COMMON RAIL DIRECT INJECTION

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Abstract-*This paper deals with the study of Common Rail Direct Injection. Diesel engines are getting more attention thanks to their low emissions and low fuel consumption. The working and emissions of diesel engines are strictly shaped by the injection pattern and the induced air quality. Employment of diesel engines along with mechatronic systems together with the advent of common-rail injection systems, which facilitates the flexibility of injection control, has helped diesel engine to gain favourability and decrease the level of pertinent emissions and noise. Expansion of mechatronic systems in the case of common-rail system has lead to a complex multi-stage development procedure. Common-rail technology is designed to improve the pulverization process.*

Conventional direct injection diesel engines for each injection must repeatedly generate fuel pressure but in case of Common Rail Direct Injection (CRDI) engines the pressure is built up autonomously of the injection sequence and remains constantly available in the fuel line. In this system the high-speed solenoid valves are regulated by the electronic engine management which individually control the injection timing and the amount of fuel to be injected for each cylinder as a function of the cylinder's genuine need. In short, pressure generation and fuel injection are independent of each other. This is a considerable upper hand of common-rail injection over conventional fuel injection systems as CRDI expands the controllability of the individual injection processes and also refines fuel atomization, which contributes the saving of fuel and reducing the emissions.

Keywords: *Common Rail Direct Injection; Injection pattern; mechatronic; solenoid valves; pulverization*

1. INTRODUCTION

Contrary to gasoline engines, diesel engines do not need a combustion system because of the inherent properties of diesel, the combustion process will automatically take place under certain pressure and temperature at the end of the diesel cycle. Usually, this cycle requires a high compression ratio of about 22: 1 for a non-turbocharged motor. Moreover, it is necessary to have a medium and heavy machine case and block to manage with high fire pressure. Hence, diesel engines are always bulkier than petrol engines of same capacity. On the one hand, high pressure and heavy pistons avoid diesel engines from rotating at high speeds like petrol engines (In most diesel engines the maximum torque stays below 4,500 rpm).[1]

CRDI stands for Common Rail Direct Injection that means, direct injection of fuel into the cylinders of a diesel engine through a single, common line, called the common rail which is connected to all the fuel injectors. Common rail direct injection is a direct fuel injection system employed for diesel engines. CRDI system uses an ion sensor to provide the real-time combustion data for individual cylinder. The common rail upstream of the cylinders acts as an accumulator which distributes the fuel to the injectors at a constant pressure up to 1600 bar. Fig.1 Shows the typical CRDI system layout.

Fuel economy of 25 to 35 % is obtained over a standard diesel engine and a substantial noise reduction is achieved due to a more synchronized timing operation. A common rail and injector is controlled by engine ECU (Electrical Control Unit) with many input sensors in HSDI (High Speed Direct Injection) diesel engine. The engine ECU plays the most important role in controlling the diesel engine.

The system layout includes high pressure pump, rail and pipes, injector, ECU, and sensors. Electronics has greatly contributed to the development of internal combustion engine. This progress has resulted in reducing environmental degradation, and yet continuing to support improvements in performance. Moreover regarding gasoline engine, a considerable step forward has been achieved by Common Rail (CR) technology able to exactly regulate the injection pressure during whole engine speed range.[2],[12] Fig 1. Shows the layout of the CRDI system.

The principle of CRDI is also used in petrol engines as dealt with the GDI (Gasoline Direct Injection), which removes to a great extent the draw backs of the conventional carburetors and the MPFI systems. Both petrol and diesel engines use a common 'fuel-rail' which supplies the fuel to injectors. However, in diesel engines, manufacturers refer to this technology as CRDi whereas

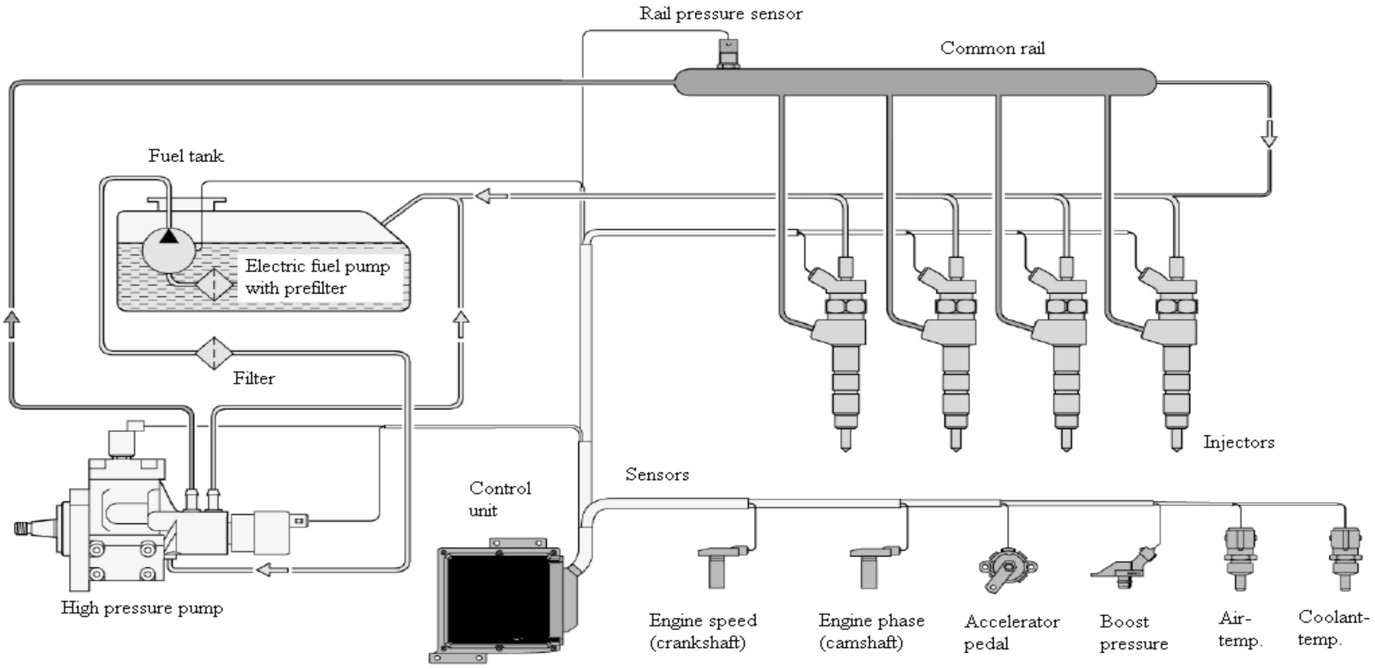

Figure 1: System layout[8]

Petrol engines term it as Gasoline Direct Injection (GDI) or Fuel Stratified Injection (FSI). Both these technologies have a similarity in design since they consist of "fuel-rail" which supplies fuel to injectors. However, they considerably differ from each other on parameters such as pressure & type of fuel used. [12],[13]

It features a high-pressure (over 2,000 bar or 200 MPa or 29,000 psi) fuel rail feeding solenoid valves, as opposed to a low-pressure fuel pump feeding unit injectors (or pump nozzles). Third-generation common rail diesels now features piezoelectric injectors for increased precision, with fuel pressures up to 2,500 bar (250 MPa; 36,000 psi). High pressure injection delivers power and fuel consumption benefits over earlier lower pressure fuel injection, by injecting fuel as a larger number of smaller droplets, giving a much higher ratio of surface area to volume. This provides improved vaporization from the surface of the fuel droplets, and so more efficient combining of atmospheric oxygen with vaporized fuel delivering more complete combustion.[11]

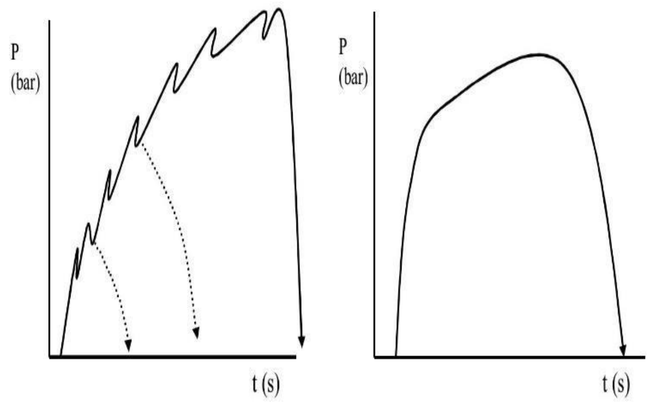

Figure 2: The injection pressure of a conventional fuel system and the common rail system[1]

Diesel engines are currently being paid more attention owing to their natural high efficiency and low fuel consumption. On the other hand, the diffuse type of combustion occurs in diesel engines, leading to generation of emissions and noise. It has been proved that the emissions from a diesel engine depend on the fuel injection specifications such as the injection pressure, the timing and the quantity. Application of mechatronic systems to diesel engines increases the ability of designers to reduce the emissions, the fuel consumption and the diesel noise. Increases in the numbers of sensors and actuators lead to a complicated and time consuming design procedure. Hence CRDI (Common Rail Direct Injection) controls a spray pressure, spray ratio, and multiple injections for saving fuel and reducing both the noise and exhaust gas .Also, it can control the spray timing and pressure without engine operation.[9]

2. HISTORY

The common rail system prototype was developed in the late 1960s by Robert Huber of Switzerland, and the technology was further developed by Dr. Marco Ganser at the Swiss Federal Institute of Technology in Zurich, later of Ganser-Hydromag AG (est.1995) in Oberägeri.

The first successful use in a production vehicle began in Japan by the mid-1990s. Dr. Shohei Itoh and Masahiko Miyaki of the Denso Corporation, a Japanese automotive-parts manufacturer, developed the common rail fuel system for heavy-duty vehicles and turned it into practical use on their ECD-U2 common rail system mounted on the Hino Ranger truck and sold for general use in 1995. Denso claims the first commercial high-pressure common rail system in 1995.[11]

3. CRDI FEATURES

Common rail refers to the single fuel injection line on the CRDI engines. Conventional direct injection diesel engines must repeatedly generate fuel pressure for each injection, in CRDI engines the pressure is built up independently of the injection sequence and remains permanently available in the fuel line. In the CRDI system developed jointly by Mercedes-Benz and Bosch, the electronic engine management system continually adjusts the peak fuel pressure according to engine speed and throttle position. Sensor data from the camshaft and crankshaft provide the foundation for the electronic control unit to adapt the injection pressure precisely to demand.

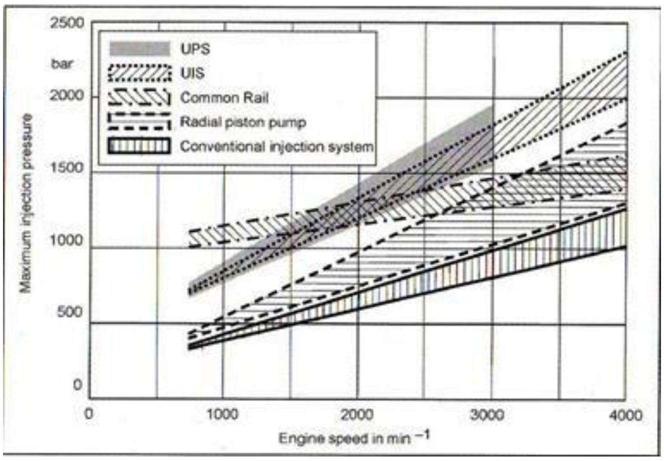

Figure 3: Comparison of spray pressure for different injection technologies[1]

Common Rail Direct Injection is different from the conventional Diesel engines. Without being introduced to an antechamber the fuel is supplied directly to a common rail from where it is injected directly onto the pistons which ensures the onset of the combustion in the whole fuel mixture at the same time. There is no glow plug since the injection pressure is high. The fact that there is no glow plug lowers the maintenance costs and the fuel consumption. Compared with petrol, diesel is the lower quality fuel from petroleum family.

Diesel particles are larger and heavier than petrol, thus more difficult to pulverize. Imperfect pulverization leads to more unburned particles, hence more pollutant, lower fuel efficiency and less power. Common-rail technology is intended to improve the pulverization process. To improve pulverization, the fuel must be injected at a very high pressure, so high that normal fuel injectors cannot achieve it. In common-rail system; the fuel pressure is implemented by a very strong pump instead of fuel injectors. The high-pressure fuel is fed to individual fuel injectors via a common rigid pipe (hence the name of "common-rail"). [2]

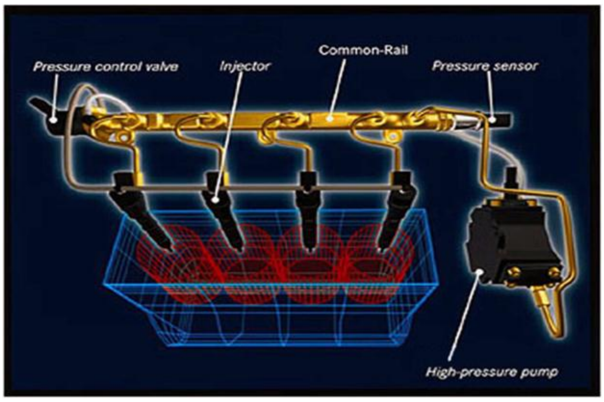

Figure 4: Flow of Common Rail Injection System[2]

In a common rail injection system the fuel is pressurised by a hydrostatic high pressure pump and fed to a 'common rail' arranged near the injectors for all cylinders. The injection event is electronically controlled by a solenoid valve. The rail pressure is controlled by a pressure control valve. The key advantage of the common rail system is that the pressure generation and the injection process are separated and, over the whole engine operating range, the start and end of injection as well as the pressure within permissible/useful limits can be chosen independently of the engine speed and load. Fig.4 Illustrates the flow of Common rail Injection System

The average rail pressure remains constant prior to the injection and the injected quantity is the result of the rail pressure, the flow losses in the injector and the opening duration of the electromagnetic valve. The injected quantity can be varied by the injector needle lift control. By opening and closing the solenoid valve, the pressure in the control volume is modulated and, thereby, the needle opens and closes. The solenoid valve has switching times which are smaller than 200 ms and this is essential for small quantities (1–2 mm3 per injection) for example for pilot injection. The rate of injection, i.e.

the rate at which fuel is injected as function of crank angle is an important feature of the injection process which affects the combustion process, fuel consumption and emissions.[5]

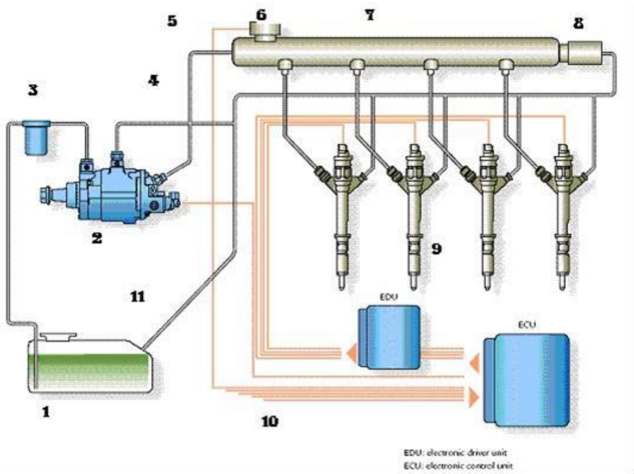

Figure 5: Diagram of operating principle of Common Rail fuel supply system [1]

Today as we know that a huge effort is devoted by companies to preserve the earth's environment. In particular, automobile industry has to comply both the reduction of pollutant emissions enforced by international regulations and the improvement of performance required by the customers. In this scenario, the GDI engines with High Pressure (HP) fuel injection systems, based on the CR architecture, can be considered a good solution to this aim. In fact, electronically controlled HP fuel injection system holds an important role concerning both the emission control strategy and the improvement of internal combustion engine performance.

High pressure injection allows to finely atomize the fuel spray and to promote fuel and air mixing, resulting in significant combustion improvements. Diesel fuel system is constantly improved, with optimal technical solutions to reduce pollution generation and fuel consumption, while improving reliability and engine power. Diesel engine scientists have come up with various measures like the CRDI which assists the spraying techniques and organizing combustion processes to improve the quality of fuel injection to limit pollutants.[4]

4. DESCRIPTION OF THE SYSTEM

A mechanically or electrically driven feed pump delivers the fuel through a fuel filter to the High Pressure Pump.

4.1 High Pressure Pump

The engine driven High Pressure Pump operates as a 3-plunger radial-piston pump. The current maximum system pressure of 1600 bar, and the operating pressure is controlled by the pressure regulator valve. [8]

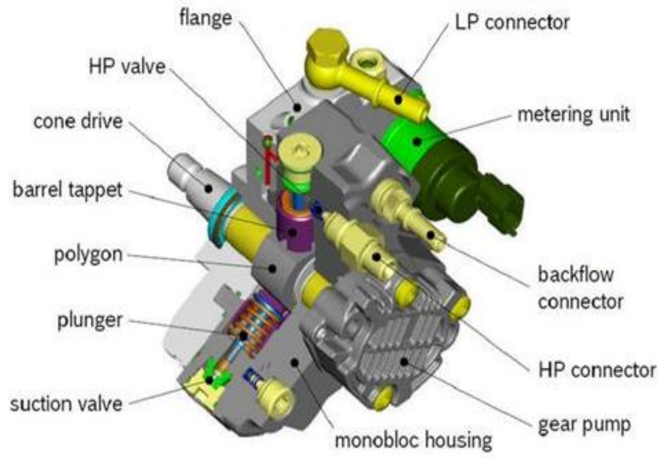

Figure 6: Structure of high pressure pump for Common rail system[1]

4.2 Piping System and Rail

In modern common rail systems, the injector supply pipe dimensions and rail volume are critical parameters that can affect injection system dynamic performance. The sizing of these components has a significant impact on critical fuel injection variables such as the dwell time between multiple injections and the minimum fuel injection quantity. With increased use of multiple injections and the need to accurately control small fuel injection quantities starting at about the Euro 4 phase, manufacturers have paid more attention these seemingly mundane components. High pressure pipes connect the High Pressure Pump with the accumulator, called the "rail".

Attached to the rail are the Rail Pressure Sensor for the acquisition of the rail pressure and the Pressure Limiter Valve which protects the components from excessive pressure. The rail is a thick walled tube designed to act as an accumulator to prevent significant pressure drop at the full fueling rate by providing hydraulic capacitance to the high pressure circuit. The volume of the rail varies from only a few cubic centimeters in passenger cars, to as much as 60 cm3 in heavy-duty applications. In most cases, a metering valve at the high pressure pump controls the high pressure fuel delivery to the rail. The rail pressure can be controlled to a value that depends on the needs of any particular engine operating condition. In some cases, rail pressures can reach 300 MPa.

Just as is the case with P-L-N systems, common rail systems are also prone to effects related to wave dynamics in the rail and in fuel lines. Waves generated by sudden changes in pressure in one part of the system, such as when injection needle valve is opened, may become reflected at rigid terminations in the system and return to their origins, causing unwelcome consequences such as reduced injection pressure and variations in injection quantity.In order to better control the pressure at the injector nozzle, some common rail injectors include an additional accumulator volume in the injector.[8],[15]

4.3 The Injector

Fig.7 shows Bosch Common Rai Injector. A fuel injector is nothing but an electronically controlled valve. It is supplied with pressurized fuel by the fuel pump, and it is capable of opening and closing many times per second. The interior design of the injector is nearly identical for different applications. However, the nozzle, direction of spray, number and diameter of spray holes and the injector body must be specifically adapted to suit to the design of the cylinder head of the engine used.When the injector is energized, an electromagnet moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a tiny nozzle. The nozzle is designed to atomize the fuel -- to make as fine a mist as possible so that it can burn easily.

The amount of fuel supplied to the engine is determined by the amount of time the fuel injector stays open. This is called the pulse width, and it is controlled by the ECU. The injectors are mounted in the intake manifold so that they spray fuel directly at the intake valves. A pipe called the fuel rail supplies pressurized fuel to all of the injectors. Each injector is complete and self-contained with nozzle, hydraulic intensifier, and electronic digital valve.

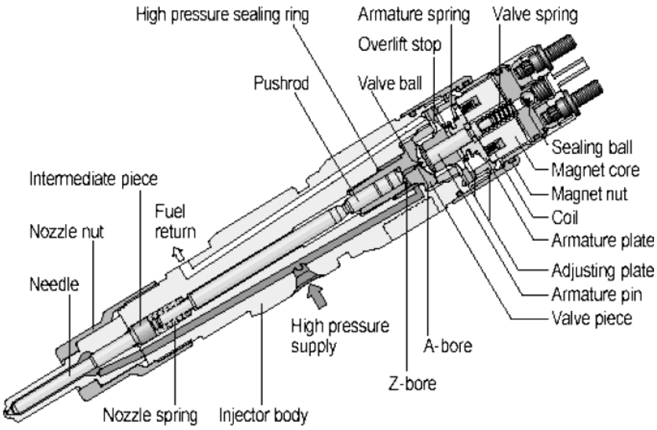

Figure 7: Bosch common rail injector for commercial vehicle applications[5]

At the end of each injector, a rapid-acting solenoid valve adjusts both the injection timing and the amount of fuel injected. A microcomputer controls each valve's opening and closing sequence. The reproducibility or stroke-to-stroke spread of the injected fuel quantity depends largely on the friction of moving parts. Therefore the nozzle needles have been coated with carbon in the area of the guides. Furthermore, the seat geometry of the Common Rail nozzle ensures that the small fuel quantities for the pilot injection remain constant throughout engine lifetime. [8],[14]

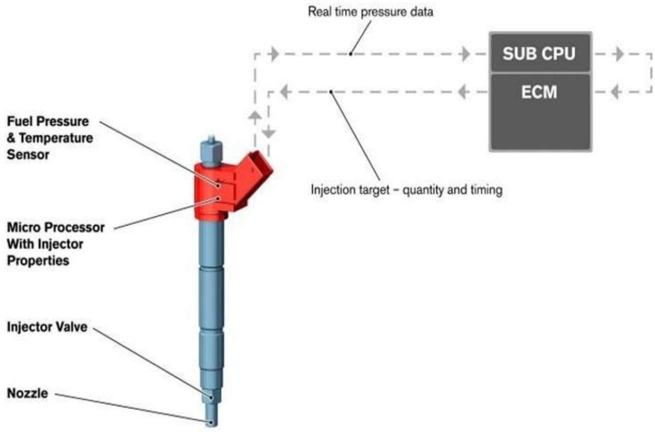

Figure 8: Injector with sensor and integrated processor[1]

4.4 Powerful Microcomputer (ECU/ECM-Electronic Control Unit/Module)

The new direct-injection motors are regulated by a powerful microcomputer linked via CAN (Controller Area Network) data bus to other control devices on board. These devices exchange data. The engine's electrical controls are a central element of the common rail system because regulation of injection pressure and control of the solenoid valves for each cylinder – both indispensable for variable control of the motor – would be unthinkable without them.

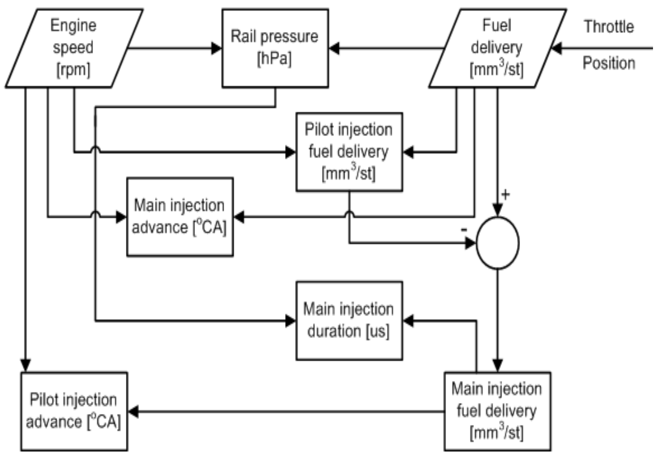

Figure 9: ECU flowchart for the calculation of the main injection parameters (common rail injection system) [18]

The electronic engine management network is a critical element of the common rail system because only the speed and spontaneity of electronics can ensure immediate pressure injection adjustment and cylinder-specific control of the injector solenoid valves. The ECU is based on a platform concept both for the mechanical and electronic parts. ECU's for Common Rail Systems are characterized by the sophisticated power stages which operate the solenoid valves of the injectors and the rail pressure closed-loop control.[8] . Fig. 10 shows Bosch MS4 Sport Electronic Control Unit.

Figure 10: Bosch MS4 Sport Electronic Control Unit[19]

4.5 Sensors

All sensors and actuators of a Common Rail System with the exception of the Rail Pressure Sensor are taken from the existing Diesel injection systems. The fuel pressure is measured by the Rail Pressure Sensor and in this first generation adjusted by the Pressure Regulator Valve to the correct stationary or dynamic set point in accordance with the engine operating conditions such as engine speed, load and temperature.

Fig. 11 shows a Block Diagram of the High Pressure Control function. We distinguish between three tasks within the High Pressure Control function: rail pressure setpoint, rail pressure control and rail pressure monitoring .The engine speed, the injected fuel quantity, the air pressure, the intake air temperature and the coolant temperature all have an influence on rail pressure setpoint.

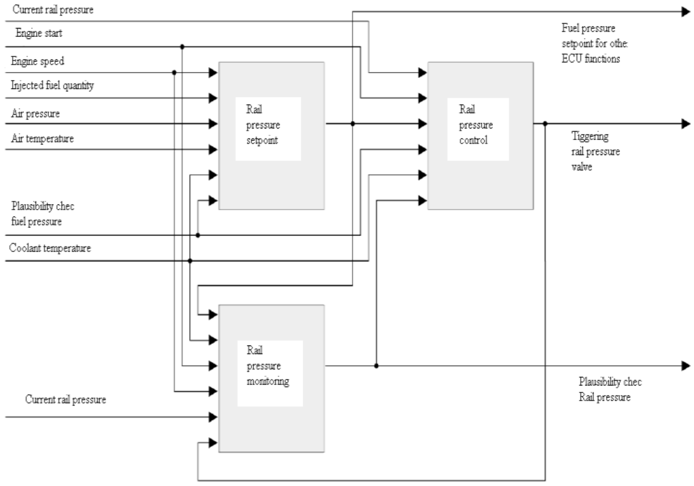

Figure 11: Block diagram of the high pressure control[8]

This setpoint acts as an input for the Rail Pressure Control. In addition, the current rail pressure, engine start, monitored by the Rail Pressure Sensor and the coolant temperature are conveyed directly to the Rail Pressure Control. The Rail Pressure Monitoring compares the current rail pressure and the setpoint of the Rail Pressure Control. Furthermore, the engine speed, the engine start, coolant temperature and rail pressure values are also conveyed directly to the Rail Pressure Monitoring. [8]

In order to provide the correct amount of fuel for every operating condition, the engine control unit (ECU) has to monitor a huge number of input sensors. Here are just a few:

- Mass airflow sensor - Tells the ECU the mass of air entering the engine
- Oxygen sensor(s) - Monitors the amount of oxygen in the exhaust so the ECU can determine how rich or lean the fuel mixture is and make adjustments accordingly
- Throttle position sensor - Monitors the throttle valve position (which determines how much air goes into the engine) so the ECU can respond quickly to changes, increasing or decreasing the fuel rate as necessary
- Coolant temperature sensor - Allows the ECU to determine when the engine has reached its proper operating temperature
- Voltage sensor - Monitors the system voltage in the car so the ECU can raise the idle speed if voltage is dropping (which would indicate a high electrical load)
- Manifold absolute pressure sensor - Monitors the pressure of the air in the intake manifold
- The amount of air being drawn into the engine is a good indication of how much power it is producing; and the more air that goes into the

engine, the lower the manifold pressure, so this reading is used to gauge how much power is being produced.

- Engine speed sensor - Monitors engine speed, which is one of the factors used to calculate the pulse width[14]

5. ADVANTAGES

1) Reduced noise and vibration.
2) Reduced smoke, particulates and exhaust.
3) Increased fuel economy.
4) Higher power output even at lower rpm.

6. DISADVANTAGES

1) High cost due to high pressure pump and ECU.
2) Technology cannot be employed in present engines.

7. CONCLUSIONS

Therefore new technologies and continuous improvements in fuel delivery systems like Common Rail Direct Injection system have greatly contributed towards improved engine performance, improved economy, saving fuel and limiting the pollution levels. In this system it is seen that the CRDI engine develops more power and also increases the fuel efficiency. Using this system reduces the noise and Pollutants. Particulates of exhaust are reduced. Recirculation of exhaust gas is enhanced and precise injection timing is achieved. Better pulverization of fuel is obtained in this system.

Also integration of the electronics with the mechanical components have made the process automatic, intelligent and far better than the old versions. The powerful microcomputer makes the whole system more complete and flawless and also doubles the torque at lower engine speeds. This technology assists new generation of engines to meet strict emission regulations to achieve environmental protection and sustainable development. Looking at the current pace of rising pollution and depletion of the fossil fuels, it is very important and crutial task for scientists, especially in the developing countries to look forward for the adaption and carring out research in this domain. With such advancement in the crdi technologies, in the near future diesel engines will work more efficiently, reduce fuel consumption and furthermore help reduce environmental pollution emissions.

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