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Simulation of Assembly Tolerance and Characteristics of High Pressure Common Rail Injector

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Abstract

Fuel injector is the key part of a high-pressure common rail fuel injection system. Its manufacturing precision and assembly quality affect system's property and performance. According to the characteristics and demands of assembly of the fuel injector, an intelligent optimization algorithm is proposed to resolve the problem of assembly sequence planning. Based on geometric modeling, assembly dimension chain of the injector control chamber is established, and the relationship between assembly tolerance and volume change of control chamber is analyzed. The optimization model of the assembly is established. The impact of assembly tolerance on injector's performance is simulated according to the optimization algorithm. The simulation result shows that quantity of injection fuel changes correspondingly with the change of assembly tolerance, while injection rate and pressure do not change significantly, and the response rate of needle considerably slow. Similarly, the leakage rate of fuel in control chamber is calculated, indicating that the assembly tolerance has obvious impact on fuel leakage and its rate. The study illuminates that injector's assembly tolerance has prominent effect on injection.

Keywords: assembly tolerance, intelligent optimization algorithm, high pressure common rail, simulation

1. Introduction

The rigorous exhaust emission legislation and increasingly development of diesel engine electronic control technology make high-pressure common-rail fuel injection system come into the world. It initiates the new era of diesel engine fuel injection technology. As a high flexible fuel injection system, the high-pressure common-rail injection system has become a trend of the diesel engine technology for its remarkable characteristics. Acting as the execution unit, Fuel injector is the

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key part of a high-pressure common rail fuel injection system. Its structural parameters, manufacturing precision, assembly quality have an important impact on the injecting of the fuel system[1-2]. Based on the structural analysis of the fuel injector, a study on assembly dimension chain of the injector control chamber is conducted. And the impact of assembly tolerance on injector's performance is simulated with Hydsim software. On this basis, the principle of selective assembly for injector assembly is put forward.

2. The Geometric Model of an Injector

The common rail fuel injector is made up of an electromagnetic valve, a sealing ball valve, an orifice of oil feeding and return, a control piston, an adjust shim, a press-adjusting spring, a tappet, a combining seat, a needle valve, a needle-valve body, and nozzle nuts[3]. The structural drawing of an injector is shown in the Fig.1.

3. The Assembly Dimension Chain of the Injector Control Chamber

The control chamber is a key part of a fuel injector, which important parameters include the minimum volume, the diameter and lift of the control piston, the clearance between control piston and control chamber. The motional regulation of the injector needle is decided by the process of pressure variation in the chamber, and the oil injecting rule is fixed[4-5]. The key parameters of the control chamber are theoretically calculated and simulated. According to analysis the impact of relative parameters on the injector fuel injection performance is given out. And it provides theoretical basis for tolerance parameter optimization of the injector control chamber.

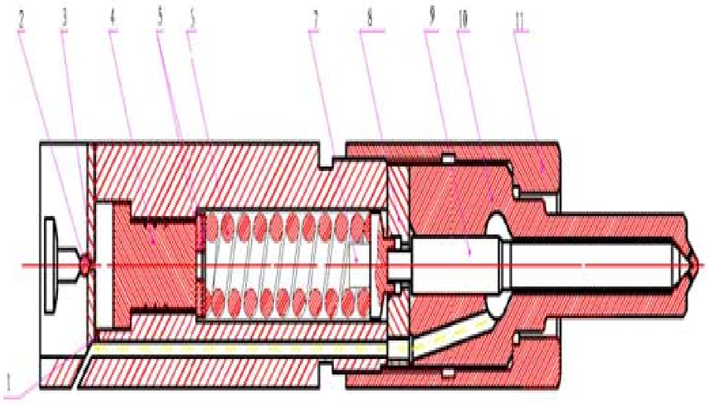

Fig.1 The structural drawing of an injector1-orifice of oil feeding 2-sealing ball valve 3-orifice of oil return 4-control piston 5-adjust shim 6- press-adjusting spring 7-tappet 8-combining seat 9-needle valve 10-needle-valve body 11-nozzle nut

In the Fig.2, there is a assembly dimension chain, which contains the piston length a_1, the piston chamber length a_2 and the maximum lift dimension a_0, and a0 is closed-loop. According to the formula of assembly dimension chain, the upper deviation, the lower deviation and tolerance is expressed respectively as the following:

$$
\begin{aligned}
ES_0 &= ES_{a2} - EI_{a1} \\
EI_0 &= EI_{a2} - ES_{a1} \\
T_0 &= T_1 + T_2
\end{aligned} \quad (1)
$$

Assuming that the machining dimension of piston chamber and piston is a'_2 and a'_1, the practical machining error is T'_2 and T'_1, then:

$$T_1' = a_1' - a_1 \qquad (2)$$
$$T_2' = a_2' - a_2$$

As is illustrated in fig.2, the volume variation of the control chamber is as the following:

$$\Delta V = \pi * (d_1 / 2)^2 * (a'_2 - a'_1 - a_2 + a_1) \qquad (3)$$

In Fig.2 the radial dimension chain of control piston and chamber is shown, d1 is the control-piston diameter, d2 is the topper-cylinder diameter of control piston, and d0 is the tolerance clearance between control piston and chamber.

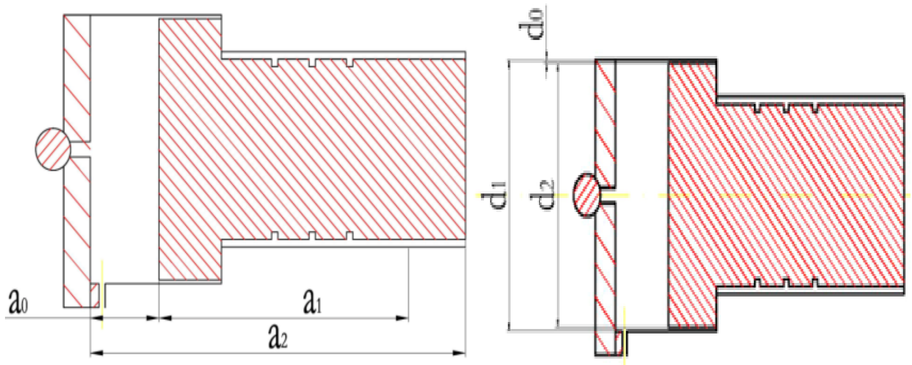

Fig.2 Assembly dimension chain of injector control chamber

4. Simulation of Injector Characteristic

4.1 simulation model of injector

In this research, the simulation software is Hydsim, which is the professional software in Fuel Injection System of Diesel Engine. The simulation model is established, as shown in fig.3.

In this model, the nozzle adopts the module of "VOC(Extended model)". The needle adopts "Needle(Standard)" module. The control piston adopts "Piston (Standard)" module. The chamber of control piston and accumulator both adopt "Volume (Stan- dard)" module. The leakage of needle valve and piston both adopt "Leakage(Annular Gap)" module. The others of the model adopt common module[6,7,8].

In the previous discussion, the paper focuses on the change of volume of control chamber from the change of tolerance on the axial and radial. In the next, the change of volume because of the tolerance change is analyzed, and the impact to the inject performance is discussed.

4.2 Simulation of the inject performance for the axial tolerance change of control chamber

In the axial dimension of the assembly, the tolerance of the closed loop T_0 is the most important tolerance which must be guaranteed. The tolerance of the compositional loops is divided into a, b, c, d, e, f, g, seven classes[9,10,11]. The tolerance of every class is shown in table.1.

According to the class of tolerance, the volume of control piston and the length of control chamber which are changed for the tolerance change are divided into a, b, c, d, e, f, g , seven classes. In Hydsim, the seven sets of data are entered as input parameters to the control piston and control chamber. The simulation curves of quantity of injector and injection rate and the regulation of the needle movement are shown in Fig. 4, Fig.5, Fig.6 and Fig.7.

As the tolerance of control piston increases within the range of T1 from 0.01-0.07 on the one side, the tolerance of control chamber-T2 decreases correspondingly from the 0.07-0.01 on the other side. From the Fig.4, the quantity of injection is gradually increasing.

Table 1 the tolerance class of the control piston and control chamber

Name	T_1	T_2
a	0.01	0.07
b	0.02	0.06
c	0.03	0.05
d	0.04	0.04
e	0.05	0.03
f	0.06	0.02
g	0.07	0.01

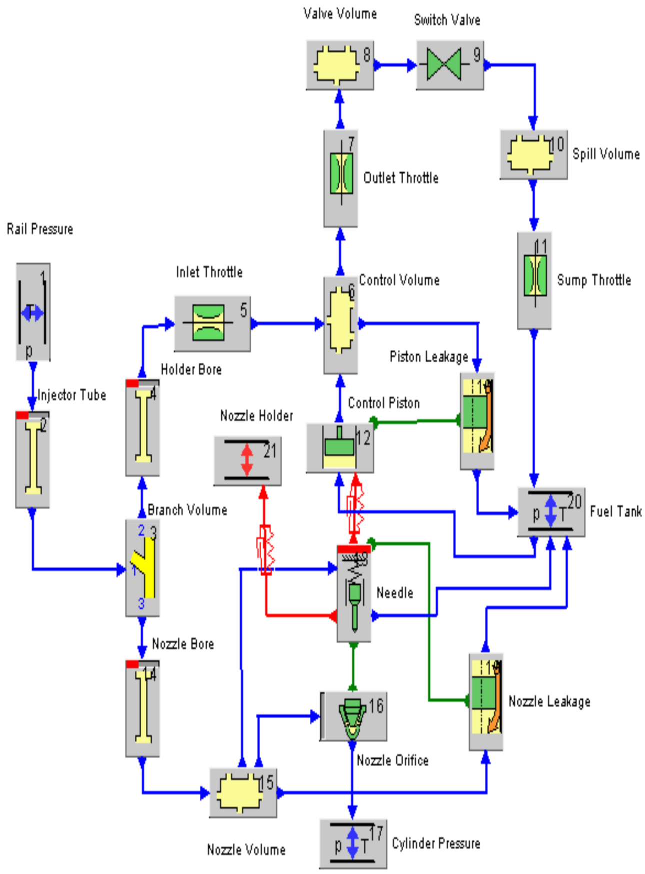

Fig.3 the simulation model of injector characteristic

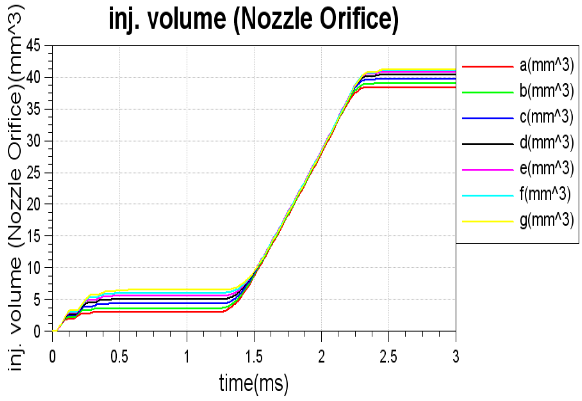

Fig.4 The influence to the fuel injection quantity

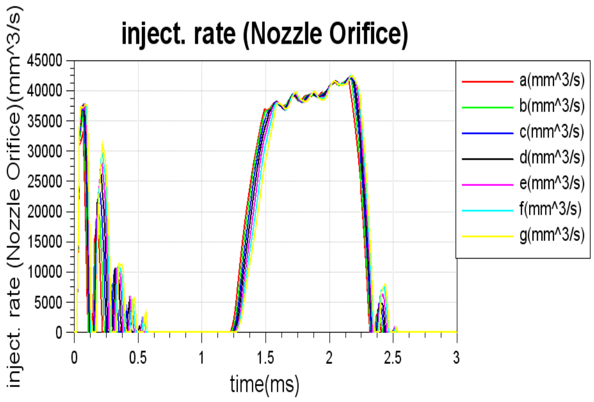

Fig.5 the influence to the injection rate

In Fig.5 there is no significant change about injection rate, but the starting and ending time are delayed, which meansto increase the response time of injector. In Fig.6, there is no significant change about the pressure in control chamber, as the changes with the tolerance impact on the change of volume is almost negligible to the size of control chamber itself. In Fig.7 the response rate of needle is significantly slower from the regulation of movement

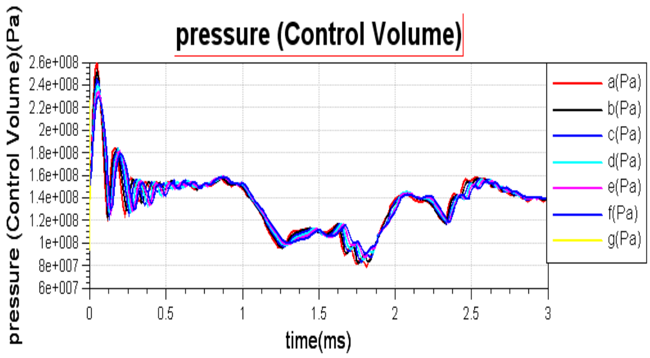

Fig.6 the influence to the pressure fluctuations

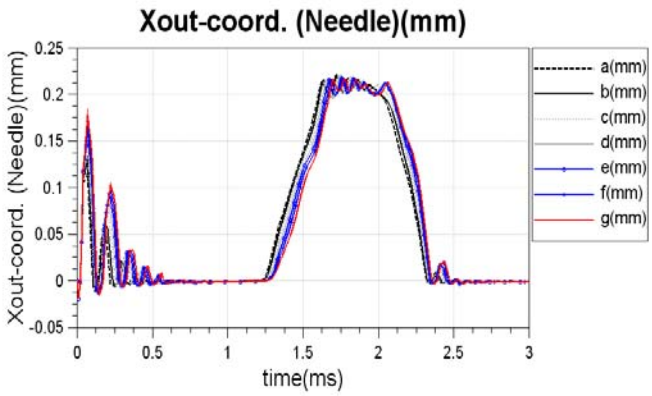

Fig.7 the influence to the needle move

4.3 Leakage calculation to the control chamber

According to fluid mechanics knowledge, assume injector needle in the course of the movement has the same lift and speed with the control piston, according to the formula(8), the leakage about the pieces of control piston is calculated.

$$Q_{cx} = \frac{\pi d_c |p_c - p_o| \delta_c^3}{12\eta l_c} \quad (8)$$

Where

dc：the diameter of control chamber（mm）；

δc：the average gap between the control piston and control chamber（mm）；

lc： the length of mating annular face about the pieces of control piston

η： fluid dynamic viscosity

In the formula leakage is proportional to the diameter of control piston and the cube of the gap between the control piston and control chamber, inversely proportional to the length of mating annular face[12,13].

4.4 Simulation for the leakage of control chamber

Similarly, the pieces of the control piston tolerances in the radial direction is also divided into a, b, c, d, e, f, g seven classes, these classes are shown in table 2.

The simulation model is input with the mating gap, calculated and analyzed[14]. The curves of simulation about the leakage rate and quantity respectively are shown in Fig.8 and Fig.9.

Table 2 the classes for mating gap between the control piston and chamber

Name	a	b	c	d	e	f	g
Gap	0.003	0.004	0.005	0.006	0.007	0.008	0.009

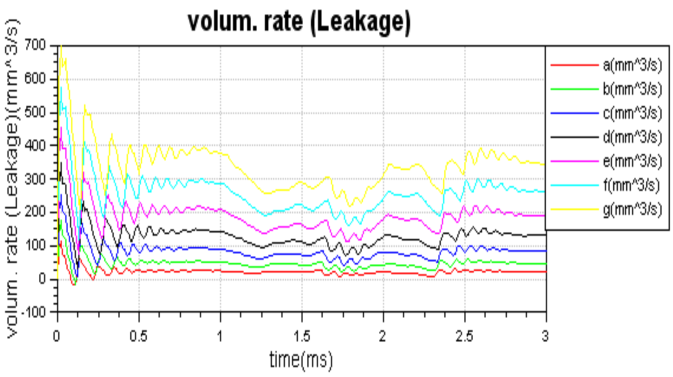

Fig.8 the leakage rate of fuel in control chamber

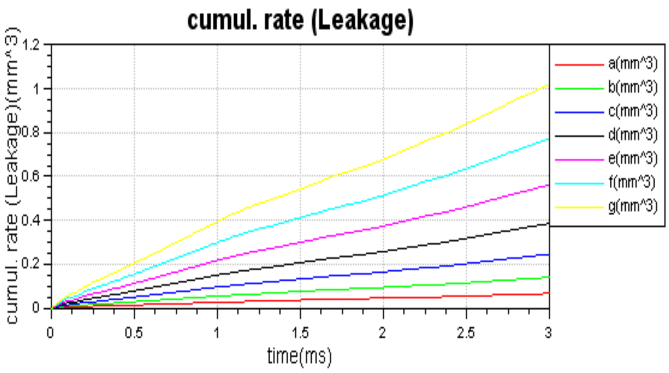

Fig.9 the leakage quantity of fuel in control chamber

From Fig. 8 and Fig. 9 it can be drawn that the impact of fuel leakage and fuel leak rate which comes from the assembly gap has been very clear. In the assembly process, the process must be reasonable and the assembly tolerances must be strictly controlled.

5. Conclusions

Based on the theoretical calculation and simulation analysis, the following conclusions can be drawn:
1) When the assembly design tolerance of the control chamber T0 is 0.08mm, in the case of ensuring the assembly tolerance T_0, the smaller tolerance of control piston on axial direction is, and the greater tolerance of control chamber on axis direction is, the better the characteristic of the injection system is.
2) For the gap between the control piston and chamber, the tolerance must be strictly controlled in the design value. The simulation results show that if the gap tolerance were increased 0.001mm, the amount of fuel leaked and leakage rate would be doubly increased.

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