# Design and stability factors analysis of electro-hydraulic driving system for load-sensing electro-hydraulic robot

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**Abstract.** Aiming at the shortage of electro-hydraulic robot in terms of system fluctuation and response speed compared with electric robot. The static and dynamic characteristics of a load-sensitive electro-hydraulic robot electro-hydraulic driving system are simulated based on AMESim software in this paper. By analysing the static and dynamic characteristics of the system, the theoretical knowledge is combined with the simulation results. The factors that affect the stability of the system are emphatically explored to provide ideas for optimizing and improving the stability of the electro-hydraulic driving system of load-sensitive electro-hydraulic robots.

## 1. Introduction

In recent years, the majority of mainstream electric robots have been driven by motors. With the low power density of motor drive and small output torque, the electro-hydraulic robot with the advantages of light weight, small volume, low cost, high speed range and strong bearing capacity increasingly attracted people's attention. However, there are still many areas for improvement and optimization in terms of stability performance, which has driven many scholars to conduct in-depth research on this issue. For example, in order to solve the problem that the interaction between the load and the load sensitive system can make the dynamic response of the system unstable, the design method of load sensing oil pressure system based on dynamic characteristics and overall efficiency evaluation is proposed by Yasuo Sakurai , the feasibility of this method is proved by software simulation[1].With the introduction of the original plan of shunting pressure compensation is put forward by scholars T.J.Malon and J.C.Paul in 1974[2]. The nagging problem of flow-saturation in the load-sensitive system is solved, but the phenomenon of system vibration still need to be improved as the trapped-oil and pressure rise suddenly. Through the simulation of load-sensitive electro-hydraulic driving system, Book and Goering find that the instability of hydraulic system caused by inertia load can be solved by adding damping[3]. Through the functional analysis and load-sensitive electro-hydraulic robots, the electro-hydraulic driving system of the load-sensitive electro-hydraulic robot designed in this paper uses a constant pressure variable pump combination with a Load-sensitive proportional multi-way valve, which satisfies pressure-flow adaptability and guarantees the independence of each load.
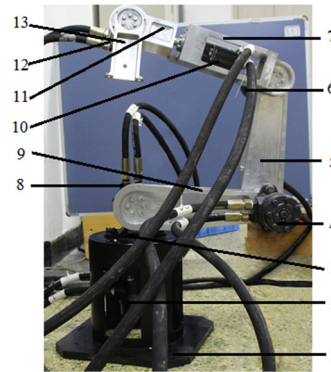
## 2. Electro-hydraulic driving system structure and analysis

### 2.1. Structure of Electro-hydraulic robot

A six degree of freedom electro-hydraulic robot is consists of base, waist, upper arm, median arm, lower arm, wrist, and hand parts, with six degrees of freedom are shown in figure 1. Joint is directly

driven by motor. Joint I and V can rotate around their own axes, respectively, while other Joints can pitch move around their own axes. Each joint of the robot is driven by a motor.
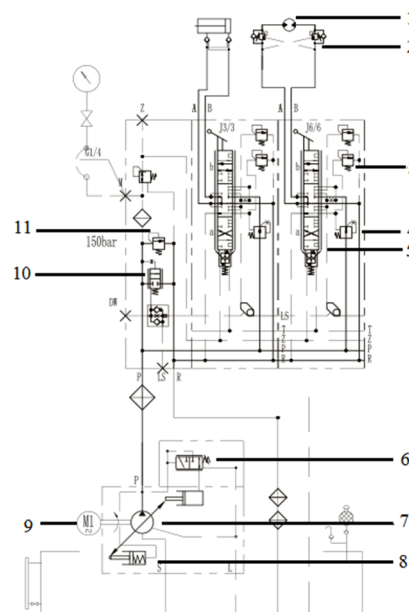


1-base 2-joint I 3-waist 4-joint III 5-median arm 6-joint IV 7-lower arm 8-joint II 9-udder arm 10-joint V 11-wrist 12- joint VI 13- hand
Figure 1. Structure of electro-hydraulic robot.

*2.2. Structure and principle of electro-hydraulic driving system*
According to the system composition and figure1 set up two-way electro-hydraulic schematic diagram as shown in figure 2. The power source mainly consists of two parts: electric machinery and plunger variable pump. Variable mechanism and constant pressure valve constitute a pressure flow regulation core mechanism of constant pressure variable pump. The robot of figure 1 currently has six degrees of freedom with six actuators, and these actuators are controlled using a load-sensitive proportional multi-way valve.



1-motor 2-bidirectional balancing valve 3-secondary pressure-limiting valve 4-two-way flow control valve 5-main valve 6-constant pressure valve 7-plunger variable pump 8-variable mechanism 9-electric machinery 10-threewayflowcontrolvalve 11-mainpressure limiting valve
Figure 2. The electro-hydraulic driving schematic of the load-sensitive electro-hydraulic robot.

When the output pressure of the constant pressure variable pump is greater than its set pressure, traffic begins to change and traffic drops to steep lines. If the output pressure does not reach the set pressure, full displacement output pressure oil, that is, quantitative output. After the pressure of the output oil reaches the constant pressure valve pressure, as the load continues to increase, the variable mechanism automatically adjusts the flow of the plunger variable pump to meet the load pressure requirements. The load-sensitive proportional multi-way valve can control the total flow of the system and control the flow of each valve through the three-way flow control valve, which is complementary to the flow regulation mechanism of the constant pressure variable pump to ensure the flow independence of each valve. The pressure sensitive load mainly depends on the two-way flow control valve, which will leak the maximum pressure of each input to the required pressure and play a load sensitive role.

## 3. Analysis of system characteristics

Based on the pressure flow characteristics of the system and the structure characteristics of the main components in the system, a mathematical model was established to analysis the system characteristics and stability influencing factors from the theoretical perspective.

### 3.1. Pump characteristics on the constant pressure variable pump

Drawing the adjustment principle diagram as shown in figure 3. Above all, according to the required setting pressure $p_0$ regulates the preload of the constant pressure valve in the constant pressure variable pump. When the load pressure is higher than the set pressure in a certain range of pressure adjustment, the constant pressure valve with the pilot valve function in the constant pressure variable pump system starts to run. Push up the differential piston in a variable mechanism move upward by changing the spool displacement of the constant pressure valve $x_F$, and then diminish the swash plate angle $\gamma$ and the flow rate $q$ of the pump.
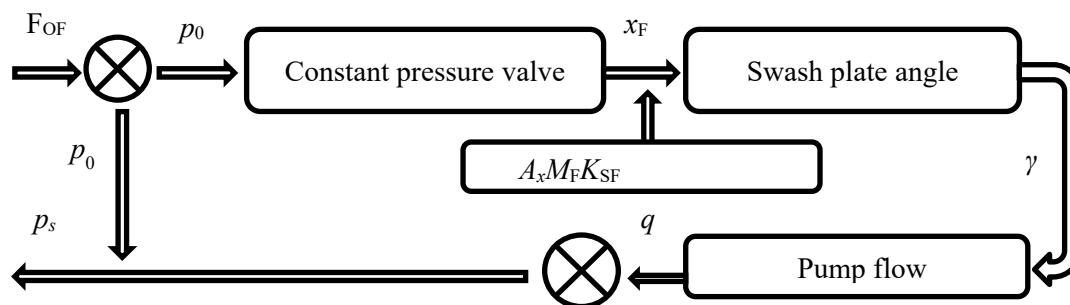


Figure 3. Constant pressure variable pump adjustment diagram.

Establish partial equation of constant pressure variable pump from figure 3 and the structural principles of each component.

Ignoring the influence of friction, obtain the valve core force balance equation:

$$p_s A_x = 2C_d C_v f\, x_F \left( p_s - p_1 \right) \cos\theta + K_{SF} \left( x_F + x_1 \right) \tag{1}$$

Where $p_s$ is the output pressure of pump; $A_x$ is the spool area; $C_d$ is the discharge coefficient of throttle; $C_v$ is the velocity coefficient; $f$ is the window area gradient; $p_1$ is the cavity pressure of differential piston; $\theta$ is the liquid jet angle of throttle; $K_{SF}$ is the spring stiffness of constant pressure valve; $x_F$ is the spool displacement of constant pressure valve; $x_1$ is the pre-compression of spring.

According to the structure and force of the constant pressure valve, the motion differential equation of the constant pressure valve spool is obtained with ignoring the friction force.

$$p_S A_x - F_{OF} = M_F \frac{d^2 x_F}{dt^2} + K_{SF} x_F \tag{2}$$

Where $F_{OF}$ is the pre-tightening force of constant pressure valve; $M_F$ is the spool quality of constant pressure valve.

### 3.2. Pressure-flow characteristics of the main valve to the actuators

There are damping holes between the two valves, which can reduce the fluctuation and cushion. It is considered that the flow of hydraulic oil is laminar flow through the damping hole $R$, and the flow equation of the fixed damping hole is

$$q_R = K_a{}^2 \frac{\pi}{2vp} d_R{}^3 \Delta p_R \tag{3}$$

Where $q_R$ is the pore flow; $K_a$ is the gain of the flow coefficient with respect to the square root of Reynolds number; $v$ is the kinematic viscosity of medium; $p$ is the specific gravity of medium; $d_R$ is the damped hole diameter; $\Delta p_R$ pressure difference before and after the damping hole.

The flow rate of the damping hole passes through the main valve, and the flow continuity equation of the main valve is obtained.

$$q_L = A_h \frac{dx_m}{dt} + \frac{V_c dp_z}{\beta_1 dt} + C_{ip} p_z + C_{ep} p_z \tag{4}$$

Where $q_L$ is the main valve flow; $A_h$ is the control cavity area of main valve; $V_c$ is the left cavity volume of main valve; $\beta_1$ is the effective volume elastic modulus; $C_{ip}$ is the internal leakage coefficient; $C_{ep}$ is the external leakage coefficient; $p_z$ is the main valve control cavity pressure; $x_m$ is the spool displacement of main valve.

The force balance equation of the main valve spool.

$$p_z A_h - F_{OM} = M_m \frac{d^2 x_m}{dt^2} + B_1 \frac{dx_m}{dt} + K_m x_m \tag{5}$$

Where $F_{OM}$ is the pre-compression of main valve; $M_m$ is the quality of main valve spool; $B_1$ is the viscous damping coefficient of the main valve spool; $K_m$ is the spring stiffness of main valve.

## 4. AMESim model analysis

The paper only establishes the AMESim system diagram of two valves to analysis the system characteristics, especially for the factors that affect the steady state of the system.
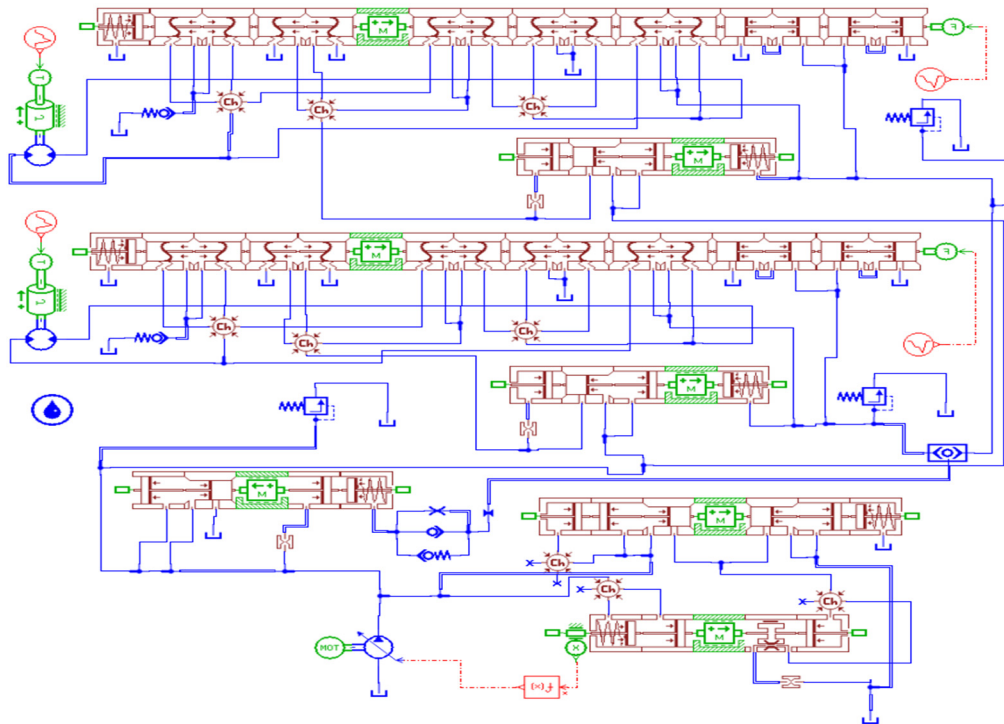
Figure 4. AMESim model of the electro-hydraulic driving system.

*4.1. Dynamic characteristics*

The stability of system pressure-flow affects the normal operation of the system and determines whether the operation process of the actuator can work smoothly and quickly

*4.1.1. Dynamic characteristics of constant pressure variable pump.* The influencing factors of the spool displacement are $A_x$, $K_{SF}$, $M_F$ and so on, of which the $A_x$ is directly proportional to spool diameter $D_X$. The paper focuses on the control area of constant pressure valve $A_x$ and spool quality $M_F$ influences the spool displacement.
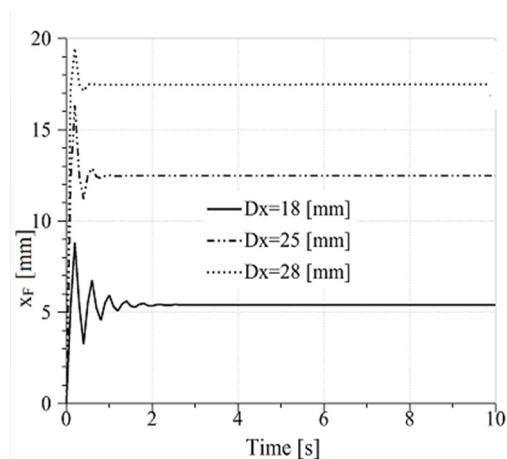


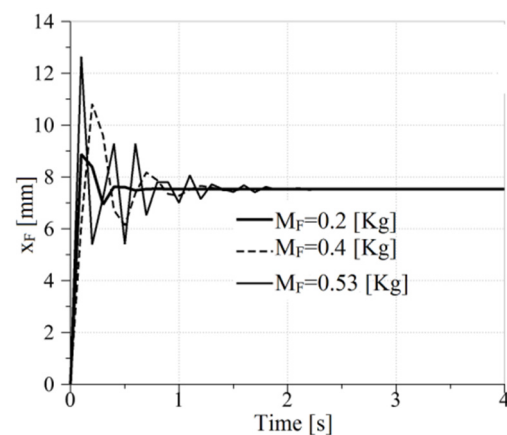Figure 5. The diagram of $D_x$ to $x_F$.              Figure 6. The diagram of $M_F$ to $x_F$.

Figure5 and 6 show the reasonable control area and spool quality should be selected in the principle of considering the stability and response time

*4.1.2. Dynamic characteristics of the main valve block in the load-sensitive proportional multi-way valve.* When the AMESim model is established, the damping hole model is set between the two component models, by giving different diameters of the damped holes, the effect of different damping values on the system characteristics is explored of the electro-hydraulic driving system. The fluctuation of pressure-flow is inevitable, when the main valve control opening changes, the input signal usually superimposes a tremor signal, which can make the pressure of the control cavity in main valve and the spool displacement fluctuate, and if the pressure stability is too good, there may be friction and spool stagnation. Therefore, it is of great significance to reasonably select the damping value and discriminate the blocking orifice of the multi-way valve damping orifice.
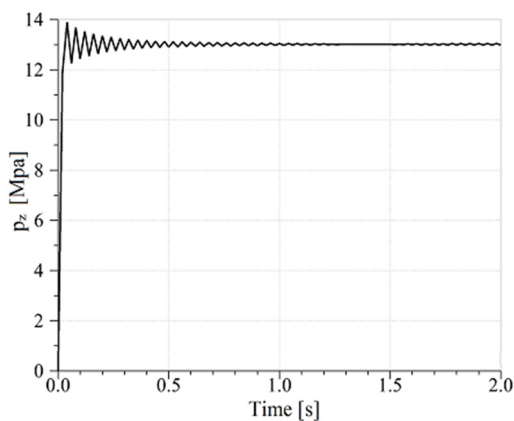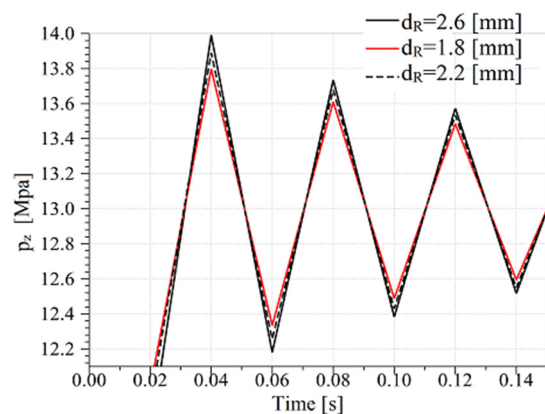


| Figure 7. The $p_z$ chart. | Figure 8. Local enlarged drawing of $p_z$ chart with different $d_R$. |
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Given a step signal to the main valve, the pressure of the control cavity in main valve rapidly increases and then starts to fluctuate. In about one second, the fluctuation gradually converges in a sinusoidal manner and tends to be stable, the trend of change is shown in figure 7. The local enlargement diagram of control cavity pressure with different orifice diameters are shown in figure 8, as the diameter of the damping hole increases (damping value decreases), the overshoot increases and the response speed increases. According to the formula (3) and (4), the relationship between the damping diameter of different diameters and the flow fluctuation is explored.
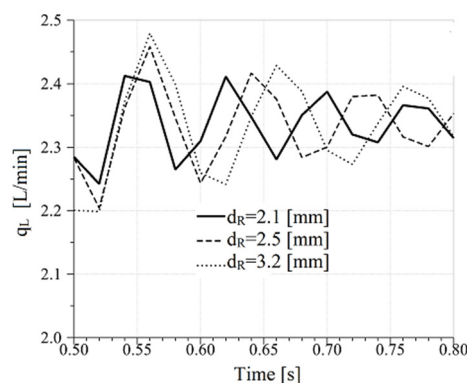


Figure 9. Local enlarged drawing of $q_L$ chart
with different $d_R$.

It can be seen from the diagram that with the decrease of the damping hole diameter (the damping increase) reduces the fluctuation of the flow rate, the running of the actuator is more stable and the response speed is reduced.

## 5. Conclusion

The electro-hydraulic driving system of the load-sensitive electro-hydraulic robot designed in this paper can satisfies the work of multiple actuators without interference at the same time, it has load sensitive function in pressure, saves energy and responds quickly. The constant pressure valve mainly affects the stability of the constant pressure variable pump even the whole system through the spool displacement, so it is important to ensure the stability of the spool displacement. By analyzing the different damping values between the two-way flow control valve and the main valve control chamber in the main valve block, it provides reference for the optimization and improvement of the load sensing proportional multiplex valve.

## Acknowledgments

## References

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