DEVELOPMENT OF A COMMON RAIL TEST BENCH

CRASI Milan, MIHAI Ioan,
"Ştefan cel Mare" University
13 University Street, 720 225 Suceava, Romania
cramil@fim.usv.ro

Key Words: Common rail test equipment, Piezoelectric Common Rail injector**,** test bench;

Abstract: The Common Rail system in particular gives Diesel engines the means to become even quieter, more fuel efficient, cleaner and more powerful, without major modification of the engine. A high-pressure pump generates in an accumulator – the rail – a pressure determined by the injection pressure setting in the engine control unit, independently of the engine speed and the quantity of fuel injected. Most automakers have Common Rail Diesel engines in their model line-ups, even for commercial and heavy duty vehicles. This test bench has been developed to diagnose efficiently and accurately the vehicles engine with common rail system.

1. PRINCIPLES OF COMMON RAIL INJECTION

The design and achievement of a test bench for common rail injection is a tough job because we must employ all the equipment from a car engine, normally controlled by the ECU unit. It is necessary to substitute the ECU function by some electronic modules optimizing injection timing and quantity of fuel. The electronic device assists the control of the fuel injectors.

In this paper we will present main components and elements of the fuel circuit in an injection system. The electronically controlled common rail diesel fuel system can be divided into two sub-systems, the fuel pressure system and the fuel injection system. The fuel circuit contains the low-pressure circuit which has the task of supplying the high-pressure pump and the high pressure pump circuit.

1.1. Low pressure circuit

Fuel system schematic is presented in figure 1.1. The low-pressure system includes [1, 2] an electric pre-supply pump 1 that supplies fuel from the fuel tank 2. When ignition key is turn on, the pump is activated immediately or with some time delay (about 10 sec.), to raise the pressure in the circuit. The fuel pump pressure is limited to $0.5 \cdot 10^5$ N/m^2 by a pressure throttle mounted after the fuel filter. However, at the output of the fuel pump, there is an escape valve adjusted to $8 \cdot 10^5$ N/m^2.This valve performs two functions: protects the circuit if a fuel line is cracked or clogged and provide sufficient pressure to the fuel to pass through a clogged up filter.

The fuel pump flow is about 160 l/h and the nominal pressure is about $0,5 \cdot 10^5$ N/m^2 (relative pressure). Maximum pressure is $8 \cdot 10^5$ N/m^2 (relative pressure) in an extreme case of clogging of filter or fuel line. Low-pressure fuel lines are current plastic hoses and fitted with clutch hoses. If either hose is leaking or clutch hose is broken it must be replaced as quickly as possible.

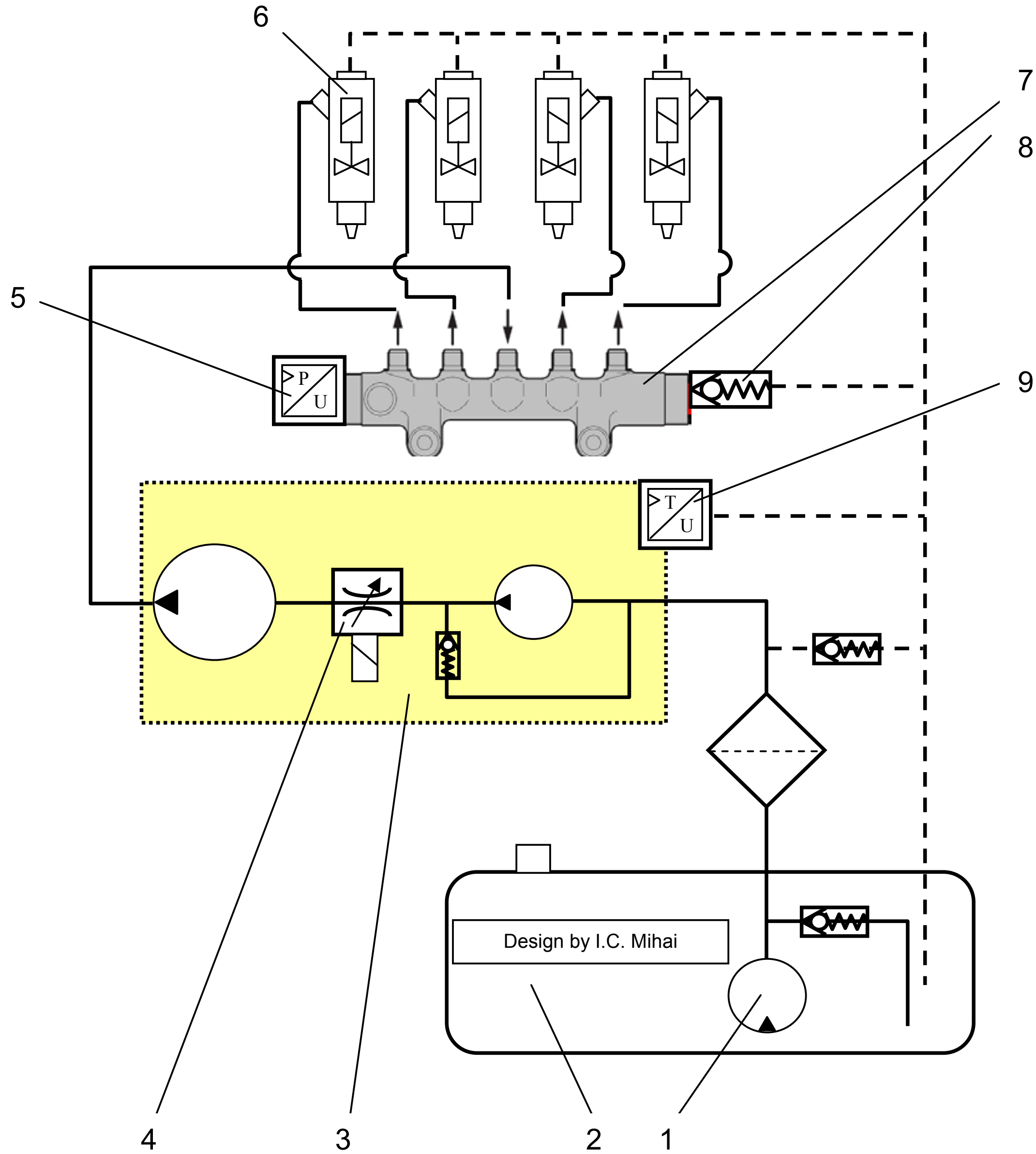

Figure 1.1: Fuel system, schematic diagram:
1 – pre-supply pump; 2 – fuel tank; 3 – fuel flow regulator; 4 – safety valve; 5 – fuel pressure sensor; 6 - injectors; 7 – common rail; 8 – pressure relief valve; 9 – fuel temperature sensor

1.2. High pressure circuit

The pressure range in the common rail circuit varies between $220 \cdot 10^5$ N/m^2 to $1500 \cdot 10^5$ N/m^2 corresponding to maximum load and full throttle. This pressure is delivered by a high pressure pump driven by a variable speed motor.

The fuel transfer pump is mounted on the high pressure fuel pump and is driven by the

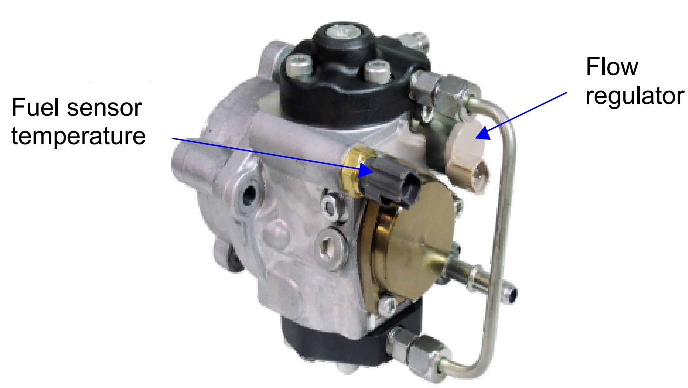

Figure 1.2: High pressure pump

high pressure fuel pump camshaft. The transfer pump draws fuel from the fuel tank and into the transfer pump inlet. Fuel is then pressurized and exits through the outlet to high pressure fuel pump. The transfer pump and the high pressure fuel pump come as an assembled unit (fig. 1.2.). The transfer pump usually has internal gearing (or trochoid pump) and supplies fuel to two pumping pistons.
The transfer pump provides the internal circulation of the fuel in the high pressure pump, cool and lubricate moving parts (pistons, pump shaft, etc.).
Common rail 7 acts as an accumulator to feed fuel to all of the injectors. The common rail system stores a constant amount of high pressure fuel at the rail and right up to the injectors.
Fuel rail pressure sensor 5 is a device that measures the pressure of the fuel that is to be delivered to the fuel injectors. This measurement is used by the engine control computer to determine how long the injectors need to be driven open to deliver a specific amount of fuel. If needed, the Electronic Control Unit (ECU) adjust the flow regulator 3, so the fuel is always at the correct pressure to suit the engine operating conditions.
Fuel temperature sensor 9 is located in the fuel return line between the fuel pump and the fuel cooler (if exists). It determines the current temperature of the fuel at that point. This signal is needed to calculate the start of injection point and the injection quantity so that allowance can be made for the density of the fuel at different temperatures. This signal is also used to determine the timing for switching on the fuel cooling pump or reducing the pressure in the rail.
Figure 1.3 puts in the high pressure fuel system schematic.

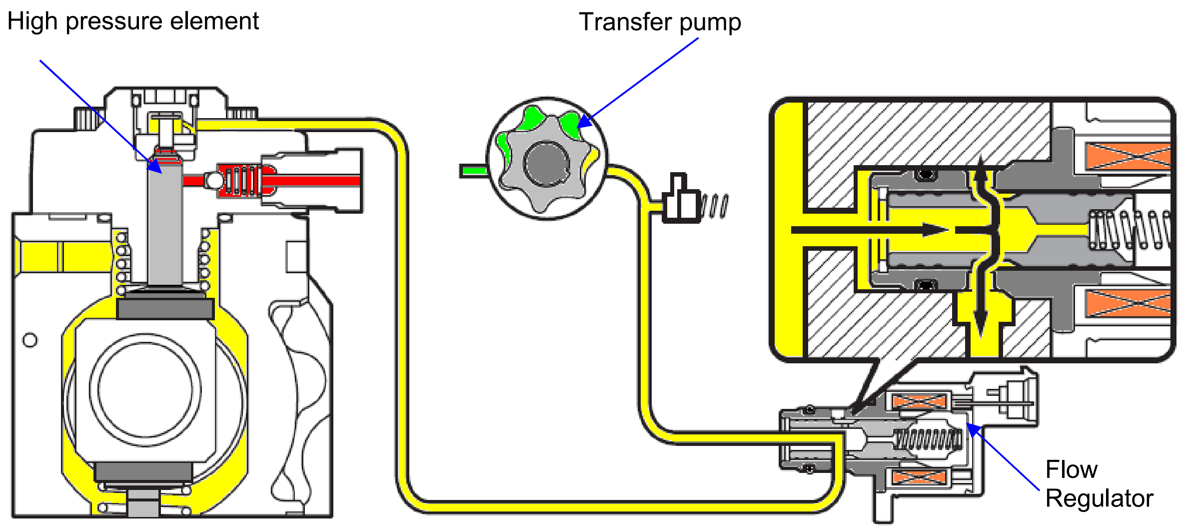

Figure 1.3: High pressure fuel system schematic

Flow regulator valve controls the fuel flow into the high pressure pump. This valve is driven by the ECU having a ratio of cyclic closing (because it is open without energizing).
Pressure relief valve (pressure limiter) 8 is shown in figure 1.1 and details are given in figure 1.4.
The valve is placed in the opposite end of the common rail (at one end being the pressure sensor). The common rail has a relief valve for controlling the maximum pressure in the common rail chamber avoiding pipe cracking, pump and injectors overheating, etc.

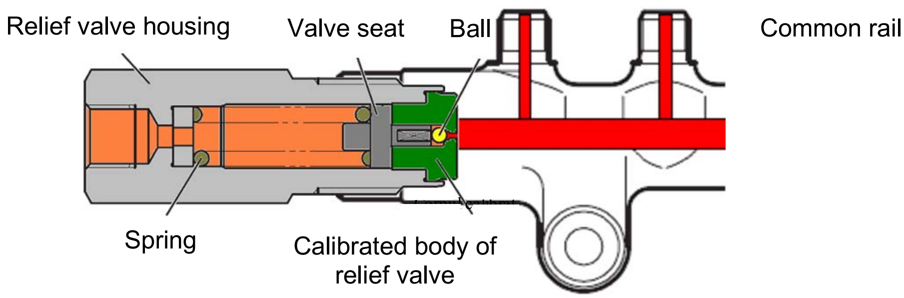

Figure 1.4: Pressure relief valve.

If the pressure in the common rail exceeds $2000{\cdot}10^5$ N/m^2, (in case of presence of CO gas in flow, the regulator would then be fully open) ball valve is removed from the seat and the pressure is discharged immediately to return the tank. However, the engine is not stopped because it establishes a balance of pressure caused by the relief valve and flow of high pressure pump. In the Common Rail accumulator injection system, the generation of the injection pressure is separate from the injection itself.
Pressure in common rail is about $2000{\cdot}10^5$ N/m^2 (see figure 1.5.). If fault is intermittent, once the pressure in the common rail falls below $500{\cdot}10^5$ N/m^2, the ball run back to its seat and relief valve is closed.
Conversely, if the fault is permanent, the pressure stabilizes to the steady value of $500{\cdot}10^5$ N/m^2 and the relief valve remains open. The relief valve will not close until cessation of electric contact, and the next start will rise again if the fault is still present.

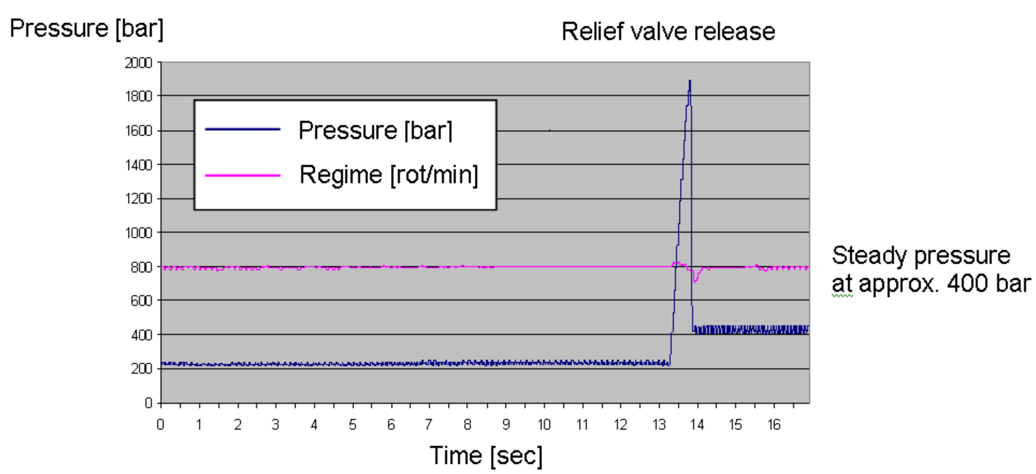

Figure 1.5: Disconnection of flow regulator in idle regime

Engine operation when the relief valve is open damaged the ball seat. Therefore, to avoid sudden relief valve opening while the engine would operate between normal pressures, the valve should be replaced after any trigger. Injectors 6 in figure 1.1 are controlled electromagnetic.
They are using (see figure 1.6) a valve under pressure of a spring which obstructs the rest of an outlet. In this position, the injector is closed because the pressure is applied on top of the needle, an area larger than the bottom. When the injection must occur, the injector solenoid is driven by the electronic control unit and the inlet valve leakage is open by the valve that arises under the influence of the magnetic field of the coil.

Thus the pressure applied over the needle drops, while the force is applied underneath remains identical: the needle arises and injection may occur. To lower the needle it is sufficient to stop energizing the solenoid of the electromagnetic valve.
The pressures will equilibrate again and force applied over the needle will be higher than that which applies below.

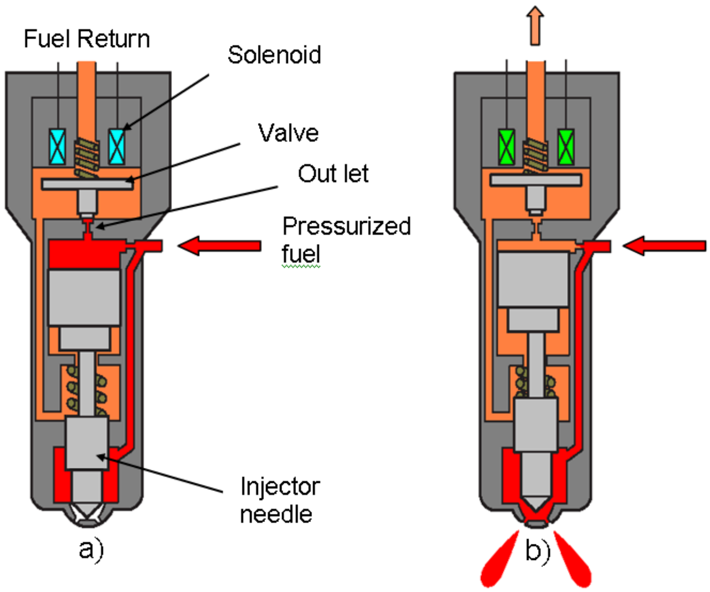

Figure: 1.6. Schematic diagram of the injector: a) Injector closed; b) Injector open

All injectors have manufacturing differences, no matter how small, which affects the control of the injected fuel.

2. EXPERIMENTAL COMMON RAIL STAND DESCRIPTION

To conduct an experimental study, a test bench was designed (shown in figure 2.1.) The most important elements are: a supply pump, an oil filter, a high pressure pump, a flow regulator, a common rail, a relief valve and four injectors.

Figure 2.1: Overview of the experimental stand.

High pressure pump is driven by a motor with an output of about 3 kW powered by 220-230 VAC, 50 Hz. The link between pump and motor shaft is provided by a coupling. The supply power for electronic injector drive and control is ensured by a switching-mode power supply. DC power supply is characterized by the following parameters: voltage input is 220-230 VAC, output voltages available 5 VDC, 5A, 12VDC, 10A and 12VDC, 5A.
For injector drive we used a saw tooth signal, thereby simulating the operation of the engine. It is forbidden to feed the injectors drive at 12 VDC, because it destroys the electromagnetic coil. During the experiments, following an electronic component failure, the drive power in electromagnets was increased from about 0,3÷0.6 ms at 0.5÷1 s for a short period (15÷30 s) which destroyed all four solenoids. After that, we replaced the timer with a more reliable one.

3. CONCLUSIONS

In the first part of the paper we present some principles that differentiate the functioning of common rail injection from conventional systems. There are differences between the two systems considering extremely high pressure injection values.
The particular design of Common Rail, with its flexible division of injection into several pre, main and post-injections, allows the engine and the injection system to be matched to each other in the best possible way. In the Common Rail accumulator injection system, the generation of the injection pressure is separate from the injection itself.
The high-pressure pump generates in an accumulator – the rail – a pressure of up to 1,600 bar (determined by the injection pressure setting in the engine control unit), independently of the engine speed and the quantity of fuel injected. This makes the injector drive more difficult, wear can be a destructive factor of the equipment and the temperature can lead to functional block.
After presenting some functional details we have made references to the achievement of the experimental stand. This stand meets our expectations on performance and cost, industrial made stands costing over thousands of Euro.
The modules description in detail was avoided because it will be, probably, subject to patents. Measurements performed are presented in another article.

References

[1.] VICTOR HILLIER, PETER COOMBES, NELSON THORNES: Fundamentals of motor vehicle technology, Ltd , 2004
[2.] ***NCT-1500 **Common Rail Tester** Quick Manual www.nex-tek.com/.../NCT-1500%20 MANUAL.pdf