Establishment and Research of Control Model of Check Valve Based on Difference Equation

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Abstract: This paper studies the pressure control problem of high-pressure oil pipes, and establishes a one-way valve control model based on the difference equation. First, the function relationship between elastic modulus and pressure in the data is obtained by fitting. The relationship between the pressure and the flow rate into the high-pressure oil pipe, and the time at which the check valve opens in a cycle (100ms) is set to t, the time at which the injector is opened is the initial time, and the time interval is 0.01ms. A differential equation model was established, with the minimum fluctuation of the pressure in the high-pressure tubing as the objective function, and solved using a cyclic traversal algorithm. When the pressure in the tubing was stabilized at about 100 MPa, the check valve opened at 1.77 ms and closed at 4.47 ms.

1. Introduction

How to improve the efficiency of the engine is a problem commonly faced by the machinery industry.The high-pressure fuel pipe for fuel entering and ejecting the engine is the basis of many fuel engines. The intermittent working process of the injection and ejection of the engine will cause the intermittent pressure in the high-pressure fuel pipe. Due to the changes in the fuel, the amount of fuel sprayed will deviate, which will affect the working efficiency of the engine. Now that the relevant operating parameters of the high-pressure oil pipe, high-pressure oil pump and injector are known, the opening time of the check valve on the high-pressure oil pump needs to be designed Makes the pressure of the high-pressure oil pipe stable at about 100MPa.

2. Model Establishment

The change in fuel pressure is proportional to the change in density, and the proportionality factor is:

$$\frac{dp}{d\rho} = \frac{E}{\rho}$$

Where e is the elastic modulus of the fuel, from which the density of the fuel in the high-pressure oil pump can be obtained.

Because the injection rate of injector B is not a constant, the fuel flow at the injector at time i can be expressed as:

$$Qc_{(i)} = \begin{cases} 100i, 0 \le i \le 0.2 \\ 20, 0.2 \le i \le 2.2 \\ 100i + 240, 2.2 \le i \le 2.4 \\ 0, others \end{cases}$$

The fuel flow from the high pressure oil pump into the high pressure oil pipe is:

$$Qr_{(i)} = CA\sqrt{\frac{2\Delta P}{\rho}} = 0.85 \times \frac{\pi}{4} \times D^2 \times \sqrt{\frac{2 \times \left(160 - p_{(i)}\right)}{\rho_H}}$$

Because the working mode of the fuel injector is to inject fuel 10 times per second and fuel injection is 2.4s each time, it can be considered that the fuel injector has a working cycle of 100ms. In this cycle, the fuel injector and fuel inlet Jointly adjust the amount of fuel in the fuel pipe to maintain the pressure of the fuel at 100MPa. At each moment i, the quality of the fuel entering the fuel pipe:

$$m_{in} = Qr_{(i)} \times \Delta i \times \rho_H$$

Among them, m_i represents the quality of the original fuel inside the fuel pipe immediately before time i, which satisfies $m_i = \rho_{(i)} \times V$.

Assume that the oil pump starts to inject fuel into the oil pipe at time t. When i ⩽t, $Qr_{(i)} = 0$, otherwise $Qr_{(i)} =/ 0$. Simultaneously, the above equations are obtained to obtain the difference equation expression of the density at time i :

$$\rho_{(i+1)} = \begin{cases} \dfrac{\rho_{(i)} \times V + Qr_{(i)} \times \Delta i \times \rho_H - Qc_{(i)} \times \Delta i \times \rho_{(i)}}{V}, i \geq t \\ \dfrac{\rho_{(i)} \times V - Qc_{(i-r+1)} \times \Delta i \times \rho_{(i)}}{V}, i < t \end{cases}$$

The final optimization problem is to make the internal pressure of the oil pipe deviate from the predetermined value by 100MPa to a minimum. Since the injector's working time is 100ms each time, 100ms is taken as a calculation cycle, and the step size after orientation is Δi = 0.01ms, which divides one cycle. Into 10,000 time nodes. The difference between the pressure of each node and the predetermined pressure of 100MPa must be kept to a minimum. Therefore:

$$min \sum_{i=1}^{1000} \left[p_{(i)} - 100\right]^2$$

In summary, the mathematical expression of the check valve opening time model is:

$$min \sum_{i=1}^{1000} \left[p_{(i)} - 100\right]^2$$

$$s.t. \begin{cases} p_{(i+1)} = \dfrac{E}{\rho_{(i)} \times \left[\rho_{(i+1)} - \rho_{(i)}\right]} + \rho_{(i)} \\ \rho_{(i+1)} = \begin{cases} \dfrac{\rho_{(i)} \times V + Qr_{(i)} \times \Delta i \times \rho_H - Qc_{(i)} \times \Delta i \times \rho_{(i)}}{V}, i \geq t \\ \dfrac{\rho_{(i)} \times V - Qc_{(i-r+1)} \times \Delta i \times \rho_{(i)}}{V}, i < t \end{cases} \\ Qr_{(i)} = CA\sqrt{\dfrac{2\Delta P}{\rho}} = 0.85 \times \dfrac{\pi}{4} \times D^2 \times \sqrt{\dfrac{2 \times \left(160 - p_{(i)}\right)}{\rho_H}} \\ Qc_{(i)} = \begin{cases} 100i, 0 \leq i \leq 2 \\ 20, 0.2 \leq i \leq 2.2 \\ 100i + 240, 2.2 \leq i \leq 2.4 \\ 0, others \end{cases} \end{cases}$$

t——the moment when the oil pump starts to inject fuel;

ρ_H-the density of the fuel in the high-pressure oil pump, ρ_H = 160MPa;

Δi-time step of backward difference, Δi = 0.01ms;

D-diameter at high pressure oil pump, D = 1.4mm.

3. Model Solving

3.1 Solving the check valve opening time

In the solution of this model, the relationship between E and p needs to be obtained by fitting, and the opening force and duration of the check valve when the amount of fuel entering the fuel pipe is the smallest can be obtained by using the model and the difference equation. This study uses an exponential function to It is fitted. The result of the fit is:

$$E = 1489e^{0.002849p} + 48.79e^{0.01376p}$$

Bring the above equation into the differential equation, and p = 100, ρ = 0.85 into it, and solve the differential equation to get $\rho_H = 0.8711$. With MATLAB, use the cyclic traversal method to get the single valve in 1.7ms Turn on and turn off at 4.47ms, and run 2.77ms during the cycle, as shown in Figure 1:

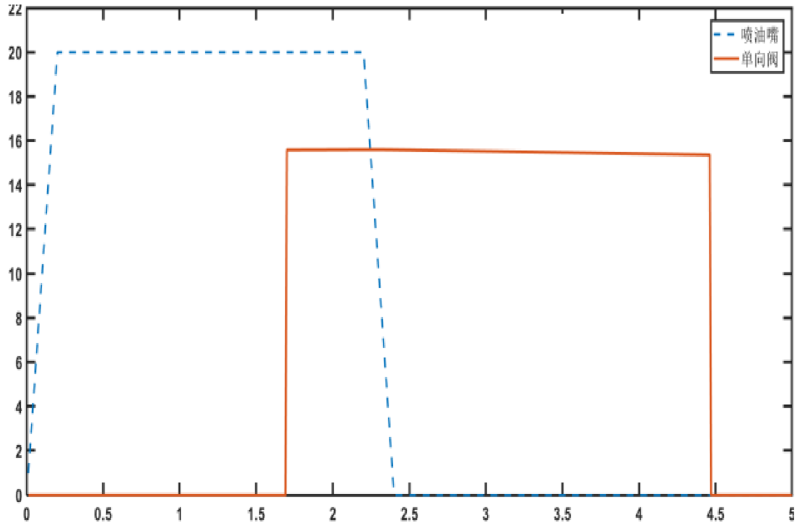

Figure 1 Time chart of check valve and injector switching

3.2 Solving the problem of reaching the predetermined pressure at a specified time

For the case of reaching 150 MPa in 2s, first take T = 2, so the range of j becomes:

$$j = 1,2, ..., 20 \text{ and } j \in N_+$$

So the mathematical model at t = 2 becomes:

$$\min \sum_{i=1}^{1000} \left[p_{(i)} - 150\right]^2$$

$$s.t.\begin{cases} \rho_{(j+1),(i)} = \rho_{j,(i)} \\ p_{(i+1),(i)} = p_{j,(i)} \\ p_{(i+1)} = \dfrac{E}{\rho_{(i)} \times \left[\rho_{(i+1)} - \rho_{(i)}\right]} + \rho_{(i)} \\ \rho_{(i+1)} = \begin{cases} \dfrac{\rho_{(i)} \times V + Qr_{(i)} \times \Delta i \times \rho_H - Qc_{(i)} \times \Delta i \times \rho_{(i)}}{V}, i \geq t \\ \dfrac{\rho_{(i)} \times V - Qc_{(i-r+1)} \times \Delta i \times \rho_{(i)}}{V}, i < t \end{cases} \\ Qr_{(i)} = CA\sqrt{\dfrac{2\Delta P}{\rho}} = 0.85 \times \dfrac{\pi}{4} \times D^2 \times \sqrt{\dfrac{2 \times \left(160 - p_{(i)}\right)}{\rho_H}} \\ Qc_{(i)} = \begin{cases} 100i, 0 \leq i \leq 2 \\ 20, 0.2 \leq i \leq 2.2 \\ 100i + 240, 2.2 \leq i \leq 2.4 \\ 0, others \end{cases} \end{cases}$$

Using a search algorithm, write a corresponding program to search the time and duration of the check valve opening to ensure that the pressure deviation is minimal after the pressure reaches 150 MPa. The following are some results from the initial moment as the starting point for timing and reach 150 MPa in 2 seconds:

Table 1. 2s to reach 150MPa check valve opening time

Open	0.31	101.25	200.11	301.19	401	500.37	601.47	700.91
shut down	5.98	107	205.98	307.15	407.08	506.59	607.81	707.41

4. Conclusion

The fuel entering and exiting the high-pressure fuel pump will cause deviations in the amount of fuel injected, which will affect the efficiency of the engine. The model of this paper has been modeled and solved by the corresponding differential equation. When the oil pressure stabilizes at a certain pressure after a certain period of time, the The cycles of all cycles are divided into two parts: one is to increase the pressure from the initial value of 100 MPa to 150 MPa, and the other is to stabilize the pressure around 150 MPa. Therefore, it can be assumed that the value of the increased pressure in each cycle is constant. In order to solve the problem, it is necessary to solve the opening and closing time and duration of the check valve in each cycle. In short, the model in this paper can adjust the time and duration of fuel entering and exiting the high-pressure fuel pipe, which is certain to improve the efficiency of the engine and reduce the failure rate Role.

References

[1] Edited by Liu Xiangjun. Engineering Fluid Mechanics (Second Edition). Beijing: China Electric Power Press, 2013.9.

[2] Yan Song. Simulation of pressure dynamic characteristics of diesel high-pressure common rail system [D]. Zhejiang University, 2005.

[3] He Yongling, Zhao Zhihe, Liu Jianxin, Fan Yongjian, Deng Bendu, Guo Jiyao. Research on Pressure Wave Propagation Velocity in Diesel Engine Fuel Injection System under Oil-Gas Two-phase Flow State [J]. Journal of Internal Combustion Engines, 1995 (04): 368-375.

[4] Zhu Jianxin, Li Youfa. Numerical methods. Beijing: Higher Education Press, 2012.7

[5] Cai Liping. Simulation calculation of high pressure injection process of diesel engine based on matlab [D]. Huazhong University of Science and Technology, 2005.

[6] Lian Li. Study on oil supply characteristics of common rail system high pressure oil pump [D]. Harbin Engineering University, 2015.