Simulation Analysis and Parameter Optimization of The Electronic Controlled Injector

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Abstract. In order to improve the dynamic response characteristics of the electronic controlled injector, a simulation model for the response characteristics of the electronic controlled injector was established. By comparing the calculation results of the simulation model with the experimental results, the validity and accuracy of the model are verified. The influence of inlet hole diameter, outlet hole diameter and needle valve diameter on the dynamic response characteristics of the needle valve of the electronic control injector was studied. The results show that the closing delay time of the needle valve decreases with the increase of the inlet hole diameter of the control chamber, the opening delay time of the needle valve decreases with the increase of the oil outlet diameter of the control chamber, and the closing delay time of the increase of the diameter of the needle valve and the opening delay time decreases. An orthogonal experiment with three factors and four levels was designed to optimize the structural parameters of the electronic control injector. The optimized results show that the dynamic response characteristics of the injector are improved.

1. Introduction

With the increasingly strict Marine diesel emission regulations, the precise control of fuel injection process and the requirement of fuel injection law are more and more high. The importance of injector performance in high pressure common rail system has been paid more and more attention. For Marine common rail system, because of the large amount of circulating fuel injection, the size of the injector and the mass of the moving parts are generally large, which brings difficulties to realize the rapid response of the injection control. In addition, the Marine diesel engine has many cylinders and injectors, and the pressure fluctuation in the system caused by the injection process has a negative effect on the consistency and stability of the injection [1-3].

The structural parameters of the injector will directly or indirectly affect the cycle fuel injection amount and fuel injection duration of the system, and seven lead to the large fluctuation of the cycle fuel injection amount of the diesel engine, thus making the working stability of the diesel engine worse [4-5].

Therefore, it is of great significance to study the influence of the structural parameters of the electronic control injector on the performance of fuel injection, and to design and optimize the structural parameters of the electronic control injector, and to improve the consistency and stability of the fuel injection system [6-8].
In this paper, the simulation model of the electronic control injector is established, and the simulation results are compared with the test results to verify the accuracy of the simulation model. The influence of the oil inlet hole, the oil outlet hole and the diameter of the needle valve of the control chamber on the dynamic response of the electronic control injector was studied, and the key structural parameters of the electronic control injector were optimized.

2. Mathematical Model
The model of electronic injector is shown in Figure 1. Its main structural parameter is shown in Table 1.

![Figure 1. The model of electronic injector](image)

| parameter                  | reference value |
|----------------------------|-----------------|
| rail pressure              | 160MPa          |
| high pressure tubing length| 0.4m            |
| high pressure tubing diameter | 5mm            |
| ball valve spring stiffness | 70N/m           |
| inlet hole diameter        | 0.36mm          |
| needle valve lift           | 0.5mm           |
| needle valve diameter       | 4.2mm           |
| nozzle number              | 10              |
| nozzle diameter            | 0.51mm          |
| ball valve lift             | 0.15mm          |
| outlet hole diameter        | 0.52mm          |
| ball valve diameter         | 1.5mm           |

Comparison of simulation results and test results of fuel injection under different working conditions is shown in Table 2. It can be seen that the maximum error is 4.7%.
Figure 2 shows the comparison between the simulation and test results of the injection law when the rail pressure is 1600bar and the injection pulse width is 2900μs. It can be seen from that the injection law is in good agreement, and the error between the simulation and the test results of the single injection quantity is 2.5%. From the above analysis, it can be concluded that the simulation model of high-pressure common rail system established in this paper has a good accuracy.

| Rail pressure /bar | pulse width /μs | fuel injection quantity test/mm³ | simulation/mm³ | error |
|--------------------|-----------------|-----------------------------------|----------------|-------|
| 1150               | 950             | 1480                              | 1485           | 0.4%  |
| 1150               | 2000            | 2470                              | 2472           | 0.1%  |
| 1150               | 3500            | 3750                              | 3585           | 4.4%  |
| 1600               | 900             | 1730                              | 1811           | 4.7%  |
| 1600               | 2000            | 3020                              | 2900           | 4.0%  |
| 1600               | 2900            | 3810                              | 3713           | 2.5%  |

Figure 2. Comparison of injection law between simulation results and test results

3. Simulation Analysis

When the outlet diameter of the control oil chamber is 0.52mm, the inlet diameter of the control oil chamber is less than 0.2mm, the needle valve of fuel injector cannot be seated. Therefore, the oil inlet hole is set to 0.24mm, 0.26mm, 0.38mm, 0.30mm, 0.32mm. The established model was used to simulate the response characteristics of the injector, and the response characteristics of the needle valve are shown in Figure 3.

Figure 3. Influence of inlet hole diameter on dynamic response characteristics
As can be seen from Figure 3, the closing delay time of the needle valve decreases when the diameter of the oil inlet hole increases, but which will be less circulating fuel injection. Keeping the diameter of the oil inlet hole in the control oil chamber unchanged at 0.25mm, and the diameter of the oil outlet hole is 0.4mm, 0.45mm, 0.50mm, 0.55mm, 0.60mm. Through simulation study, the response characteristics of the needle valve are shown in Figure 4.

![Figure 4](image)

**Figure 4.** Influence of outlet hole diameter on dynamic response characteristics

As can be seen from Figure 4, when the diameter of oil inlet hole remains unchanged, increasing the diameter of oil outlet hole can reduce the opening delay of the dynamic response speed of the needle valve. But this has no effect on the closing delay time.

To sum up, the oil inlet and outlet holes of the control chamber have a great influence on the dynamic response speed of the injector needle valve.

The diameter of the needle valve affects the quality of the needle valve, thus affecting the dynamic response speed of the needle valve. Needle valve diameters are 4.5mm, 5.0mm, 5.5mm, 6.0mm and 6.3mm respectively. The dynamic response curve of needle valve is shown in Figure 5.

![Figure 5](image)

**Figure 5.** Influence of needle valve diameter on dynamic response characteristics

As can be seen from Figure 5, when the diameter of the needle valve increases, the opening delay time of the needle valve decreases but the closing delay time increases. Therefore, it is very important to select the appropriate diameter of the needle valve for the response characteristics of the electronic control injector.
4. optimization of structure parameters of electric control injector
According to the previous analysis, structural parameters such as inlet hole diameter, outlet hole diameter and needle valve diameter control the oil chamber have a great influence on the dynamic response characteristics of the needle valve. Therefore, the dynamic response speed of the needle valve of the electronic control injector is improved by optimizing the three structure parameters. For horizontal quantities of three parameters were determined by orthogonal test. Table 3 is the table of experimental factors after determining the experimental level.

Table 3. Table of experimental factors

| factor level | d₁(mm) | d₂(mm) | d₃ (mm) |
|--------------|--------|--------|---------|
| 1            | 0.23   | 0.45   | 5.5     |
| 2            | 0.25   | 0.50   | 5.7     |
| 3            | 0.27   | 0.55   | 5.9     |
| 4            | 0.29   | 0.60   | 6.1     |

According to Table 3, the experimental level and experimental factors of the orthogonal experiment are determined, and the orthogonal experiment table L₁₆(4³) is designed (see Table 4).
It can be seen from Table 4 that test 12 has the best result in the orthogonal experiment because Y of this group is the smallest. The calculation result of the data in test 12 was taken as the optimized result. The response characteristics of needle valve before and after optimization of structural parameters are shown in Figure 6. As can be seen from Figure 6, although the opening delay time of the injector needle valve changed little after optimization, the closing delay time was greatly reduced. Therefore, the response characteristics of the injector needle valve are improved by structural parameter optimization.

Table 4. Orthogonal experiment table

| Test | d₁/mm | d₂/mm | d₃/mm | T_open/ms | T_close/ms | Y    |
|------|-------|-------|-------|-----------|------------|------|
| 1    | 0.23  | 0.45  | 5.5   | 0.15      | 2.32       | 17.2 |
| 2    | 0.23  | 0.50  | 5.7   | 0.14      | 2.21       | 16.3 |
| 3    | 0.23  | 0.55  | 5.9   | 0.12      | 2.20       | 15.8 |
| 4    | 0.23  | 0.60  | 6.1   | 0.11      | 2.18       | 15.4 |
| 5    | 0.25  | 0.45  | 5.7   | 0.16      | 2.32       | 17.3 |
| 6    | 0.25  | 0.50  | 5.5   | 0.14      | 2.32       | 16.0 |
| 7    | 0.25  | 0.55  | 6.1   | 0.13      | 2.32       | 15.8 |
| 8    | 0.25  | 0.60  | 5.9   | 0.11      | 2.32       | 15.4 |
| 9    | 0.27  | 0.45  | 5.9   | 0.14      | 2.17       | 15.9 |
| 10   | 0.27  | 0.50  | 6.1   | 0.14      | 2.13       | 15.7 |
| 11   | 0.27  | 0.55  | 5.5   | 0.12      | 2.07       | 15.0 |
| 12   | 0.27  | 0.60  | 5.7   | 0.11      | 2.02       | 14.4 |
| 13   | 0.29  | 0.45  | 6.1   | 0.17      | 2.31       | 17.7 |
| 14   | 0.29  | 0.50  | 5.9   | 0.17      | 2.32       | 17.7 |
| 15   | 0.29  | 0.55  | 5.7   | 0.16      | 2.32       | 17.5 |
| 16   | 0.29  | 0.60  | 5.5   | 0.15      | 2.32       | 17.1 |
The $Y_i$ in the table is

$$Y_i = \sum_{j=1}^{k} \omega_j \frac{X_{ij}}{S_j}$$  \hspace{1cm} (1)

Where, $Y_i$—composite score,
$\omega_j$—weight coefficient,
$S_j$—standard deviation,
$X_{ij}$—experimental index value.

5. Conclusions
The simulation model for the response characteristics of the electronic controlled injector was established. By comparing the calculation results of the simulation model with the experimental results, the validity and accuracy of the model are verified.

The influence of inlet hole diameter, outlet hole diameter and needle valve diameter on the dynamic response characteristics of the needle valve of the electronic control injector was studied. An orthogonal experiment with three factors and four levels was designed to optimize the structural parameters of the electronic control injector. The optimized results show that the dynamic response characteristics of the injector are improved.

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Figure 6. Comparison of needle valve lift curves before and after optimization
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