Design Engineering

ISSN: 0011-9342
Issue: 11 | Pages: 423 - 434

Study on Structural Optimization of Fuel Electronic Injection Device for Diesel Engine

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Abstract:

The fuel injection devicefor diesel engine is the most important part in the combustion process, which is one of the key issues to optimize the dynamic performance, discharge and economy of diesel engine. The combustion process is directly related to the structure of electronic fuel injection device.In this paper, the fuel injection device controlled electronically by time and pressure inthe diesel engine of high pressure common rail is taken as the research object. The simulation model of injection device is established by using the simulation platformbased on Hydsim. The influence of structure optimization on the movement state of needle valve, the fuel pressure at the injection hole and the injection rate is studied. The results show that the optimized injection device can eliminate the hydraulic delay, reduce the fluctuation of injection pressure, and shorten the injection duration.And it lays the foundation for multiple injection. By the above structure optimization, the atomization effect of fuel is improved, and the purpose of improving economy and reducing emission is achieved.

***Keywords**: Fuel injection device,High pressure common rail,Diesel engine,Fuel injection rate,Needle valve lift,Structure optimization.*

I. INTRODUCTION

At present, the current situation is energy shortage and environmental pollution in society. Diesel engine is better in line with the needs of the times because of high thermal efficiency, good performance and high power. How to optimize the dynamic performance, discharge and economy of diesel engine is the focus and important research content at present. The key is to perfect the combustion process. The fuel injection device in diesel engine is the most important part of the combustion process. So how to optimize the fuel injection structure and control strategy of diesel engine is the mainstream direction of the development of diesel engine technology.

The overseas research in the aspect of electronically controlled fuel injection device is

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relatively early, and the corresponding products have been applied in actual production and life. There are Italian Fiat Company, German Bosch Company and Japanese Electrical Equipment Company. Fiat Italian company developed “Unijet” system. The high-pressure pump in the system has its own pressure regulator, which enables the system to better control the injection pressure in the pre-injection stage, thus reducing the emissions of nitrogen oxides and carbon dioxide [1]. In addition, the system can adjust the injection timing and injection pressure flexibly, which further reduces the combustion noise and soot emissions. The common rail (CR) system was developed by German Bosch Company. The system is equipped with a new type of injector with pressure conversion device, which makes the injection response speed of the system be accelerated obviously and the injection effect be improved obviously [2]. In addition, the system has good adaptability in practical application and can be successfully matched with a large number of diesel engines. It is one of the most widely used high-pressure common rail fuel injection systems at present. ECD-U2 system has been developed by Japan Electric Equipment Company. The system has the throttle hole and control piston which can obtain ideal injection rate. In addition, by adjusting the solenoid valve, the system can achieve multiple injection, further perfect the operation stability, and reduce the working noise and the emission of nitrogen oxides [3].

Domestic research in this field started relatively late and is still in the stage of experimental research. Chen Liyong of Tianjin University proposed a new control strategy for the system solenoid valve [4]. Huang Zheng of Shanghai Jiaotong University mainly studied the relationship between emission particles and combustion characteristics [5]. Zhang Peng of Beijing University of Technology designed a new solenoid valve and further improved its response speed [6]. In addition, Tianjin University independently designed FIRCRI system on the basis of CR system of Bosch Company, which can achieve stable micro pre-injection and multiple injection. Shanghai Jiaotong University independently designed GD-1 system on the basis of ECD-U2 system of Japan Electric Equipment Company, and successfully matched it on Yuchai diesel engine.

At present, most commercial softwares are used in simulating fuel injection system at home and abroad, such as Matlab/Simulink, AMESim and Hydsim. Matlab/Simulink can carry on the simulation analysis to the system structure, but needs to write the complex simulation program. The non-professional programmer is very difficult to establish the system simulation model [7]. AMESim can build the multi-disciplinary intercross system model. However, it is necessary to construct a complicated model scheme by oneself, and the experimenters should have rich experience in model building [8]. Hydsim uses its graphical and modular modeling method to establish the fuel injection simulation model. The simulation model can simulate and analyze the structural parameters of the system without writing complicated programs and constructing complicated schemes, which greatly reduces the difficulty of the simulation model construction.

II. OPTIMUMDESIGNOFINJECTORSTRUCTURE

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Time-pressure control is a great innovation of electronic fuel injection device. It uses high-pressure common rail pipe to control the pressure. The stabilized fuel enters the injector for fuel injection. It mainly consists of fuel tank, low and high pressure fuel pumps, filter, common rail pipe, fuel injector, electronic control unit (ECU), sensors and a series of auxiliary monitoring devices [9]. The time-pressure controlled injection device is shown in Fig 1.

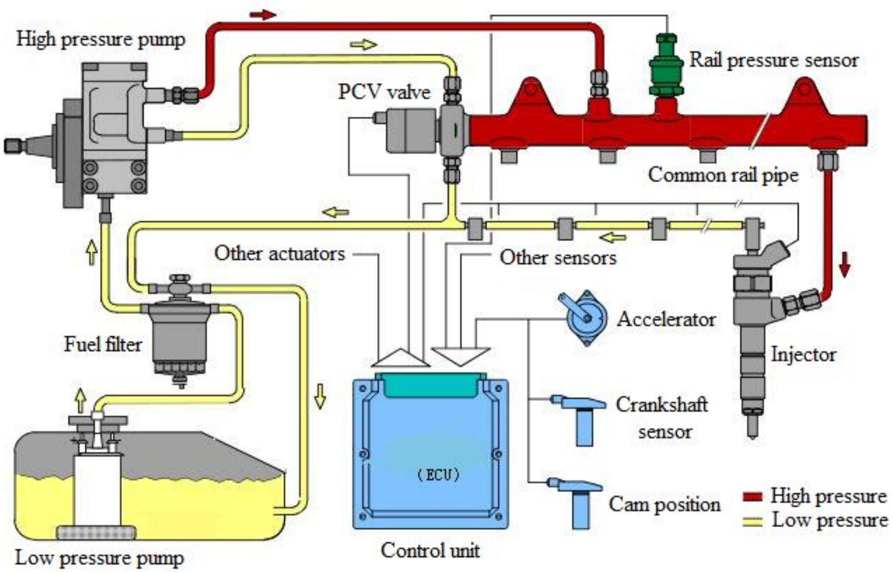

Fig 1: Time-pressure controlled injection device

The fuel in the fuel tank is first sent to the high pressure pump by the low pressure pump. The high pressure pump makes the radial piston compress the low pressure oil into the high pressure state through reciprocating motion, and then the oil is transported to the common rail pipe. After entering the injector through the common rail pipe, it is divided into two ways, one flow into the oil chamber, and the other flow into the control chamber [10]. The injector electromagnetic valve, driven by the ECU signal, changes the pressure in the control chamber to allow the needle valve to move in order to achieve fuel injection. The pressure quickly decreases when the power is switched on. Then the needle valve rises, and the fuel in the oil chamber is injected into the cylinder. When the power is cut off, because the pressure exists in the common rail pipe, the pressure in the control chamber is quickly restored. Then the needle valve falls back and the fuel injection is completed. Therefore, each time the amount of fuel injected into the cylinder is mainly determined by the electrification time of the electromagnetic valve and the common rail pressure. The oil pressure in the common rail pipe is determined by the amount of oil flowing into it. The state parameter signal of ECU output can adjust the proportional throttle valve opening at the inlet of the high pressure oil pump. Once the pressure in the common rail is too large, you can quickly and significantly reduce the pressure by the positive crankcase ventilation (PCV) valve. In addition, the rail pressure sensor monitors the pressure in the pipe in real time and gives feedback to ECU for the closed loop control to

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achieve the desired common rail pressure under each operating condition.

Compared with the traditional fuel injection device, the time-pressure control not only retains the advantages of high precision and fast response of electromagnetic valve control, but also cuts off the direct relationship between fuel injection rate and pump speed. It can control the fuel injection rate accurately, so that the fuel injection characteristics are not affected by the pump speed, and can control the fuel injection characteristics flexibly to a greater extent to achieve the best fuel injection effect.

The switch speed of needle valve and the injection rate can be adjusted by the structural parameters such as the area of throttle orifice and the diameter of control piston. However, no matter how to adjust the throttle orifice area and control the piston diameter, there is a hydraulic delay phenomenon, that is, there is a time interval between the opening and closing of electromagnetic valve and the start and end of injection. The time interval is difficult to measure. So, it is necessary to optimize the structure of electronic control injection device for diesel engine under high-pressure common rail in order to eliminate the hydraulic delay at the opening time of electromagnetic valve and needle valve. Then the starting and ending time of injection synchronize with the opening and closing time of electromagnetic valve, and to a certain extent slow down the fluctuation of needle valve.

The optimized electromagnetic valve controls the injector to directly let high-pressure fuel into the accumulated chamber, eliminating the high-pressure oil circuit leading to the control chamber, solving the hydraulic delay phenomenon existing in the opening time of electromagnetic valve, outlet control valve and needle valve of the conventional injection device, and slowing down the fuel injection pressure fluctuation and reduction caused by the internal fuel back-flow of the accumulated chamber in the condition that the existing electromagnetic valve controls injector.

III. SIMULATING MODEL FOR FUEL INJECTION

Hydsim simulation platform is used to establish the simulating model for the optimized fuel injection device, as shown in Fig2. The electronically controlled fuel injection device with optimized structure directly lets high-pressure oil enter the accumulated chamber, eliminates the high-pressure oil circuit leading to the control chamber, and simplifies the control state of electromagnetic valve into the time-displacement of the nozzle seat. In addition, the Hydsim simulation model of the fuel injection device after structural optimization has been simplified to a certain extent, which makes the optimized simulation model more concise and clear when the conditions are satisfied.

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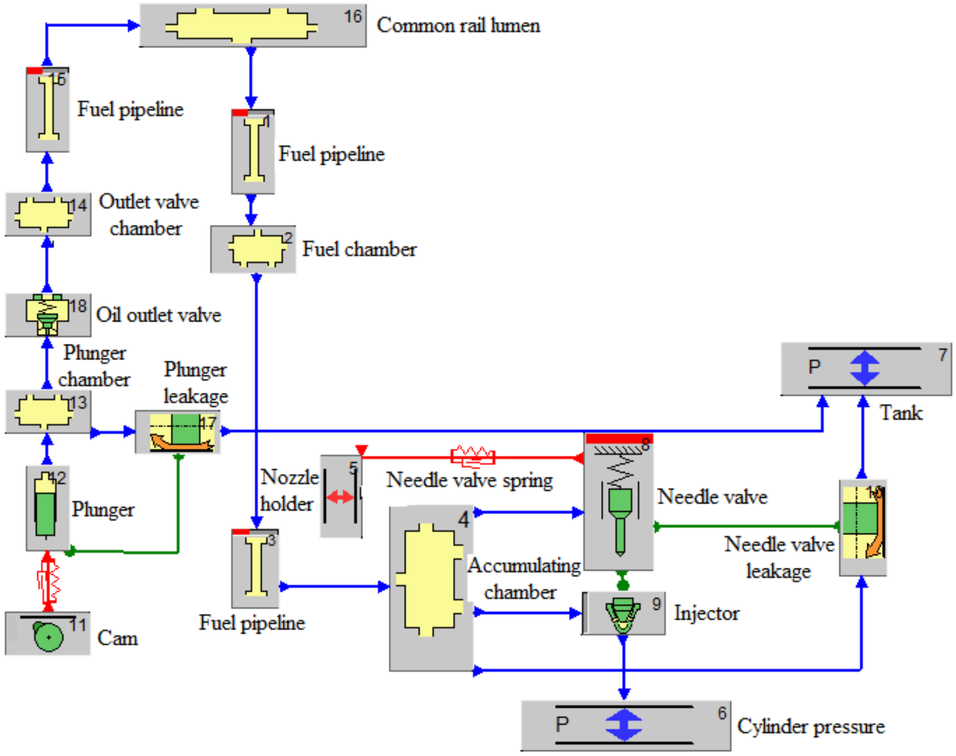

Fig 2: Simulatiing model for fuel injection device after structure optimization

Hydraulic Connection: The fuel oil in the plunger cavity is connected to the high pressure Common rail pipe cavity through the oil outlet valve cavity and the fuel pipeline. The fuel in the common rail pipe cavity is divided into two branches at the junction of the fuel chamber. One is connected to the pressure chamber through the fuel pipe, and then to the needle valve and the nozzle, and the nozzle is connected to the cylinder pressure. The other is connected to the control chamber which is connected with the control piston and the oil outlet throttle valve respectively. The oil outlet throttle valve is connected with the electromagnetic valve through the oil outlet throttle cavity, and the fuel is fed into the tank through the overflow chamber and the tank throttle.

Mechanical Connection: Cam and plunger are connected through a greater stiffness of the spring. That is to say, the connection between the cam and plunger does not consider elastic deformation, and plunger movement is completely determined by the cam. The needle valve has two mechanical connections. One is the needle valve spring of less rigid, which is connected to a non-moving mechanical boundary (nozzle seat), indicating that the needle valve spring is fixed on the mechanical boundary (nozzle seat). The other is the spring with more stiffness, which is connected to the control piston, indicating a fixed connection between the needle valve and the control piston.

Special Connection: Special connection between piston and piston leakage indicates fuel leakage when passing through the motion pair of piston and cylinder. Special connection

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between control piston and control piston leakage indicates fuel leakage when passing through the motion pair of control piston and cylinder. Special connection between the needle valve and the needle valve leakage means fuel leaks when passing through the motion pair of needle valve and cylinder. In addition, the needle valve and the nozzle are also specially connected.

IV. RESULTS OF OPTIMIZATION ANALYSIS

The injection rate of the injection device depends entirely on the injection timing and injection pressure. The injection timing is controlled by the motion state of the needle valve, while the injection pressure is controlled by the fuel pressure at the nozzle [11-12]. In order to study the injection rate of the optimized injection device, the motion state of the needle valve, the fuel pressure at the nozzle and the injection rate of the device are analyzed in this paper.

4.1Contrastive Analysis of Needle Valve Lift

The contrast chart of needle valve lift of injection device before and after structural optimization is shown in Fig 3. According to the control state curve of electromagnetic valve and the needle valve motion curve, after structure optimization, the optimized needle valve motion curve is highly consistent with the control state curve of electromagnetic valve (the time-displacement curve of nozzle seat), no matter when it is opened, when it is seated and when it is fully opened. Only when the needle valve is fully opened, the high-pressure fuel in the accumulator injects into the cylinder at the maximum injection rate, which causes the fluctuation of the fuel pressure in the accumulator in a certain range, and causes the fluctuation of the needle valve in a small range, but its fluctuation is relatively small and can be neglected.

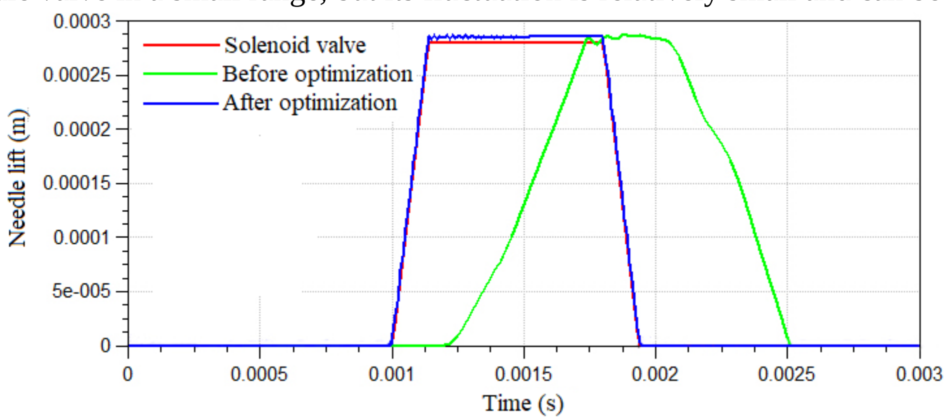

Fig3:Comparison of needle valve lift

According to the needle valve motion curve before structural optimization and the needle valve motion curve after optimization, the optimized injection device can open the needle valve ahead of time, which is consistent with the opening time of the electromagnetic valve. That is to say, the hydraulic delay between the electromagnetic valve and the needle valve is eliminated. Secondly, the time of needle valve opening process and needle valve seating process are reduced after optimization, and the duration of needle valve opening is increased. On the

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premise of satisfying the fuel injection volume of the device, the duration of needle valve opening is reduced by about 28%, which lays a foundation for multiple injection. Finally, the optimized injection device has certain advantages in the stability of the needle valve. When the needle valve is fully opened, the fluctuation range of the needle valve in the optimized injection device is smaller than that before optimization. This is because the fluctuation range of the needle valve in the pre-optimized injection device is relatively large due to the internal fuel back-flow in the accumulated chamber. The optimized injection device cancels the high-pressure oil path leading to the control chamber, directly lets the high-pressure fuel into the accumulated chamber, reduces the fluctuation of the fuel pressure in the chamber, and thus guarantees the stability of the needle valve movement.

4.2 Contrastive Analysis of Injection Pressure

The fuel pressure comparison of the nozzle before and after structural optimization is shown in Fig 4. Firstly, when the electromagnetic valve is opened, the optimized injection device starts to inject high-pressure fuel into the cylinder as the nozzle seat moves upward. Secondly, the fuel injection pressure of the optimized device increases rapidly compared with that before optimization, because the optimized device cancels the high-pressure oil circuit leading to the control chamber, avoids the fuel back-flow of the device before optimization, which leads to the decrease of the fuel pressure in the accumulated chamber, and makes the optimized device have greater injection pressure at the beginning of injection. When the needle valve is fully opened, the injection pressure of the optimized injection device is slightly larger than that of the original one, which is closer to the rail pressure value. The main reason is that the optimized device avoids diverting fuel into the control chamber. Even so, injection pressure in the optimized device is slightly lower than the rail pressure value, which is about 143MPa. This is because the fuel leakage occurs when passing through the cylinder motion pair of the needle valve, resulting in the decrease of the injection pressure of the nozzle. Finally, when the injection time is satisfied, the nozzle seat moves downward, driving the needle valve until it closes. Compared with the rapid drop before optimization, the optimized device can cut off the fuel circuit quickly, which is better in line with the injection characteristics.

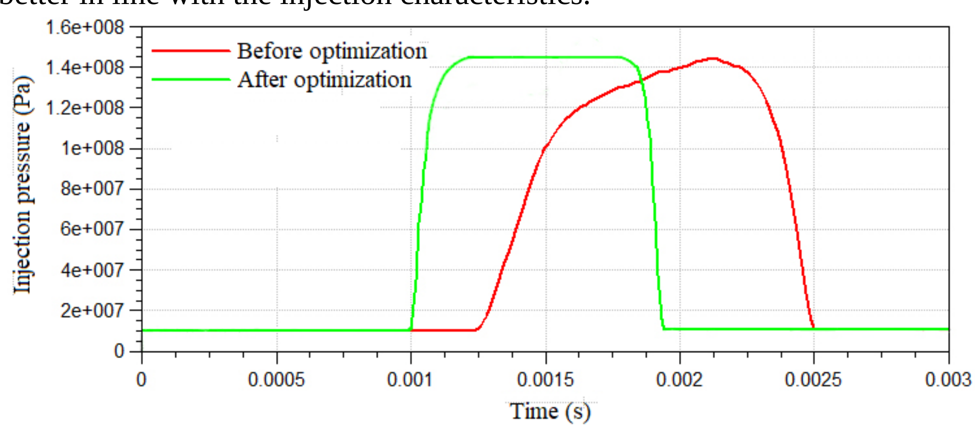

Fig4:Comparison of fuel pressure

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4.3 Contrastive Analysis of Fuel Injection Rate

The fuel injection rate comparison chart of the device before and after structural optimization is shown in Fig 5. Firstly, the fuel injection rate of the optimized device increases rapidly when the nozzle seat moves upward (electromagnetic valve opens). Compared with the device before optimization, the start time of fuel injection is earlier. Secondly, the fuel pressure of the optimized device is relatively stable, and the change of fuel injection rate is mainly determined by the opening speed of needle valve, which makes the control of fuel injection rate simpler. In addition, when the needle valve is fully opened, the maximum injection rate of the optimized device is slightly higher than that before optimization, because the optimized device has a higher injection pressure, and the fuel can achieve the expected injection volume in less time.

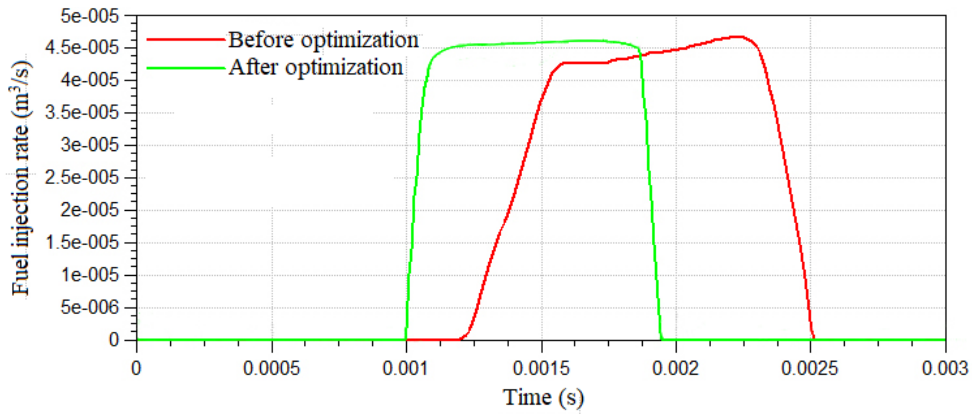

Fig5:Comparison of fuel injection rate

V. VERIFICATION OF SIMULATION AND TEST FOR FUEL INJECTION DEVICE

In this paper, the 186FA injector is selected. Its physical object is shown in Fig 6, and its main structural parameters are shown in TABLE I. The electromagnetic valve control status is shown in TABLE II. Under the given rail pressure 150MPA, the main injection test was carried out.

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Fig6:Physical drawing of electronically controlled injector

TABLE I. Main parameters of fuel injector

Parameter	Value	Unit
Control cavity volume	2e-8	m^3
Volume of accumulator chamber	1.7e-7	m^3
Diameter of needle valve conduit	4e-3	m
Spray hole number	4	
Spray hole diameter	9e-4	m

TABLE II. Solenoid control status

Control status	Time/s
Opening time	1e-3
Full open	1.138e-3
Shut-down time	1.8 e-3
Complete shut down	1.936e-3

In order to verify the accuracy of the simulation model of fuel injection device, the simulation value, the test value and the standard value are compared. The simulation value, test value and standard value of the fuel injection rate are compared as shown in Fig 7, and the simulation value, test value and standard value of the fuel injection quantity are compared as shown in Fig 8.

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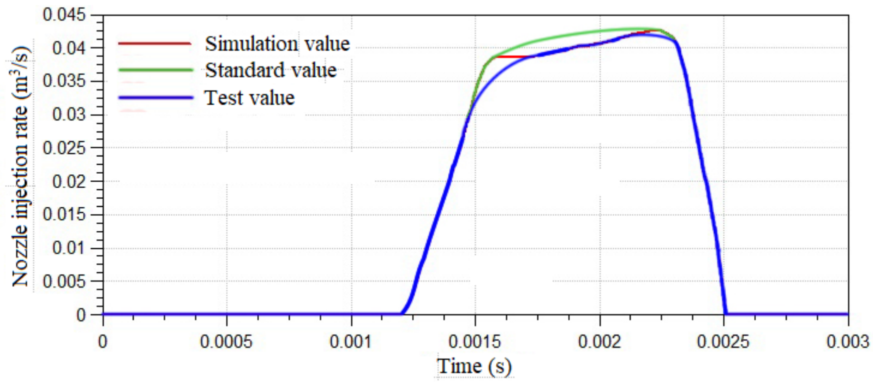

Fig7:Comparison of simulation value, test value and standard value of injection rate

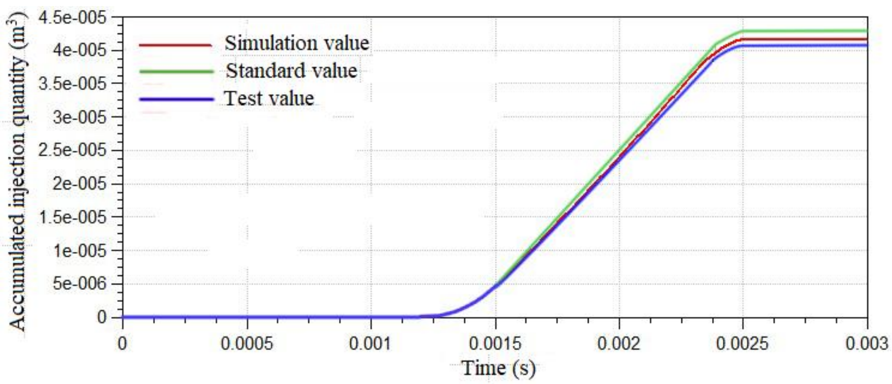

Fig8:Comparison of simulation value, test value and standard value of injection quantity

The errors between the simulation value, the test value and the standard value are analyzed. The results show that the maximum error between simulation value and test value of fuel injection rate is 6.5%, and the maximum error between simulation value and test value of fuel injection quantity is 2.5%. The maximum error between test value and standard value of fuel injection rate is 6%, and the maximum error between test value and standard value of fuel injection quantity is 5%. In addition, the maximum error between simulation value and standard value of fuel injection rate is 6%, and the maximum error between simulation value and standard value of fuel injection quantity is 3.5%. Therefore, it can be considered that the simulation model is correct and effective, and can describe the actual working process of the fuel injection device relatively accurately.

VI. CONCLUSION

From the above analysis, it can be concluded that:

(1) The motion state of needle valve in the optimized injection device is almost the same as that of electromagnetic valve, eliminating the time interval between needle valve motion and electromagnetic valve control. Compared with the fuel injection device before optimization, the needle valve motion is relatively stable and the opening time of needle valve is relatively small,

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which lays a foundation for multiple injection of the device.

(2) The change of injection pressure of the optimized device can keep relative consistency with the needle valve movement, that is to say, it is consistent with the control state of the electromagnetic valve. In addition, under the same rail pressure conditions, the optimized device injection pressure is slightly higher than that before optimization, which can better improve the fuel atomization effect.

(3) The change of fuel injection rate of the device after structural optimization can keep relative consistency with the needle valve movement, that is, with the control state of electromagnetic valve. In addition, the maximum fuel injection rate of the optimized device is slightly higher than that before optimization, which makes the fuel achieve the expected fuel injection volume in a shorter time and further shortens the duration of fuel injection.

In summary, the optimized device can reduce the fluctuation of injection pressure and shorten the injection duration for eliminating the hydraulic delay, thus laying the foundation for multiple injection of the device.

ACKNOWLEDGEMENTS

This research was financially supported by the National Science Foundation (NO. 51675148).

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