Pressure control of high pressure oil pipe based on PID

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Abstract: Due to the comprehensive consideration of power, economy and emission of the fuel engine, the high-pressure common rail system emerges as the times require and develops rapidly. The advantage of high pressure common rail system is that it can realize the flexible control of fuel injection, and it can realize the precise control of fuel injection quantity, timing and pressure, and it can realize multiple injections, even the flexible control of fuel injection. However, in the intermittent process of the actual fuel entering and ejecting process, there will be pressure changes in the high-pressure fuel pipe, as well as changes in the internal fuel density.S o it is very important to establish the time model of one-way valve based on PID control, high-pressure oil pipe, needle valve cam control model, fuel wave movement model and so on, and to give a reasonable evaluation combined with the actual situation.

1. Wave process of fuel

Actual fuel oil is a kind of compressible liquid. When the one-way outlet valve is opened and the fuel oil flows into the high-pressure oil pipe, the fuel oil in the whole high-pressure oil pipe will not be compressed, but only a layer of fuel oil near the one-way outlet valve in the high-pressure oil pipe will be compressed, the density will increase and the pressure will increase. However, the fuel that is far away from the one-way outlet valve still keeps its original density and pressure unchanged. This layer is located near the one-way outlet valve to compress the adjacent fuel. The fuel input from the high-pressure oil pump to the high-pressure oil pipe continuously compresses the fuel near the one-way oil outlet valve, so that its density and pressure increase again. This layer of fuel continues to compress the adjacent layer of fuel. Such a layer of compression in the past, forming a gradually increasing amplitude of the pressure wave along the high-pressure oil pipe propagation. Therefore, the movement of fuel itself is very small in the high-pressure fuel pipe, and the pressure is established and propagated in the form of waves.

2. Modeling based on PID

2.1 Establishment and simplification of actual working conditions

Given the length of the inner cavity of the high pressure oil pipe is 500mm, the size of the inner diameter is 10 mm, and the diameter of the small hole at the oil supply inlet is 1.4 mm. It is determined that the working condition of the injector is 10 times per second, and the injection time is 2.4ms at each time. In 2.4ms, the injection rate increases from 0 to 20 at a constant speed. In the time, the injection rate remains the same, and in the meantime, the injection rate decreases to 0 at a constant speed. Ensure that the pressure at inlet a is 160MPa, and keep the internal pressure of high-pressure oil pipe stable at the initial pressure as much as possible, i.e. 100MPa. In the case of one-way valve, it needs to be closed for 10ms after each opening. Now, it is necessary to choose how to set the opening time of one-way valve.

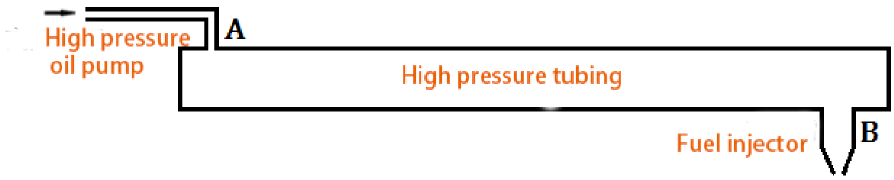

Figure 1.Simplified model diagram

2.2 Model hypothesis

1. The opening and closing state of the check valve is periodic, and there is a duty cycle Q.

2. Mineral oil has the ability to dissolve air and other gases. The results show that under normal temperature and pressure, the dissolved gases in mineral oil account for 8% - 10% of its volume, but the situation is complex at this time, so it can be considered that liquid oil is single-phase liquid.

3. The cam of the oil pump supplies oil at the same speed.

4. The fuel transfer process is to maintain one-dimensional form, that is, there is no pressure difference or density difference in the longitudinal section.

2.3 Symbolic explanation

Table 1. Symbolic explanation.

Symbol	q	E	ρ	ΔP	$\Delta\rho$
Significance	Duty cycle	Modulus of elasticity	Fuel density	Pressure variation	Density variation
Symbol	A	ρ_1	C	ΔP_1	Q
Significance	Area of small hole	Fuel density at high pressure side	discharge coefficient	Pressure difference on both sides of the orifice	Fuel flow through the orifice per unit time
Symbol	a	t_p	t_r	ρ	t_s
Significance	Propagation velocity of pressure wave	Peak time	rise time	Overshoot	Adjustment time

2.4 Establishment and solution of the model

2.4.1 Relationship between fuel pressure change and density change.

In order to make the physical parameters of fuel clearer, the relationship of fuel density can be defined as follows [2]:

$$\rho = \rho_0[1+(0.69\times10^{-9}p)/(1+3.23\times10^{-9})-\lambda t(T-T_0)] \tag{1}$$

Among them, T represents the ambient temperature of fuel, T represents the temperature of fuel. In a more accurate and profound empirical formula, the density of fuel will change with the ambient temperature of fuel and the temperature of fuel itself. In the current fuel density model, there are also factors such as fuel compression rate, dynamic viscosity, kinematic viscosity, viscosity temperature index and viscosity pressure index.

2.4.2 Differential form analysis of pressure wave

The propagation of pressure wave satisfies one-dimensional unsteady compressible partial differential equations：

$$\begin{cases} \frac{\partial P}{\partial t} + u\frac{\partial P}{\partial x} + a^2\rho\frac{\partial u}{\partial x} = 0 \\ \frac{\partial P}{\partial x} + \rho\frac{\partial u}{\partial t} + \rho u\frac{\partial u}{\partial x} = 0 \end{cases} \tag{2}$$

In this formula, the flow resistance coefficient of fuel is not considered, where u is the flow rate and a is the propagation speed of pressure wave.

$$a = \sqrt{\frac{E}{\rho}} \tag{3}$$

The relationship between the change of total pressure DP and the change of velocity Du at a certain time is as follows:

$$dP = dP_R + dP_L$$
$$du = du_R + du_L \tag{4}$$

2.4.3 Pressure control model based on PID

PID control, which is widely used in engineering practice, is a kind of proportional, integral and differential control regulator. Its advantages are simple structure, good stability, reliable operation, convenient adjustment. It is suitable for us to use when we do not fully understand a system and controlled object, or get an inaccurate mathematical model.

To build PID pressure control model in MATLAB, first of all, we determined that the total time of the research is 10000ms, and set the sampling interval as 0.1ms. In the actual engineering calculation, the precision and research scope will be limited mutually, so we selected that the sampling interval can be determined as small as possible to ensure the accuracy of the model as much as possible, and as rich as possible The total range ensures the best choice in a few cycles or so.

Side a of high pressure oil pump:

$$Q_1 = CA\sqrt{\frac{2\Delta P_1}{\rho_1}} = 0.85\times1.539\times\sqrt{\frac{2\times60}{0.8375}} = 15.659 mm^3/ms$$

In the initial case of side a of high-pressure oil pump, the initial value of pressure is 60MPa, and the initial value of density is. The fuel flow through the small hole in unit time is calculated. In this model, we assume that the oil delivery of the high-pressure oil pump is completely periodic, and then there will be a duty cycle Q, that is, in a cycle T, there will be q time to spray oil, and in the time of (t-q) there will be no injection operation. And in the PID control, every 0.1ms sampling process, read the data, calculate the amount of oil, real-time detection and correction of the amount of oil.

According to the research method of pressure wave, when considering the elastic deformation of the pipe wall and crude oil, the theoretical formula for calculating the pressure wave velocity of the pipe is as follows[3]: $a = \sqrt{\frac{K/\rho}{1+\frac{KD}{E_1\delta}C_1}}$

Where, is the elastic modulus of the pipe wall, K is the original volume elastic coefficient, is the constraint coefficient of the pipe, is the thickness of the pipe wall, and D is the inner diameter of the pipe wall.

The bulk elastic coefficient of crude oil is calculated by the following formula[4]:

$$\ln(\frac{1}{K}\times10^{10}) = 0.51992 + 0.0023662t + \frac{946596}{\rho_0^2} + 2366.67\frac{t}{\rho_0^2}$$

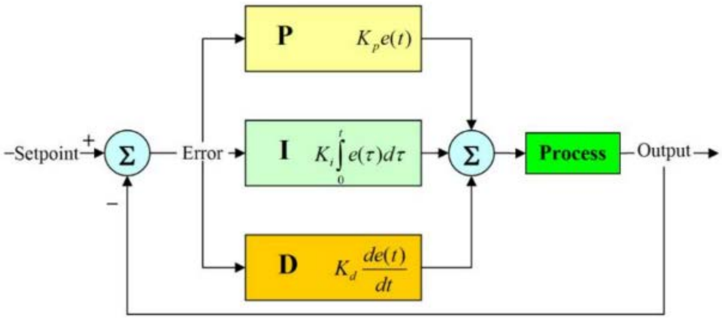

Figure 2.PID schematic diagram

Inside the nozzle: The selection and establishment of the fuel injection process are established according to the given image. Each time interval is 0.1ms, select a data point to read in. Within the total time of 10000ms, there are 100 cycles for the fuel injection nozzle, that is, open the fuel injection nozzle in each cycle for fuel injection

3. Conclusion

The PID model is established, and the image is as follows:

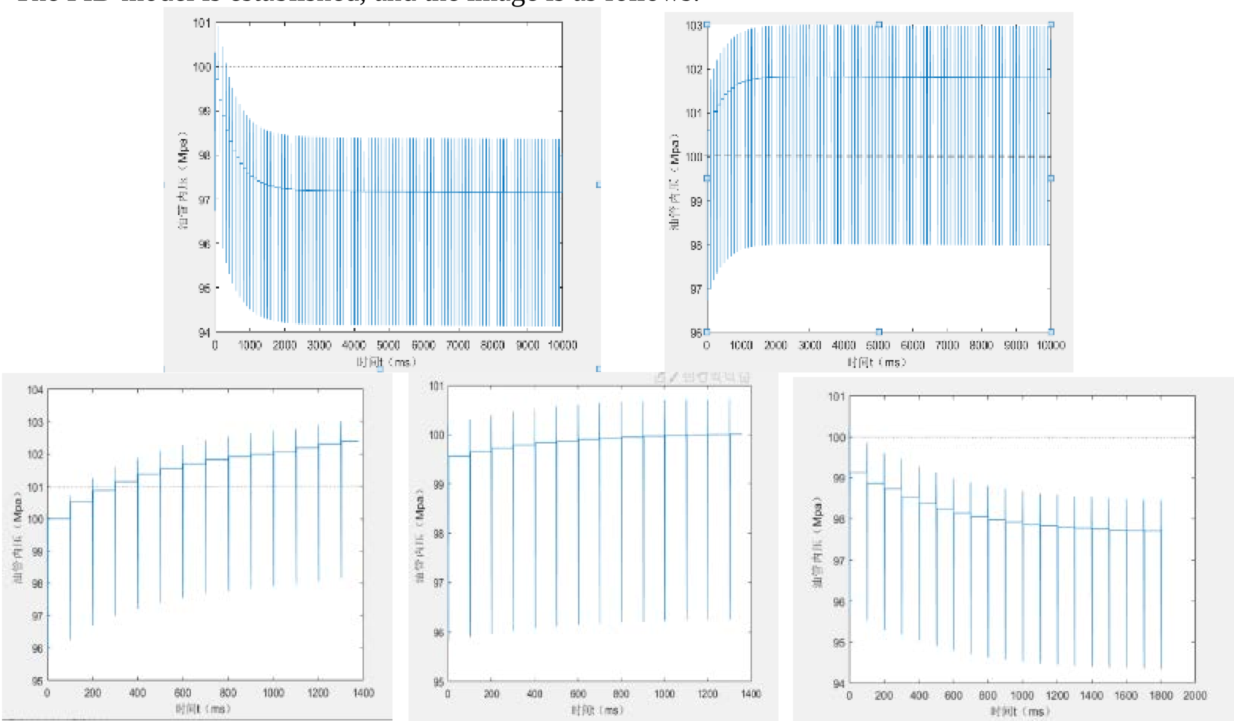

Figure 3.PID

When the accuracy is 0.1, two figures are made under the duty cycle of 2.7% and 2.8%. In the duty cycle of (2.7% ~ 2.8%), three experiments are carried out, and the pictures drawn in MATLAB are as follows.

This is the first generation of high-pressure tubing pressure model based on PID control. The conclusion of this model is also excellent in the comparison of other relevant literature. This model can also be extended to more general forms of related control.

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