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Phases PID Controller of Common-rail Pressure for Diesel Engine Electronic Injector Test Bench

Abstract. *Common-rail pressure of electronic injector test-bench is difficult to control for its time delay and flow pulse fluctuation. It shows a quick ascending and slow descending in test. In order to simulate a steady high fuel pressure provided to diesel engine injector, a simple but efficient phases PID controller was adopted. In phases PID controller, the whole process is divided into 10 phases according to the characters of error and the change rate of error. Each phase has its own PID parameters. With designed phases PID controller, common-rail fuel pressure was controlled along aimed pressure with just +/- 3 MPa deviation, which shows an excellent control results.*

Streszczenie. *Zaprezentowano ulepszony system kontroli wtrysku typu common-rail w silnikach Diesla. Cały proces jest podzielony na dziesięć faz każda każda posiadająca swój parametr PID. Z zaprojektowanym sterownikiem kontrola jest przeprowadzana z odchyłką nie większa niż 3 MPa. (**Sterowniki PID do kontroli wtrysku paliwa typu common-rail w silnikach Diesla**)*

Keywords: Electronic Injector Test Bench, High-pressure common-rail fuel control, Phases PID controller
Słowa kluczowe: kontrola wtrysku, common-rail, sterowniki PID

1. Introduction

Electronic injector performance research test-bed simulates the operating environment of electronic injector, provides smooth high-pressure common-rail（HPCR）fuel pressure, is an important platform for performance research, design and manufacturing, quality measurement of electronic injector. Electronic injector test-bench comprises hardware (such as oil or coolant tank, pumps, motors, turbocharger and valves etc) and software. Measurement and control software system controls the running of all hardware and collects, analysis data. PID fuel pressure controller of high-pressure common-rail is one part of the measurement and control system based on the test-bed. In order to assure the test-bench a maximum 200 MPa fuel pressure and enough fuel flow, turbocharger under the control of measurement and control system is used to build the fuel pressure. Continuously adjustable fuel pressure between [25 MPa, 200 MPa] is provided by the system to meet needs of different type of injector.

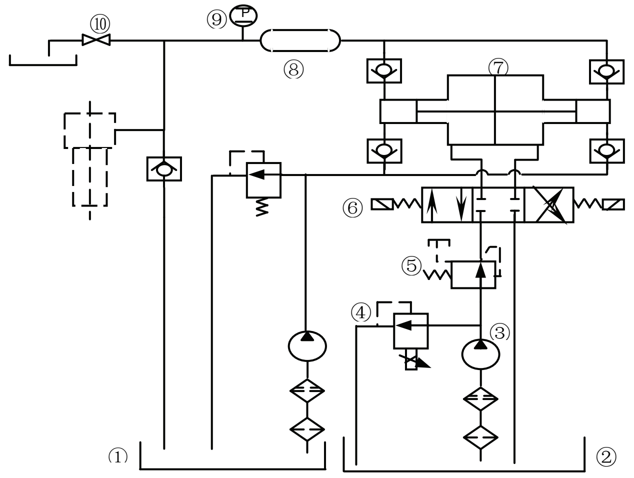

Fig.1. Oil, fuel and coolant circuits of test-bed (①Fuel Tank ② Hydraulic Tank ③Hydraulic Pump ④Proportional Relief Valve ⑤ Proportional Regulator ⑥Directional Control Valve ⑦Turbocharger ⑧Accumulator ⑨Pressure Sensor ⑩Safety Valve)

2. High-pressure oil circuits of test-bench

It is necessary to introduce the test-bed before we go forward to the phases PID controller, which is based on the test-bed. The test-bed comprises of three types of circles: (1) Hydraulic circuit, the main function of this circuit is to build itself suitable pressure, then affect fuel circuit and prompt it build high enough pressure for injector through a turbocharger. An aimed fuel pressure between [25 MPa, 200 MPa] could be set. Hydraulic circuit is started by hydraulic pump and motor. Hydraulic pressure is affected through proportional regulator and proportional relief valve. (2) Fuel circuit, it is affected by hydraulic circuit and build itself a suitable pressure for the injection of electronic injector, this circuit is started and regulated by fuel pump and motor, through circulate hydraulic and fuel separately into pressurized big cylinder and small cylinder of turbocharger and control the pressure of big cylinder, the fuel pressure of small cylinder is adjusted to aimed value. (3) Cooling circuit, this circuit is responsible for the cooling of hydraulic circuit and fuel circuit and assure the system a regulate operation. Fuel warming and cooling solenoid valves and hydro cooling solenoid valve are needed to make sure the temperatures of circuits are in the range. Fig.1 shows the theory of oil and fuel circuit.

3 Phases PID control of the common-rail pressure

3.1 Closed-loop control of common-rail pressure based on injector test-bench

As a main component of measurement and control system common-rail pressure control assures the fuel circuit a stable and suitable pressure to injector. In the subsystem, a pressure sensor (showed in fig.1) is adopted to detect pressure of fuel supply to injector. Proportional relief valve and proportional regulator (showed in fig.1) act as actuators control fuel pressure. The area ratio of higher pressure side to lower pressure side of the piston in turbocharger is 19:1. This means if 120 bar pressure was set to the inlet of turbocharger through proportional relief valve and proportional regulator, 2000 bar high pressure would be obtained at turbocharger outlet with fuel flux stable at about 4L/min. The closed-loop control of it showed in fig.2.

The subsystem of pressure PID control of high-pressure common-rail provides continuous voltage signals to proportional relief valve and proportional regulator. These two valves are opened with an initial value of zero voltage, after hydraulic pump motor started for about 2- 4 seconds, a voltage with scale of 1-10V to 0 – 200 MPa is set to proportional regulator. Fixing the voltage of proportional regulator, adjusting the voltage of proportional relief valve with phases PID control, thus fuel pressure is stabled at the given pressure.

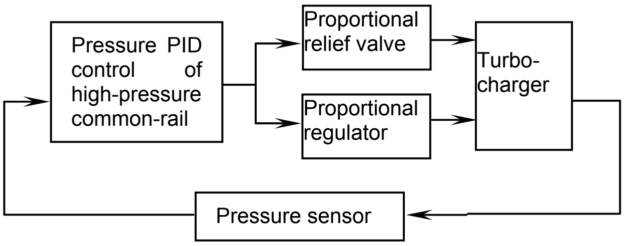

Fig.2. Closed-loop control of common-rail pressure

3.2 Error and the change rate of error of common-rail pressure

Common-rail pressure of electronic injector test-bench is difficult to control for time delay and flow pulse fluctuation. It shows a quick ascending and slow descending in test, and with sharp turning at the top and bottom points in experiments, as is showed in fig.3. The data was obtained when system is in injection and with open-loop control.

There are two lines in fig.3. The upper blue curve is proportional regulator voltage. Lower red curve is corresponding real common-rail pressure. Aimed fuel pressure is 160 MPa at first stage then changed to 190 in the end. When proportional regulator voltage is stable at 4.4V while proportional relief valve voltage is 8.1V, real pressure fluctuates with biggest error up to 9 MPa.

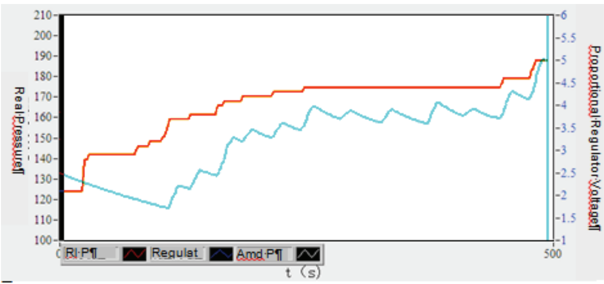

Fig.3. Error and the change rate of error of common-rail pressure in open-loop control

Table 1. The 10 phases of common-rail pressure control

Phase No.	error	Phase No.	error
1	$e \geq 50$	6	$-5 < e \leq -0.5$
2	$50 > e \geq 30$	7	$-10 < e \leq -5$
3	$30 > e \geq 10$	8	$-30 < e \leq -10$
4	$10 > e \geq 5$	9	$-50 < e \leq -30$
5	$5 > e \geq 0.5$	10	$e \leq -50$

Based on the characteristics of the error of common-rail pressure, 10 phases are divided from the whole control process, as is showed in table 1.

3.3 Phases PID controller tuning

Based on the character of error and the change rate of error shows in experiment, as is showed in fig.3, phases PID control is introduced. The whole process is divided into 10 phases with their own PID parameters in each phase. PID parameters are obtained based on experience, experiments, and the following method.

If the mathematical model of a controlled object is unknown, PID parameters usually are optimized from experiments. Critical ratio method and feasibility of closed-loop response curve are mainly adopted for PID tuning. In this paper, the simplified expanded critical ratio method introduced by Roberts.P.D in 1974 is applied.

(1) $$\Delta u(k) = K_p[2.45e(k) - 3.5e(k-1) + 1.25e(k-2)]$$

where: $e(k)$ – tracking error at time, k, K_p – proportional gains.

Adjust K_p in experiments for each phase, until the result is satisfying.

4 Control result of phases PID controller

Based on experience, expanded critical ratio method and experiments, phases PID tuning was finished with apparent improvement in pressure control. Error could be higher up to ±10 MPa in open-loop control, while lower to ± 3 MPa in phases PID controller, as could be indicated from fig. 4 and fig.5.

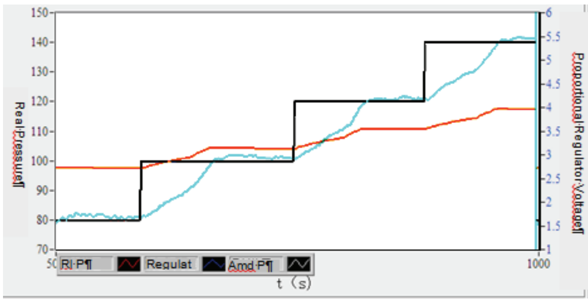

Fig.4. Controlled common-rail pressure curve at aimed value of 80 MPa, 100 MPa, 120 MPa, 140 MPa.

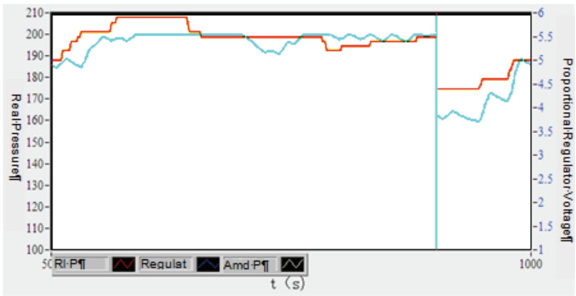

Fig.5. Controlled common-rail pressure curve at aimed value of 200 MPa

In fig.4, aimed common-rail pressure changed from 80 MPa to 100 MPa and then 120 MPa, 140 MPa, following proportional regulator voltage adjusted along blue curve and real common-rail pressure altered along red curve.

Fig.5 displays the control process when aimed common-rail pressure varied to 200 MPa. Both fig.4 and 5 demonstrate the result that control precise improved to ±3MPa in phases PID controller compared to open-loop controller.

5. Conclusion

The common-rail pressure phases PID controller provides stable and continues adjustable fuel pressure between 25 MPa to200 MPa that tested injector needs.

Many papers and experts have given efficient methods on how to tuning PID controller on temperature control, pressure and flux etc, but not so many for common-rail pressure control on test-bed. More accurate PID parameters should be found or methods should be studied on, such as cooperating PID with fuzzy control or PID with neural network, so we could have $\pm 1MPa$ or better precisions, which would be a further research to be done in the future.

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