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The simulation analysis for cartridge proportional flow valve

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Abstract. Mechanical and electrical integration is an important direction for future development of the industry. There are many products in hydraulic filed. By connecting electrical and mechanical, we can obtain more precise displacement, velocity and force of controlled object. The simulation can reduct the model and evaluate the performance of the controlled system. The overall development time and costs saved. The aim of the paper is to build a model of cartridge proportional flow valve with LMS Imagine.lab -AMESim and validate the accuracy of the built model by comparing with products catalogue.

1 Introduction

The technology which is widely used in productions is benefit from combining mechanical and electrical. The hydraulic technology is wildly used in the fields of aerospace, automobile, machine tools etc. Combining electrical and mechanical and hydraulic will improve production efficiency and obtain higher control precision. Cartridge proportional flow valve is the example of the combination.

The cartridge proportional valve was used in little flow situation at first. Now, it develops into the style of using pilot proportional to control main spool and used to control high flow. With a LVDT works as feedback unit, the control accuracy of cartridge proportional flow valve is raised [1].

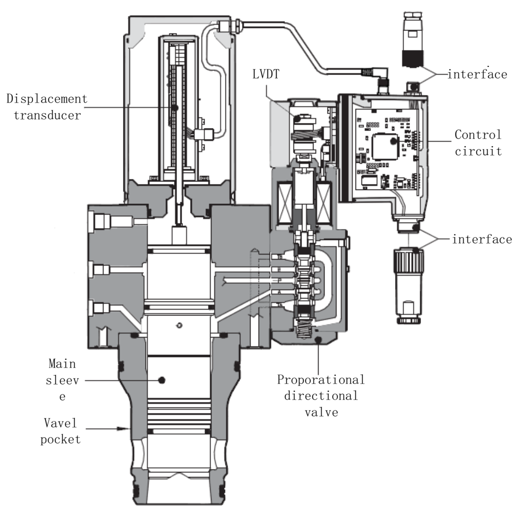

Figure 1. Cartridge proporational flow valve sketch.

The structure of cartridge is shown in figure 1. The main spool is used to control flow by using orifice, which controlled by matching main spool with valve sleeve. The displacement transducer (LVDT) is installed at the top of main spool, this unit can translate the displacement of main spool to electrical signal and feedback to control system. The proportional directional control valve is the leader of main spool, it control the displacement of main spool. Control circuit include the receiver of LVDT, and it communicate with main control system [2]. And the hydraulic system principle diagram is shown in figure 2.

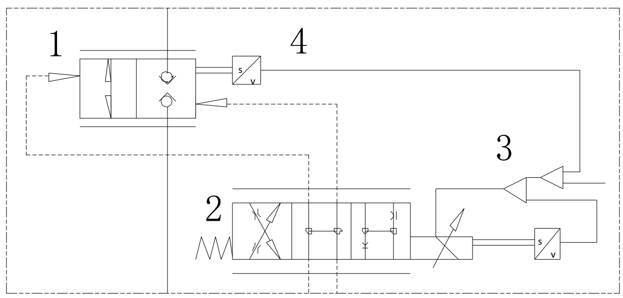

Figure 2. Hydraulic system principle diagram of cartridge proporational flow valve.

As the hydraulic system principle diagram of cartridge proportional flow valve shown, the cartridge valve simple modle as number 1 shown. The controlled flow is in its hands. And the modle of pilot proportional valve is as number 2 shown. Number 3 and 4 represent for the control circuit.

2 The mathematical modle of controlled displacement of main spool

The displacement of main spool determines path area of orifice. And the path area of the orifice influence the flow crossed by. The displacement of main spool is controlled by pilot proportional direction control valve. And the LVDT will feedback the signal of displacement to control system. The modle of pilot valve control main spool can be simplified as figure 3 shown [3, 4].

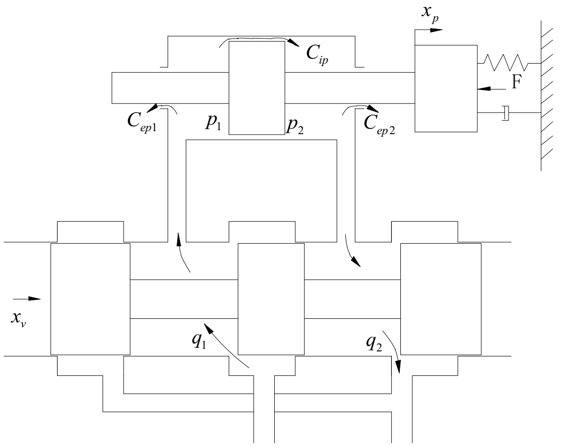

Figure 3. Valve control piston.

In this case, it is base modle of spool control cylinders.

The fundamental equations of the modle are given.

The flow equation passed by orifice is

$$q_L = K_q x_v - K_c p_L \quad (1)$$

where K_q is coefficient of flow, K_c is flow-pressure coefficient .

The flow continuity equation is

$$q_L = A_p \frac{dx_p}{dt} + C_{tp} p_L + \frac{V_t}{4\beta_e} \frac{dp_L}{dt} \quad (2)$$

where C_{tp} is total leakage coefficient of piston, V_t is total volume of fluid under compression.

The forces of the piston is

$$A_p p_L = m_t \frac{d^2 x_p}{dt^2} + B_p \frac{dx_p}{dt} + K x_p + F_L \quad (3)$$

where K is load spring gradient

After laplace transform, the transfer function can be written as

$$X_p = \frac{\frac{K_q}{A_p} X_V - \frac{K_{ce}}{A_p^2}(1 + \frac{V_t}{4\beta_e K_{ce}} s) F_L}{s\left[\frac{m_t V_t}{4\beta_e A_p^2} s^2 + (\frac{m_t K_{ce}}{A_p^2} + \frac{B_p V_t}{4\beta_e A_p^2}) s + 1\right]} \quad (4)$$

$$X_p = \frac{\frac{K_q}{A_p} X_V - \frac{K_{ce}}{A_p^2}(1 + \frac{V_t}{4\beta_e K_{ce}} s) F_L}{s\left[\frac{s^2}{\omega_h^2} + \frac{2\zeta_h}{\omega_h} s + 1\right]} \quad (5)$$

where $\omega_h = \sqrt{\frac{4\beta_e A_p^2}{V_t m_t}}$ represent for natural frequency of hydraulic. And $\zeta_h = \frac{K_{ce}}{A_P}\sqrt{\frac{\beta_e m_t}{V_t}} + \frac{B_p}{4A_p}\sqrt{\frac{V_t}{\beta_e m_t}}$.

It represent for hydraulic damping ratio, it influence the dynamic response of the system. This mathematical model express the dynamic performance of valve control piston [5, 6].

3 The simulation modle of controlled displacement of main spool

3.1 The built of simulation modle

First step, the detailed simulation modle of cartridge proportional flow controlled valve was built by using components from Hydraulic Component Design (HCD) [7] library, Mechanical library , Hydraulic library and Signal Library [8]. Refer to the structure and the operating principle of the cartridge proportional flow controlled valve. [9, 10] The simulation modle was built as figure 4. This modle requires geometrical parameters like the mass of the spool, the diameter of the piston, the diameter of internal fixed orifices, the flow of the pilot proportional direction controlled valve [11].

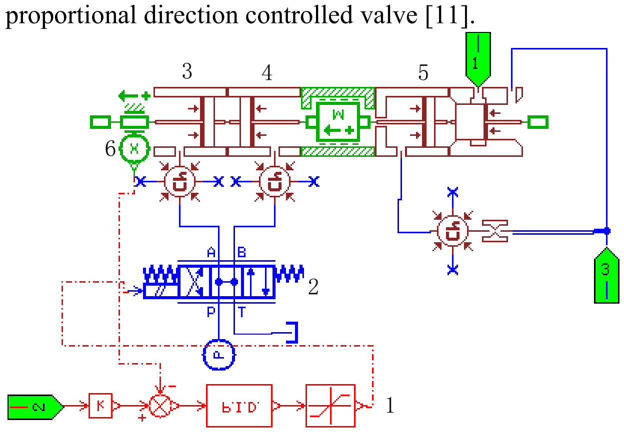

Figure 4. Simulation modle of cartridge proportional flow controlled valve.

As figure 4 shown, the simulation modle of cartridge proportional flow control valve consist of amplifier circuit (1), proportional pilot direction control valve (2). Left piston (3), right piston (4), Cartridge seating type orifice (5).

The amplifier circuit make up of one comparator which compares feedback signal with interface signal and output signal to PID controller, and one PID controller which process input signals and output to proportional solenoid. The pilot valve modle come from HYD library. It's a ideal modle which have perfect performance with control signal input. The main spool will move make orifice close when the left piston charged. And the orifice will open when the right piston charged. The flow area of orifice is depend on the diameter of main spool and the displacement of main spool [12].

3.2 The parameters of simulation modle

The simulation modle was build and the parameters of main modle was settled as table 1 shown.

Table 1. Main parameters of modle.

Name of modle	Parameters	Unit
Flow of pilot valve	90	L/min
Natural frequency of piolt valve	70	Hz
System pressure	350	bar
Diameter of main spool	75	mm
Diameter of Left cylinder	85	mm
Diameter of left piston	76	mm
Diameter of right cylinder	85	mm
Diameter of right piston	76	mm
Mass of main spool	9.6	Kg
Parameter of P	11.7	Null

The parameters of modle are set. The simulation signal is set as figure 5 shown. It includes displacemet and the corresponding time parameter. The displacemet of the spool is zero before 1second, and a ramp signal is settled during one to six seconds. This goal signal is correspond to the working condition of the spool.

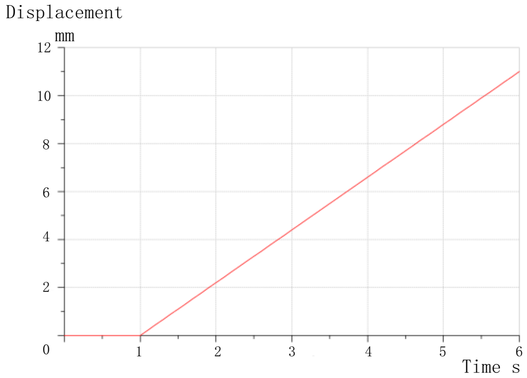

Figure 5. Goal-setting signal.

4 The ansysis of simulation results

With the input signal as figure 5 shown, the output of simulation modle is similar to input signal. The difference curves are given in figure 6 for comparing the input and the output signal.

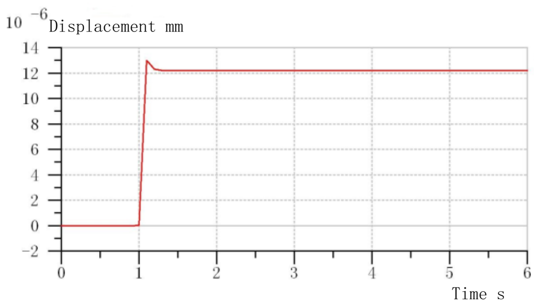

Figure 6. The difference of input and output signal.

As figure 6 shown, the difference of input and output is occurred at the first second, and the difference signal is rapidly increased. After the increasing, this signal remains stable at12 $\times 10^{-6}$mm. This difference curves means the simulation modle have a good stability.

According to the design principle of proportional flow control valve, the flow throughout the orifice is controlled by the displacement of main spool and the flow proportional to displacement. The flow curve in the catalog is shown in figure 7[13].

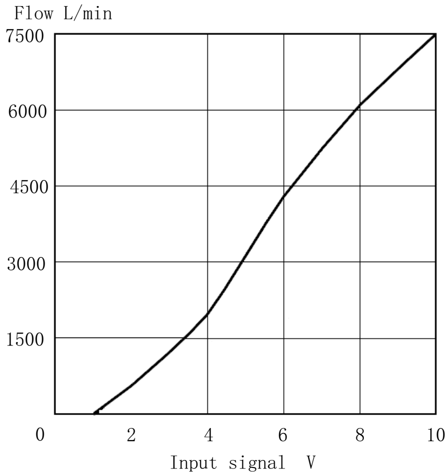

Figure 7. The flow curve given in catalog.

The curve in catalog has a dead band. After the dead band, the output flow is increased. But the trace is not straight line. The curve of the catalog reflect the law of control signal and the output flow. And the dead band is occurred at the begin of the curve for the reason of static friction between spool and valve jacket or the other reasons. With a accurate input signal, the valve will export corresponding output flow.

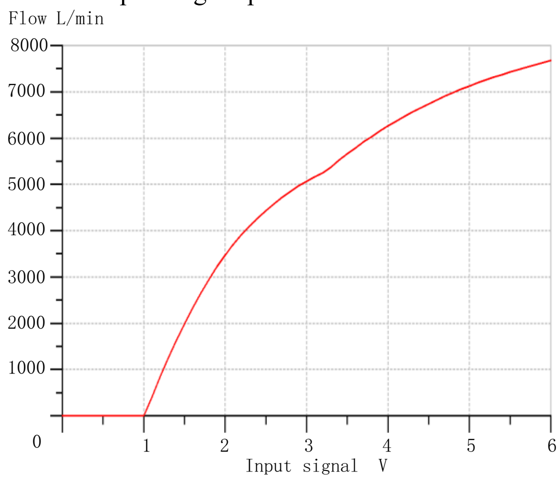

Figure 8. The output of simulation modle.

As figure 7 shown, the flow curve is similar to straight line and proportional to input signal. Because of the unstable difference pressure between orifice and other nonlinear factors, the flow curve is not straight line but similar to straight line. The output of the simulation modle is shown in figure 8.

The displacement of spool in the simulation modle is stable and the output flow curve is stable. The displacement of spool have little difference to input signal.

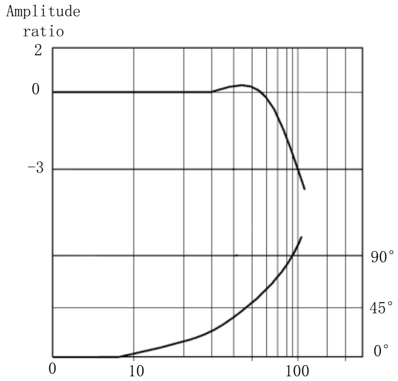

Figure 9. BODE curve given in catalog.

Compared with input signal, it is not straight line too, but it similar to input signal. Compared with flow curve given in catalog, there is some difference between them, but it does not matter. For compare the dynamic performance of the simulation modle, the BODE curve was given in figure 9 and figure 10.

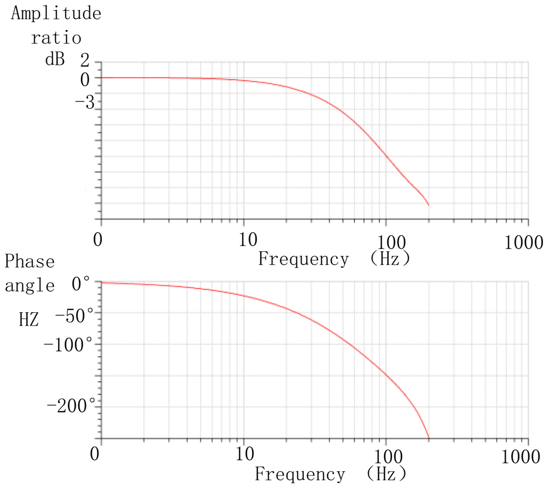

Figure 10. BODE curve output by simulation modle.

Compared the BODE curve shown in figure 10 with the BODE curve given in catalog, the difference is small and we can accept it .so, the simulation modle built in the AMESim is acceptable, and can be used to simulate the properties of the cartridge proportional flow control valve.

5 Conclusions

The control of displacement or velocity will be more precise with combination electronic technology and mechanical. Added with hydraulic technology, the electrical signal is turn into flow or press signal. There are a lot of possibilities to build a simulation modle. The simplified of cartridge proportional flow control valve turn out to be right. And the advantages of combine electrical, mechanical and hydraulic are obvious.

Acknowledgements

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