Design of Pressure Control Model for High Pressure Oil Pipe of Diesel Generator

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Abstract

Fuel into and out of high-pressure tubing is the basis of many diesel generator jobs, Pressure control and adjustment problems exist in high-pressure tubing, as well as injection and intake control strategies. Based on the principle of fuel pipe fuel total quality should remain the same, through the analysis of injection jet fuel quality, combining with the continuity theorem, step by step search method, Bernoulli equation and other high-pressure tubing pressure control model is established, using the finite difference method can be solved by the continuous system discretization model, end up with high pressure tubing pressure control and adjustment scheme. To solve the problem, we first fit the relationship between elastic modulus and pressure. Then the relation between the change of fuel density and the change of time in high-pressure tubing is deduced according to the difference between the quality of oil in and out of the inlet and outlet. The differential equation of pressure and time in high-pressure tubing is derived from the relationship among pressure change, density change and time change. According to this curve, the optimal opening time of one-way valve A is 2.8ms when the pressure is stabilized at 100MPa. The model in this paper USES the generalized formula to analyze the physical process of the system in detail, and the model obtained is universal and has a certain value of application and popularization. After improvement, it can be applied to the industries of fuel mechanism building, fault detection, power plant manufacturing and automobile and ship.

Keywords

Finite difference method continuity theorem, Bernoulli equation stepwise search.

1. Introduction

Fuel into and out of high-pressure tubing is the basis for many fuel engines, Figure 1 shows the working principle of a high-pressure fuel system. The fuel enters the high-pressure fuel pipe from A through the high-pressure oil pump, and is then sprayed from the nozzle B. The intermittent working process of its entry and ejection will cause the pressure in the high-pressure oil pipe to change, which will cause deviations in the amount of fuel ejected, which will affect the working efficiency of the generator.

2. Questions raised

The length of the inner cavity of A certain type of high-pressure tubing is 500mm, the inner diameter is 10mm, and the diameter of the hole at the oil supply inlet A is 1.4mm. The oil supply time is controlled by one-way valve switch, and the one-way valve will be closed for 10ms after each opening (1s＝1000ms)The fuel injector works 10 times per second, and the fuel injection time is 2.4ms during each operation. The fuel injection rate from the nozzle B when the fuel injector is working is shown in Figure. 2. The pressure provided by the high-pressure oil pump at inlet A is always 160 MPa, and the initial pressure in the high-pressure oil pipe is 100 MPa. If the pressure in the high-pressure tubing should be stabilized at about 100 MPa as far as possible, how to set the duration of each opening of the one-way valve?

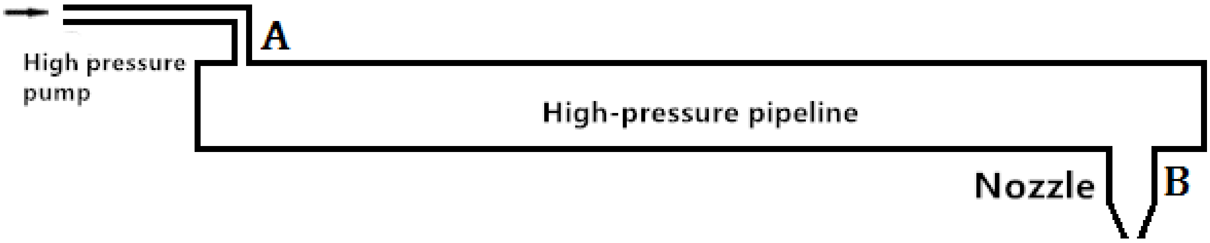

Figure. 1 schematic diagram of high-pressure tubing

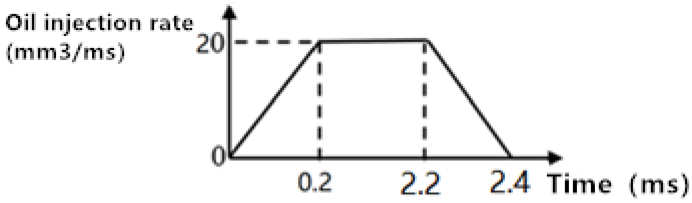

Figure. 2 The fuel injection rate

3. Problem analysis

In order to maintain the stable pressure of 100MPa in the high-pressure tubing, the one-way valve is assumed to remain open all the time, and the period of oil injection is analyzed. Since the change of fuel pressure is proportional to the change of density, the proportional coefficient is $\frac{E}{\rho}$, where ρ is the density of fuel. When the pressure is 100MPa, the density of fuel is $0.850 mg/mm^3$,E is the modulus of elasticity. We can obtain the relationship between the change in fuel pressure and the change in density, and the change in ρ is related to the inflow and outflow of the injector. Then we can find the curve of the internal pressure of the high-pressure fuel pipe over time in a cycle. By analyzing the law of fuel inflow and outflow and the obtained pressure curve, with the goal of stabilizing the pressure of 100MPa, we can determine the optimal closing time of the check valve in a cycle and obtain the check valve opening time.

4. Definition and symbol description

symbol	significance
ρ	Fuel density
P	Fuel pressure
T	Oil injection cycle
t_q	The opening time of a one-way valve
E	Modulus of elasticity
V	High pressure casing volume
Q	The fuel flow

5. The establishment and solution of the model

5.1 Calculate the relationship between fuel density and its pressure

Based on the relationship data between elastic modulus and pressure, we draw the curves of original data, quadratic fitting and cubic fitting, and the results are as follows:

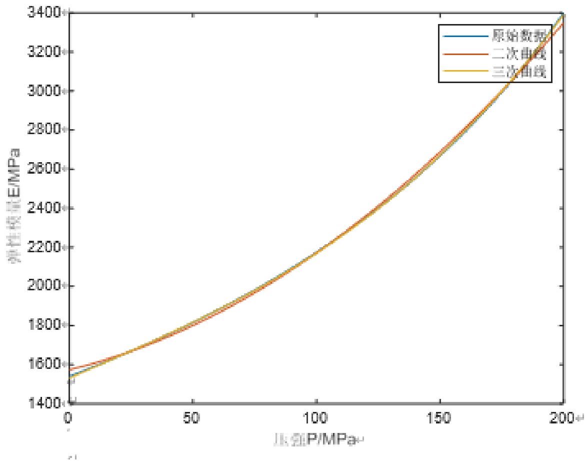

Figure 3 Polynomial fitting results

As can be seen from the above figure, the fitting accuracy of the quadratic and cubic curves is high. To simplify the calculation, we use a quadratic polynomial to fit the curve. It can be seen that the equations of the elastic modulus E and the pressure P are as follows:

$$E = 0.0289P^2 + 3.077P + 1571.58 \tag{1}$$

It can be obtained from comment 1

$$dP = \frac{E}{\rho} d\rho \tag{2}$$

By substituting equation (1) into this equation and using the boundary condition g (100MPa) = 0.85mg/mm3, the relationship between fuel density and its pressure can be obtained as follows:

$$\rho = g(P) = 0.776499e^{0.152325arctan(0.0044066P+0.234317)} \tag{3}$$

5.2 Assuming the one-way valve is continuously open, the pressure curve of the high-pressure tubing with time is calculated in one period

The injector works 10 times per second, and the working cycle T = 100ms is obtained. Taking its initial injection moment as t = 0, we assume that the one-way valve is always open, and analyze the change of the internal pressure in a cycle as follows:

1. Fuel related parameters in the injection pipe:

(a)Fuel density ρ_{in}:

The pressure provided by the high-pressure oil pump at the inlet A is constant 160 MPa, that is, P_{in}= 160 MPa. According to formula (3), we can get

$$\rho_{in} = g(P_{in}) = 0.871mg/mm^3$$

(b) The amount of fuel flowing into the tubing Q_{in}:

The flow in and out of the high-pressure tubing is $Q = CA\sqrt{\frac{2\Delta P}{\rho}}$, Where Q is the amount of fuel flowing through the small hole per unit time (mm3 / ms), C = 0.85 is the flow coefficient, and A is the area of the small hole (mm2), ΔP is the pressure difference (MPa) on both sides of the small hole, ρ is the fuel density (mg/mm^3) on the high-pressure side.

$$Q_{in} = CA\sqrt{\frac{2\Delta P}{\rho_{in}}} = C(\pi {r_A}^2)\sqrt{\frac{2(\rho_{in} - \rho_{out})}{\rho_{in}}}$$

(c) The amount of fuel flowing out of the tubing Q_{out}:

According to figure 2, the rate curve of oil injection from nozzle B when the injector is working

$$Q_{out}=\begin{cases}100t, & 0<t\le 0.2ms\\ 20, & 0.2<t\le 2.2ms\\ -100t+240, & 2.2<t\le 2.4ms\\ 0 & 2.4<t\le 100ms\end{cases}$$

(d) Micro change of pressure in tubing:

The micro - variation of fuel density $d\rho$ in the tubing is defined

$$d\rho=\frac{Q_{in}\rho_{in}dt-Q_{out}\rho_{out}dt}{V}$$

Substitute into equation (2), and get

$$dP=\frac{E}{\rho}d\rho=\frac{E}{\rho}\frac{Q_{in}\rho_{in}dt-Q_{out}\rho_{out}dt}{V}$$

Substitute the parameters shown in the question, that is, as follows:

$$\begin{cases}dP=\frac{E}{\rho}\frac{Q_{in}\rho_{in}dt-Q_{out}\rho_{out}dt}{V}\\ \rho_{in}=0.871\\ Q_{in}=0.85(\pi\times 0.7^2)\sqrt{\frac{2(160-P_{out})}{\rho_{in}}}\end{cases}$$

Where V = 500× π ×25 = 39269.91mm3, we can get

$$dP=\frac{(0.033\rho^2+3.51\rho+1791.82)\sqrt{367.39-2.3P}}{39269.91\rho}dt-\frac{(0.0289\rho^2+3.077\rho+1571.58)Q_{out}}{39269.91}dt$$

(e) The change curve of the pressure in the high-pressure tubing with time in a cycle:

Based on the discretization method of continuous system, there are

$$\Delta P=f(\Delta t)=\frac{(0.033\rho^2+3.51\rho+1791.82)\sqrt{367.39-2.3P}}{39269.91\rho}\Delta t-\frac{(0.0289\rho^2+3.077\rho+1571.58)Q_{out}}{39269.91}\Delta t$$

Where $\triangle t$ is 0.01ms.

From the above calculation, t = 0, 1, 2, · · ·, the corresponding internal pressure of the high-pressure oil pipe at 100 ms can be obtained. With the help of matlab plots, Figure 5 can be obtained.

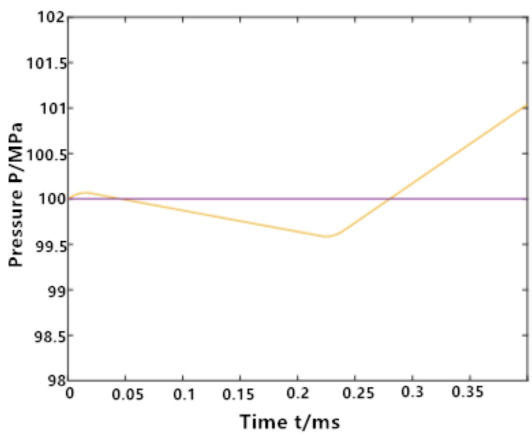

Figure 5 Determine the optimal check valve closing time

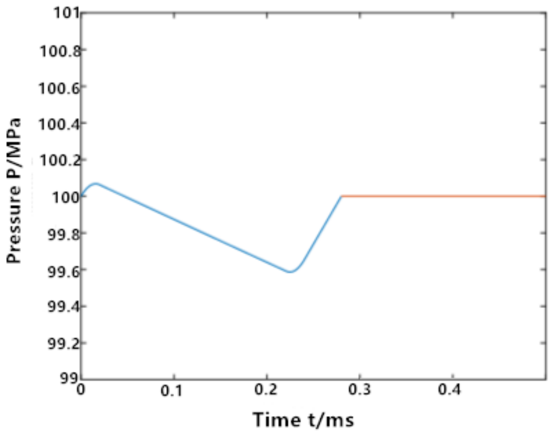

Figure 6 Pressure change curve after the check valve is controlled

[Note: The parallel straight line in Figure 5 is the 100 MPa reference line]

5.3 Determine the closing time and opening time of the check valve

Analysis of Figure 5 can be obtained as follows:

The internal pressure of the oil pipe rises first, then decreases and then rises. This is caused by the relative changes in the injection rate and the inflow rate. If the one-way valve is kept open at all times, the pressure in the pipe will increase more and more until the next cycle. After multiple cycles of accumulation, it is clear that the internal pressure of the tubing will always increase and cannot remain stable. Therefore, to maintain the pressure at about 100 MPa, we need to control the end curve. Therefore, we choose the time t_1 = 0.28ms corresponding to the intersection of the end curve and the line of P = 100MPa as the closing time of the one-way valve. After that, the fuel quality of the fuel pipe remains basically unchanged, and the pressure can be maintained at about 100MPa. And at this time, $T - t_1$ = 100 – 0.28 = 99.72ms> 10ms before the next fuel injection, which meets the set conditions.

That is, our one-way valve control strategy is: shut off after 0.28ms from the start of injection, and the opening time tq = 0.28ms every 100ms. The control effect is shown in Figure 6 (the pressure is always maintained at 100MPa in the time interval not shown)

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