Time Control Model for Increasing Work Rate to High-Pressure Tube

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Abstract. The work of the fuel engine is based on the fuel entering and expelling high-pressure tubing. The intermittent work of the fuel entering and expelling will lead to the change of pressure in the high-pressure tubing. This paper established the time control model to carry out the research. For the first question, we made the fuel entry period and injection period equal to 100ms. Because of \( \frac{\Delta P}{\Delta \rho} = \frac{E}{\rho} \), the volume of the high-pressure tubing remained constant, and the fuel mass into the high-pressure tubing was equal to the fuel mass ejected from the high-pressure tubing. The density time control model was established under the condition of mass conservation, and the opening time of each time was obtained to be 0.275ms. For the second question, we set the pressure increase after each fuel entry in the adjustment process to be equal. Due to \( \frac{\Delta P}{\Delta \rho} = \frac{E}{\rho} \), we obtained the new density value of the high-pressure tubing, and substituted the density and time model to obtain the opening time of each one-way valve.

Keywords: Mass Conservation, Fuel Injection Pipe, Fourier Function Fitting

1. Introduction

Fuel engine is the engine burning fuel for energy release, high temperature and high pressure generated by compression ignited fuel, fueling into and out of the working process of the intermittent will affect the change of the pressure in the high-pressure tubing, which has appeared deviation of jet fuel and affected the working efficiency of the engine.

Now we do a research about the pressure of high-pressure pipeline control. According to the fact that the fuel mass into the high-pressure oil pipe is equal to the fuel mass out of the high-pressure oil pipe, a time control model is established under the condition of mass conservation. When the pressure is stable at 100MPa, the opening time of the one-way valve is obtained; At the same time the high
pressure oil pipe in the process of \(2\text{s}\) to adjust each time the fuel into the pressure increase to 2.5\(MPa\), because of the pressure change of the fuel is proportional to the density variation, namely 
\[
\frac{\Delta P}{\Delta \rho} = \frac{dP}{d\rho} = \frac{E}{\rho},
\]
density value of fuel into the high pressure pipe will changes with the pressure increase, calculate the density of each fuel into value, and on the basis of the last problem improvement time function equation, the available every time the one-way valve open time.

There is less pressure control for high-pressure tubing at home and abroad, and there is no better way to solve this problem. In this paper, a time model is established to improve the working efficiency of high-pressure tubing to control the pressure of high-pressure tubing, and the real-time pressure of high-pressure tubing is better calculated by simulation according to the actual situation.

2. Problem analysis
This problem is a continuous problem. The fluid in the high-pressure tubing keeps flowing in and out. The pressure in the pipe keeps changing, and the fluid density also changes accordingly. Start from the most basic situation, and gradually consider the opening time of the one-way valve under different conditions. The problem is that the pressure in the high-pressure tubing should be as stable as possible around 100\(MPa\), and the opening time of the one-way valve should be set\([1]\).

For this problem, it is required to set the duration of each opening of the one-way valve so that the pressure in the high-pressure tubing is stable at 100\(MPa\). First, in order to keep the pressure in the high-pressure tubing as stable as possible around 100\(MPa\), the fuel entry period and ejection period are equal to 100\(ms\)\([2]\). The pressure change of fuel is proportional to the density change, and the proportional coefficient is \(\frac{E}{\rho}\). The volume of high-pressure tubing remains constant, so the fuel mass entering the high-pressure tubing is equal to the fuel mass ejected from the high-pressure tubing. The time control model is established based on the conservation of mass, and the opening time of the one-way valve can be obtained.

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density value of fuel into the high pressure pipe will changes with the pressure increase\([3]\), calculate the density of each fuel into value, and in the last question on the basis of improving time function equation, the available every time the one-way valve open time.
3. The definition and Explanation of symbols

**Table 1. Symbol and Definition**

| Symbols | Definition |
|---------|------------|
| $\rho_t$ | Real-time density of fuel flowing into high pressure tubing |
| $V_g$ | Ejecting fluid volume |
| $V_G$ | Internal fluid volume |
| $t_A$ | Opening time of one-way valve |
| $m_A$ | Into the mass of the fuel |
| $m_B$ | The mass of jet fuel |
| $m_G$ | Fluid quality in high pressure tubing |

4. Modeling Assumption

Assuming the temperature in the high-pressure tubing is constant.
Assuming the fuel in the connection between the high pressure oil pump and the high pressure oil pipe is ignored.
Assuming the viscosity of the fuel is negligible

5. Build model

5.1 The establishment and solution of time control model

The time control model can be established by observing the schematic diagram of the high pressure tubing as shown below.

![High pressure tubing diagram](image)  

**Figure1.** High pressure tubing diagram

5.1.1 Problem 1:
The injector operates 10 times per second, so the working time of each time is $100ms$, assuming that the flow from fluid entry to fluid ejection, the one-way valve is closed, and the working time is $100ms$ .

**Step1** Under the condition that the pressure in the tube is $100MPa$, the model of density and time is established\[4\]:

$$
\begin{aligned}
(V_g + V_G) \rho_t &= \rho_{100MPa} V_g + t_A C A \sqrt{2 \rho_{100MPa}} (160-P) \\
p_t &= \frac{E_{100MPa} (\rho_t - \rho_{100MPa}) + 100}{\rho_{100MPa}}
\end{aligned}
$$

(1)
Where, the pressure at the inlet of $A$ is always 160MPa, $\rho_i$ represents the real-time density of the high-pressure tubing, $V_g$ represents the volume of fuel injection, $V_G$ represents the volume of the high-pressure tubing, $P_i$ represents the real-time pressure of the high-pressure tubing, and $t_d$ represents the opening time of the one-way valve$^{[5]}$.

Step2  Condition analysis

In order to make the pressure in the high-pressure tubing as stable as possible at about 100MPa, the fuel entry period and ejection period are both 100ms. Since the pressure change of fuel is proportional to the density change, the pressure and volume of the high-pressure tubing remain unchanged$^{[6]}$, and the fuel mass in the pipe is $m_c = \rho_{100\text{MPa}} V_G$, the mass of the incoming fluid is equal to the mass of the ejecting fluid. As the fluid in the high-pressure tubing is in dynamic change, then:

$$m_i = \rho_i V_i$$
$$P_i = \rho_{100\text{MPa}} V_G + m_i - m_e$$

(2)

Where $\rho_i$ represents the density of fuel flowing from port $B$, and $m_i$ is calculated as :

$$\left\{ \begin{array}{l}
Q_d = C \cdot A \cdot \sqrt{\frac{2(160-P)}{\rho}} \\
V_d = Q_d t_d \\
m_d = \rho_{100\text{MPa}} V_d 
\end{array} \right.$$  

(3)

Substituting formula (3) into formula (2), the deformation can be obtained as follows :

$$(1+\frac{V_d}{V_i})m_i = \rho_{100\text{MPa}} V_G + m_d$$

(4)

Since the pressure change of fuel is proportional to the density change$^{[7]}$, and the proportional coefficient is $\frac{E}{\rho}$, the real-time density of fuel flowing into the high-pressure tubing is:

$$\frac{P_i \cdot \rho_{100\text{MPa}}}{\rho_i \cdot \rho_{100\text{MPa}}} = \frac{E_{100\text{MPa}}}{\rho_{100\text{MPa}}}$$

(5)

To calculate $\rho_i$, (5) can be transformed into:

$$\rho_i = \frac{(P_i \cdot \rho_{100\text{MPa}}) \rho_{100\text{MPa}}}{E_{100\text{MPa}}} + \rho_{100\text{MPa}}$$

(6)

At the same time, the high pressure tubing volume can be calculated from the following figure2.
Figure 2. Schematic diagram of fuel injection rate

For the changes in fuel density and time, the volume inside the high-pressure tubing is \( V_o = \pi r^2 l \), which is substituted into the radius of the high-pressure tubing and the length of the inner cavity to obtain \( V_o = 12500 \pi mm^3 \), and \( V_B = 44 mm^3 \) is obtained according to the rate of oil injection at nozzle \( B \). At the same time, \( \rho_{oil} \) can be calculated according to the proportional coefficient of fuel pressure and density, and \( Matlab \) can be used to fit the two. See the specific image in the appendix as follows:

Figure 3. Fitting diagram of pressure and fuel density

Get \( \rho_{oil} \approx 0.87149 mg/mm^3 \).

By substituting the given value and calculated value into formula (1), it can be concluded that the total opening time of one-way valve 100ms is 2.7504ms, and the opening time of each time is 0.275ms.

5.1.2 Problem 2:
Suppose the increase in fluid pressure of each time is 2.5MPa, so that the pressure of the high-pressure tubing increases from 100MPa to 150MPa in 2s. Since the oil supply port works 10 times per second, and the injection time of each time is 100ms, it can work for 20 times in 2s. Based on problem 1, the time function is improved:

Step1 After 2s adjusts, when the pressure inside the tube becomes 150MPa, the function of time is established as follows:

\[
(V_o + V_C)\rho_i = \rho_i \rho_i V_o + t_o C A \sqrt{2 \rho_{oil} \rho_{oil}} \sqrt{150 - P_i} \]

(7)

Step2 Condition analysis
Since the pressure change of fuel is proportional to the density change, the proportional coefficient is \( \frac{E}{P} \) and each increase in pressure is 2.5 MPa, then the pressure in the initial state of the high-pressure tubing at the first operation is 102.5 MPa, and the real-time density of fuel flowing into the high-pressure tubing is:

\[
\frac{P_i - P_{100 \text{MPa}}}{\rho_i - \rho_{100 \text{MPa}}} = \frac{E_{100 \text{MPa}}}{\rho_{100 \text{MPa}}}
\]  

(8)

As for problem 2, every increase in air pressure of 2.5 MPa leads to 2s change in real-time density value. Substitute the real-time density change value and other values into the improved time function equation (7) to obtain the opening time of the one-way valve for 20 times of operation of high-pressure tubing in B, as shown in table 1 below:

**Table 2.** 2s one-way valve opening time

| Pressure Increase (MPa) | Opening Time (s) |
|-------------------------|------------------|
| 5.784972                | 7.738401         |
| 5.918344                | 8.058928         |
| 6.061054                | 8.422023         |
| 6.214253                | 8.838071         |
| 6.379301                | 9.321394         |
| 6.55782                 | 9.892398         |
| 6.75176                 | 10.58137         |
| 6.963491                | 11.43561         |
| 7.195928                | 12.53413         |
| 7.452701                | 14.02145         |

6. Conclusion
We analyzed the real-time pressure change in the high-pressure tube, and used the integral value to reflect the cumulative change value of the corresponding quantity, which was close to the actual situation.

The corresponding calculation method is given for each problem in a complete way. In real life, the model can be improved according to the specific situation.

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