Design and Simulation of Electro-hydraulic Control Valve Based on AMESim

Bin Li 1,a*, Guyang Li 2,b, Wangyang Wu 3,c, Xue Zhang 4,d, Song Guo 4,e, Nei Wang 1,f, Xuyao Mao 1,g

1 Wuhan Second Ship Design and Research Institute, Wuhan, China
2 China state shipbuilding corporation limited engineering management center, Beijing, China
3 Third Military Representative Office of the Naval Equipment Department in Wuhan, Wuhan, China
4 Bohai Shipbuilding Heavy Industry Co. LTD, Huludao, China
*a*corresponding author: libinhappy@zju.edu.cn
b 448954534@qq.com, c 492569237@qq.com, d 476589235@qq.com, e guosongjie555@163.com, f neilwong2011@163.com, g littlemaomao@163.com

Abstract. In this paper, the electro-hydraulic control valve commonly used in ships is taken as the research object, the working principle of the valve is introduced, the model of the valve is established by AMESim software, the model parameters are set and the simulation analysis is carried out. By changing the relevant parameters of the valve, the response speed of the valve can be improved. The simulation results show that the pressure area of load sensitive cavity and the diameter of damping hole have obvious influence on the response speed of valve.

1. Introduction
Electro-hydraulic control valves are widely used in mechatronics systems. As the core control element of hydraulic system, the performance of electro-hydraulic control valve directly affects the quality of hydraulic system. In this paper, AMESim software is used to model and simulate the electro-hydraulic control valve, which plays a positive role in improving the performance of the valve.

The basic structure of electro-hydraulic control valve is shown in figure 1. It belongs to displacement feedback pilot proportional directional valve. When the input signal is zero, the pilot valve can be centered by the adjusting nut, the main spool is also in the middle, and the ring cavity pressure is equal. If the right electromagnet is energized, the electromagnetic force pushes the pilot valve to move to the left, the main spool right control chamber pressure increases, and the left chamber passes back to the oil [1]. Therefore, the main spool under the action of liquid pressure left movement, through the feedback lever, the main spool drives the pilot valve moving sleeve left movement. Then close the pilot valve port, the main spool stability in a certain position.

The displacement of the main spool is proportional to that of the pilot spool, and the ratio is related to the feedback ratio of the lever, which can be adjusted by nut 4. It belongs to displacement feedback pilot proportional direction valve.

When the input signal is zero, the pilot valve spool 3 by the spring, can also be adjusted by the spool nut. When the pilot valve spool 3 in the middle, the main valve spool 6 left and right ring cavity pressure
is equal, the main valve spool 6 is closed. The valve has two electromagnets to control the displacement of the pilot valve spool. If the electromagnet on the right is energized, the electromagnetic force pushes the pilot valve spool 3 to the left, the main valve spool 6 to the right control chamber pressure rise, and the left chamber passes back to the oil T port. Therefore, the main valve spool 6 moves to the left under the action of liquid pressure. Through the feedback lever in the figure, the main valve spool 6 drives the moving valve sleeve 2 of the pilot valve to the left. The pilot valve port opening tends to decrease until the pilot valve port is closed, the main valve spool 6 is stable in a certain position, the position and the pilot valve spool displacement. Therefore, the displacement of the main valve spool 6 is proportional to the given signal of the pilot valve spool 3 to achieve proportional control. The lever feedback ratio can be fine-tuned by spool adjustment nut 4.

Figure 1. Structure schematic diagram of electro-hydraulic control valve.

2. Mathematic models

Most of the variables and corresponding physical significances are also displayed.

- The connection pipe between pilot valve and main valve is symmetrical, short and thick.
- The pressure loss and dynamic loss in the pipe can be ignored.
- The pressure in each working chamber of the main valve is equal everywhere.
- The oil temperature and volume elastic modulus are regarded as a constant.
- The leakage inside and outside of the main valve is laminar flow.

When the spool of the main valve is in the middle of the valve sleeve, the four throttles have the same negative opening quantity \( U \).

Assuming that the valve is matched and symmetrical, and referring to the reference method of the pilot valve, the pressure-flow characteristic equation of the main valve can be expressed as:

\[
q_{z,x} = C_{dx} W_z (x_z - U) \left( \frac{1}{\rho} \left( p_{sz} - p_{lz} \right) \right)
\]  \hspace{1cm} (1)

The zero coefficient of the valve can be obtained by partial differentiation of formula 1:

\[
K_{q0} = C_{dx} W_z \left( \frac{p_{sz} - p_{lz}}{\rho} \right)
\]  \hspace{1cm} (2)

\[
K_{c0} = \frac{C_{dx} W_z (x_z - U) \left( p_{sz} - p_{lz} \right)}{\rho}
\]  \hspace{1cm} (3)

\[
K_{p0} = \frac{2(p_{sz} - p_{lz})}{x_z - U}
\]  \hspace{1cm} (4)
Where: $C_{dz}$ - main valve port flow coefficient;
$W_z$ - Gradient of main valve port area;
$p_{sz}$ - Main valve inlet pressure;
$\rho$ - Oil density.

After dimensionless processing of Formula 1:

$$q_{Lz} = (1-x_z) \sqrt{1-p_{Lz}}$$  (5)

Where,

$q_{Lz}$ - the dimensionless flowrate.
$p_{Lz}$ - the dimensionless load pressure.
$x_z$ - the dimensionless displacement of the spool.

For dimensionless equation 5, the pressure-flow curve of the main valve can be made by Matlab, as shown in figure 2 and figure 3 below [3].

![Figure 2. Pilot valve pressure - flow curve.](image1)
![Figure 3. Main valve pressure - flow curve.](image2)

Compared with Figure 2 and Figure 3, it can be seen that the pressure flow curve trend of the main valve and pilot valve are consistent, but the main valve due to positive cover, so there is an obvious dead zone, in engineering applications, greatly affects the linearity of the valve, generally used in the steady-state accuracy requirements are not high, high requirements for safety occasions.

Considering the actual dynamic testing process of the valve, the displacement state of the main valve is reflected by the flow, and the valve mouth is positive cover, so there is a zero dead zone. Load flow equation of the main valve [4]:

$$q_{Lz} = 2C_{dz} W_z (x_z - 1) \sqrt{\frac{2}{\rho} (p_c - p_{Lz})/2}$$  (6)

3. Analysis

3.1. The valve models

The simulation of static characteristics of the tested valve is usually done by AMESim software. AMESim is an engineering simulation software based on graphics, which is mainly used to
simulate the real working environment of the control object. At the same time, it has a variety of engineering design software packages, including hydraulic simulation software package, mechanical, HCD (hydraulic component design), signal and control models, hydraulic, mechanical, signal control and other basic models.

The AMESim model of electro-hydraulic control valve can be divided into three parts:
1. pressure reducing valve: adjust the working pressure of the pilot valve;
2. pilot valve: as the pilot of the main valve, control the movement of the main valve. According to the given signal, make the corresponding action.
3. the main valve: controlled by the pilot valve, by changing the valve opening of the system pressure, flow control.

Figure 4. AMESim model of electro-hydraulic control valve.

3.2. Simulation parameter setting
Working pressure and correlation coefficient are set as follows:
The flow coefficient of the throttle port is 0.61, the flow coefficient of the throttle port is 0.7, the hydraulic oil density is 850Kg/cm³, the oil supply pressure of the main valve is 10Mpa, and the oil supply pressure of the pilot valve is 4.2mpa.

The electro-hydraulic control valve related parameters are set as follows:
Pilot valve spool diameter is 25mm, pilot valve moving spool diameter is 10mm, the main valve spool diameter is 5mm, the main valve moving part of the equivalent mass 0.6kg, pilot valve moving part of the equivalent mass 0.04kg.
Set the simulation time as 1s, the simulation step size as 0.001, and adopt the time domain model for simulation.

3.3. Refine Results
This paper mainly studies the influence of valve related parameters on valve response time, so the response of valve to step signal is considered [5].
Under the input of step signal and the above parameter settings, the valve response curve is shown in figure 6.
Figure 5. Step signal.

Figure 6. Main spool displacement.

Step signal setting time is 0.3s. It can be seen from the displacement curve of the main valve that the rise time of the main valve is 20ms. You can see that the system is heavily damped.

In order to accelerate the response speed of the valve, the three parameters are mainly considered from the liquid-controlled sensitive cavity area of the main valve, the diameter of the throttle damping hole and the gradient of the pilot valve port area. AMESim software is used to simulate the influence of each parameter on the response time of the main valve spool.

3.4. Influences by different liquid-controlled sensitive cavity area of the main valve

The displacement of the main valve core was simulated by changing the liquid-controlled sensitive cavity area of the main valve and keeping other parameters unchanged.
Figure 7. Displacement curves of main spool under different liquid-sensitive cavity areas
As shown in figure 7, reducing the liquid-sensitive cavity area of the main valve can effectively improve the response time of the valve. The valve rise time is reduced from 20ms to 15ms when the liquid sensitive cavity area of the main valve is reduced by 20%.

Figure 8. Displacement curves of main spool under different diameter of damping hole
As shown in figure 8, increasing the diameter of the throttle damping hole can effectively improve the response time of the valve. The valve rise time is reduced from 20ms to 16ms when the throttle damping hole diameter is increased by 10%. The effect of increasing the diameter of the orifice is better than that of decreasing the area of the liquid sensitive cavity of the main valve [6].
As shown in figure 9, reducing the pilot valve area gradient has little effect on improving the response time of the valve, and the response time of the main valve is basically unchanged under different pilot valve areas.

4. Conclusions
The electro-hydraulic control valve is modeled, simulated and analyzed by AMESim software, and the effects of the sensing area of the main valve fluid control sensitive cavity, the diameter of the throttle damping hole and the gradient of the pilot valve port area on the valve response time are studied. Simulation results show that the response time of the valve can be effectively accelerated by decreasing the area of the fluid sensitive cavity and increasing the diameter of the throttle damping hole, and the throttle damping hole diameter has a greater impact on the response time of the valve. The influence of pilot valve area gradient on the response time of the whole electro-hydraulic control valve can be ignored.

References
[1] Flandrin P, Rilling G, Goncalves P. (2004) Empirical mode decomposition as a filter bank. IEEE signal processing letters. 11(2): 112-114
[2] R. Amirante, G. Del Vescovo, A. Lippolis. (2006) Evaluation of the flow forces on an open centre directional control valve by means of a computational fluid dynamic analysis. Energy Conversion and Management. 1748-1760
[3] Madalin Stefan Vlad, Valentin Sgarciu. (2006) Distance Process Monitoring Using LabVIEW Environment [A]. Automation Quality and Testing, Robotics, IEEE International Conference on[C]. 214-219
[4] Peder Pederson. (2000) Strategies For Stabilization of Flow Control System with Counter Balance Valve. Fluid Power Net International.
[5] Wang T, Zhang M, Yu Q, et al. (2012) Comparing the applications of EMD and EEMD on time–frequency analysis of seismic signal. 83: 29–34
[6] Egeland O and Gravdahl J T. (2002) Modeling and simulation for automatic control [M]. Trondheim, Norway: Marine Cybernetics