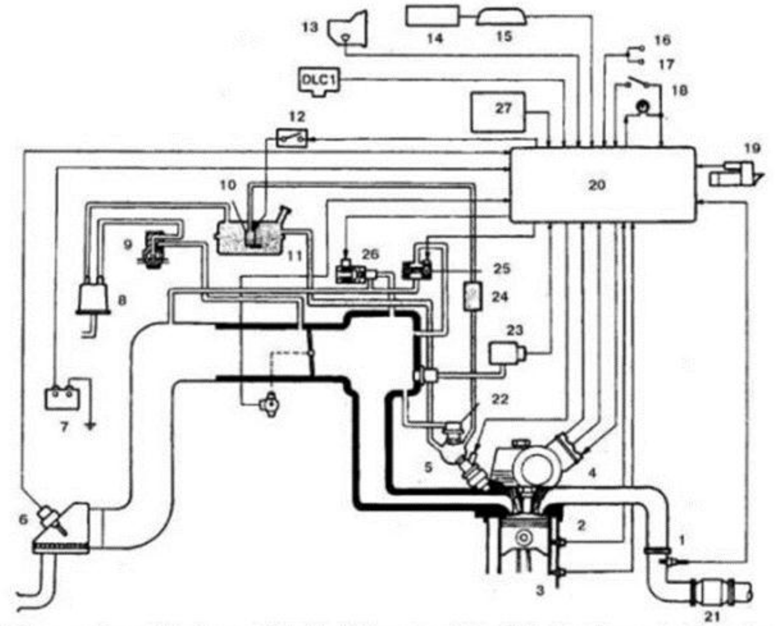


Fig.2: Block diagram of a modern Control System with ECU (Engine Control Unit)

Fig 2b below shows the Toyota electronic fuel injection system diagram



1. The gauge of concentration of oxygen; 2. A cooling fluid temperature detector; 3. The detonation gauge (only for engines of 1,8 l. 7A-FE); 4. An integrated electronic ignition unit (IIA); 5. A spray jet; 6. The temperature detector of sucked in air; 7. The battery; 8. A tank with the activated coal; 9. The vacuum valve (distributor); 10. The tuel pump; 11. A fuel tank; 12. The fuel pump relay; 13. The switch of position Park/Neutral (for cars with an automatic transmission); 14. A car speed sensor; 15. The dashboard; 16. The relay of inclusion of headlights; 17. The antifrost screen switch; 18. The stoplight switch; 19. A starter; 20. An electronic control package; 21. The catalyst converter; 22. A fuel pressure regulator; 23. The gauge of absolute pressure in an inlet valve; 24. The fuel filter; 25. The control air valve of idle running; 26. The gauge of an angle of rotation of a throttle valve; 27. The air conditioner booster.

Fig 2b: Toyota electronic fuel system diagram

3.2 Types of Electronic Fuel Injectors.

There are two types of injection systems:

i) Port Fuel Injection system (PFI), where the petrol is injected through the port i.e., at the intake manifold, and

ii) Gasoline Direct Injection (GDI), where the petrol is injected directly into the cylinders at a high pressure.

Electronic controlled Port Fuel Injection (PFI) systems instead of fuel system with carburetor have been used since 1980's. In fuel injection systems, induced air can be metered precisely and the fuel is injected in the manifold to air amount. By using the lambda sensor in exhaust system, air/fuel ratio is held of stable value. It would have been almost impossible to comply with the increasingly emissions regulation without electronic fuel control.

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3.3 Advantages on Petrol Injection in SI Engine

If port fuel injection system is compared with carburetor system, it can be seen that PFI has some advantages. These are;

1. Fuel response is practically instantaneous with increase in air flow. Because of these, there will be less emissions.
2. Increased volumetric efficiency and therefore increased output power and torque. The carburetor venturi prevents air and, in turn, volumetric efficiency decreases.
3. Low specific fuel consumption. In the engine with carburetor, fuel cannot be delivered with the same amount and with the same air/fuel ratio per cycle, for each cylinder.
4. The more rapid engine response to changes in throttle position. This increases the drive comfort.
5. For less rotation components in fuel injection system, the noise decreases.
6. Acceleration becomes faster.
7. Ice formation on the throttle plate is eliminated.
8. Starting is easier.

Though the port fuel injection system has some advantages, it cannot meet the existing continuously increasing demands on the engine performance, emission regulations and fuel economy. The electronic controlled gasoline direct injection systems were started to be used instead of port fuel injection system since 1990s.

The Gasoline Direct Injection (GDI) engines give a number of features, which could not be realized with port injected engines: avoiding fuel wall film in the manifold, improved accuracy of air/fuel ratio during dynamics, reducing throttling losses of the gas exchange by stratified and homogeneous lean operation, higher thermal efficiency by stratified operation and increased compression ratio, decreasing the fuel consumption and CO_2 emissions, lower heat losses, fast heating of the catalyst by injection during the gas expansion phase, increased performance and volumetric efficiency due to cooling of air charge, better cold start performance and better the drive comfort. PFI engines work at stoichiometric air/fuel ratio which restricts the fuel economy. Moreover, the compression ratio is about 9/1-10/1 which cannot be increased further to prevent knock. Whereas, GDI engines operate with lean mixture and unthrottled at part loads and with homogeneous charge and stoichiometric or slightly rich mixture at full load. The compression ratio is around 12/1 and the overall air/fuel ratio is lean . This certainly gives a better power output.

3.3 Disadvantages on Petrol Injection in SI Engine

1. High Initial Cost/High Replacement Cost.
2. Increased are and Attention/More Servicing Problems.
3. Requires Special Servicing Equipment to Diagnose Faults and Failures.
4. Special Knowledge of Mechanical and Electrical Systems Needed to Diagnose and Rectify Faults.
5. Injection Equipment Complicated, Delicate to Handle and Impossible to Service by Roadside Service Units.
6. Contain More Mechanical and Electrical Components Which May Go Wrong.
7. Increased Hydraulic and Mechanical Noise Due to Pumping and Metering of Fuel.
8. Very Careful Filtration Needed Due to Fine Tolerances of Metering and Discharging Components.
9. More Electrical/Mechanical Power Needed to Drive Fuel Pump and/or Injection Devices.
10. More Fuel Pumping/Injection Equipment and Pipe Plumbing Required- May be Awkwardly Placed and Bulky.

Although the number of points in disadvantages is more than the number of points in advantages, the disadvantages carry less weightage compared to weightage in advantages. The electronic fuel control system without carburetor is now a days very much preferred as the reliability and fuel efficiency are very cost effective.

3.4 Review on earlier designs on electronic fuel injection

The first commercial electronic fuel injection (EFI) system was Electrojector (which uses discrete electronic components), developed by the Bendix Corporation and was offered by American Motors Corporation (AMC) in 1957. The Electrojector was rated at 288 bhp (214.8 kW). The EFI produced peak torque 500 rpm lower than the equivalent carburetored engine. This EFI system ran fine in warm weather, but suffered hard starting in cooler temperatures.

Bosch developed an electronic fuel injection system (using discrete electronic components), called *D-Jetronic* (*D* for *Druck*, German for "pressure"), which was first used on the VW 1600TL/E in 1967. This was a speed/density system, using engine speed and intake manifold air density to calculate "air mass" flow rate and thus fuel requirements. Bosch superseded the D-Jetronic system with the *K-Jetronic* and *L-Jetronic* systems for 1974, though some cars (such as the Volvo 164) continued using D-Jetronic for the following several years.

The Cadillac Seville was introduced in 1975 with an EFI system made by Bendix and modelled very closely on Bosch's D-

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Jetronic. L-Jetronic first appeared on the 1974 which uses a mechanical airflow meter (L for ***Luft***, German for "air") that produces a signal that is proportional to "air volume". This approach required additional sensors to measure the atmospheric pressure and temperature, to ultimately calculate "air mass". L-Jetronic was widely adopted on European cars of that period, and a few Japanese models a short time later.

In Japan, the Toyota Celica used electronic, multi-port fuel injection in the in January 1974. Nissan offered electronic, multi-port fuel injection in 1975 with the Bosch L-Jetronic system. Toyota soon followed with the same technology in 1978. In 1981 saw Mazda offered fuel injection in the Mazda Luce with the Mazda FE engine, and in 1983, Subaru offered fuel injection in the Subaru EA81 engine installed in the Subaru Leone. Honda followed in 1984 with their own system, called PGM-FI in the Honda Accord, and the Honda Vigor using the Honda ES3 engine.

The limited production Chevrolet Cosworth Vega was introduced in March 1975 using a Bendix EFI system with pulse-time manifold injection, four injector valves, an electronic control unit (ECU), five independent sensors and two fuel pumps. The EFI system was developed to satisfy stringent emission control requirements and market demands for a technologically advanced responsive vehicle. 5000 hand-built Cosworth Vega engines were produced but only 3,508 cars were sold through 1976.

In 1980, Motorola introduced the world's first **microprocessor based electronic engine control unit**, the EEC III module. In 1983, the EEC III module was superseded by EEC IV module. The EEC-IV system has more diagnostic capabilities than previous EEC systems. Its integrated control of engine functions (such as fuel injection and spark timing) has now become the standard approach for electronic fuel injection systems.

4 CONCLUSION

Many researchers and scientists of America, Japan, U.K have done lot of research work related to electronic petrol injection in SI engines. This technology has been transferred in many automobile vehicles, but in India so far no remarkable research work has been done on EFI system in SI engines. This is the high time for Indian researchers and scientists to develop Direct Petrol Injection system (or Gasoline Direct Injection system) in SI engines to have better efficiency and fuel economy.

Presently, considering cost and efficiency although Port Fuel Injection technique is used in some petrol engines, the fuel economy and emissions of these engines cannot be improved further as these engines operate with stoichiometric mixture. Whereas, Gasoline Direct Injection engines have become popular due to its improved power output and emissions that are complying with stringent environmental protection agency standards. The main disadvantage of GDI engine is that this is very costly. Since this technique has potentials for reduction of toxic gases, CO_2 emissions as well as there is scope of improving fuel efficiency, further research work is needed not only for indigenous development but also for further improvement by including other variables e.g., ignition time, rpm limit, coolant temperature correction, fuel pressure modifier, and also modifying selection of fuel injection point, electronic valve control without using cam etc.

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