Journal of Applied Science and Engineering Innovation Vol.2 No.2 2015
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

# Characteristics and Control Technology Research of Three-stage Electro-hydraulic Servo Valve

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**Abstract:** The three-stage electro-hydraulic servo valve is the key component which integrates with of mechanical, electrical, hydraulic and control technology. In this paper, its working principle is introduced and its integral mathematical model is established and reasonably simplified. Then the dynamic characteristics of the valve with proportional control algorithm is studied, finally the approach of speed feedback compensation to improve the dynamic performance is proposed, the simulation results show that the valve with this control method is more stable and has good dynamic performance.

**Keywords** Three-stage electro-hydraulic servo valve; Mathematical model; Dynamic response

## INTRODUCTION

Electro-hydraulic servo valve is a highly integration of mechanism, electricity, hydraulics and control technology[1]. It is the connection between electrical and hydraulic component, which transforms the small electrical input signals into high-power hydraulic output to drive the actuators precisely and quickly and combines the advantages of convenient connection, fast delivery, easy to detect and comparable feedback of electrical signal and small inertia, great output force, quick response of hydraulic parts. Its performance directly determines the whole control system. So its control strategy research is a very significant work[2].

## MODELING ON THE SERVO VALVE

Establishing the mathematical model is the foundation of design and control, and it contributes to analyse its characteristic and influence factors in-depth.

### Principle on Three-stage Servo Valve

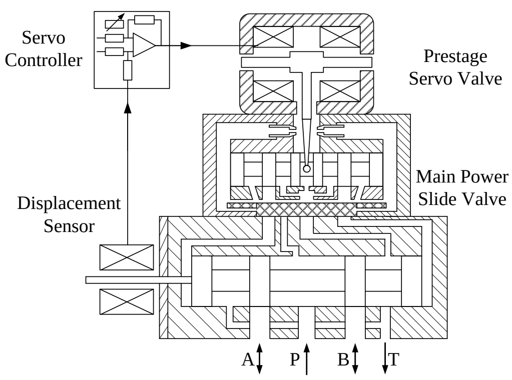



Fig. 1 Structure of three-stage servo valve

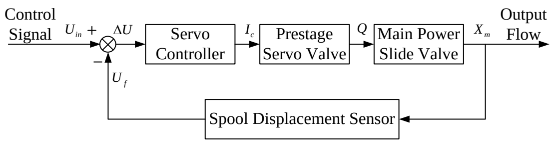



Fig.2 Control principle of servo valve

The three-stage electro-hydraulic servo valve is composed by four major parts: the servo controller, prestage servo valve (two-stage servo valve), the main power slide valve and displacement sensor, as shown in figure 1[3].

Servo controller: convert the comparison results between control and feedback signal into the current which drives the torque motor in the prestage servo valve. It also includes the differential, integral, flutter circuit etc..

Prestage servo valve: small flow 2-stage servo valve, which receives the signal from servo controller and drives the third stage slide valve.

Main power slide valve: the main power unit, namely the third stage. Its orientation depends on the position feedback, which generally is electricity or force feedback.

Displacement sensor: modulate and enlarge the proportional displacement signal of main valve spool and then feedback to the servo valve controller.

### Modeling on servo controller

The servo controller can be treated as an inertial element and its transfer function can be written as equation 1.

$$G_c = \frac{K_c}{\frac{s}{\omega_c}+1} \tag{1}$$

Where

$K_c$ —— Gain of servo controller;

$\omega_c$ —— Corner frequency of the servo controller.

### Modeling on prestage servo valve

In the three-stage servo valve, twin-jet nozzle flapper force feedback electro-hydraulic servo valve is often selected to be the prestage. By modeling and transforming the torque motor, the armature baffle components, slide valve of prestage servo valve and other parts (limited to space reason, the process is omitted), its transfer function can be abtained as equation 2 when kinematic coefficient of viscosity of the slide valve and the total leakage coefficient of the nozzle flapper are ignored,

$$G_{pv} = \frac{K_{pv}}{\frac{s^2}{\omega_{pv}^2} + \frac{2\zeta_{pv}}{\omega_{pv}} + 1} \tag{2}$$

Where

$K_{pv}$—— Gain of prestage valve;

$\omega_p$—— Inherent frequency of prestage valve;

$\zeta_{pv}$—— Damping ratio of prestage valve

**Modeling on main power slide valve**

Through considering and simplifying the flow equation, dynamic flow equation and force balance equation of main power slide valve(process omitted), the simplified dynamic equation of the main power valve can be get as equation 3 as its kinematic coefficient of viscosity and total leakage coefficient are ignored,

$$G_{mv} = \frac{K_{mv}}{\mathrm{s}\left(\frac{s^2}{\omega_{mv}^2} + \frac{2\zeta_{mv}}{\omega_{mv}} + 1\right)} \tag{3}$$

Where

$K_{mv}$—— Gain of main power slide valve;

$\omega_{mv}$—— Inherent frequency of main power slide valve;

$\zeta_{mv}$—— Damping ratio of main power slide valve.

**Modeling on displacement sensor**

The three-stage servo valve studied in this paper adopts an LVDT (linear variable differential transformer) type sensor. Its transfer function between output voltage E and displacement of main power valve spool $X_m$ is shown as equation 4.

$$G_{ds} = \frac{K_{ds}}{\frac{s}{\omega_{ds}} + 1} \tag{4}$$

Where

$K_{ds}$ ——Gain of displacement sensor;

$\omega_{ds}$ ——corner frequency of displacement sensor.

**Analysis and model simplification**

According to the equation (1)-(4), the open-loop transfer function of three-stage electro-hydraulic servo valve can be get as equation 5 and its the block diagram can be drawn as figure 3[4,5].

$$G = G_c G_{pv} G_{mv} G_{ds}$$

$$= \frac{K_c \cdot K_{pv} \cdot K_{mv} \cdot K_{ds}}{s\left(\frac{s}{\omega_c}+1\right)\left(\frac{s}{\omega_{ds}}+1\right)\left(\frac{s^2}{\omega_{pv}^2}+\frac{2\zeta_{pv}}{\omega_{pv}}+1\right)\left(\frac{s^2}{\omega_{mv}^2}+\frac{2\zeta_{mv}}{\omega_{mv}}+1\right)} \tag{5}$$

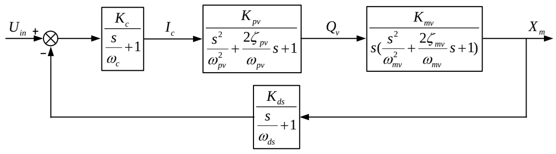
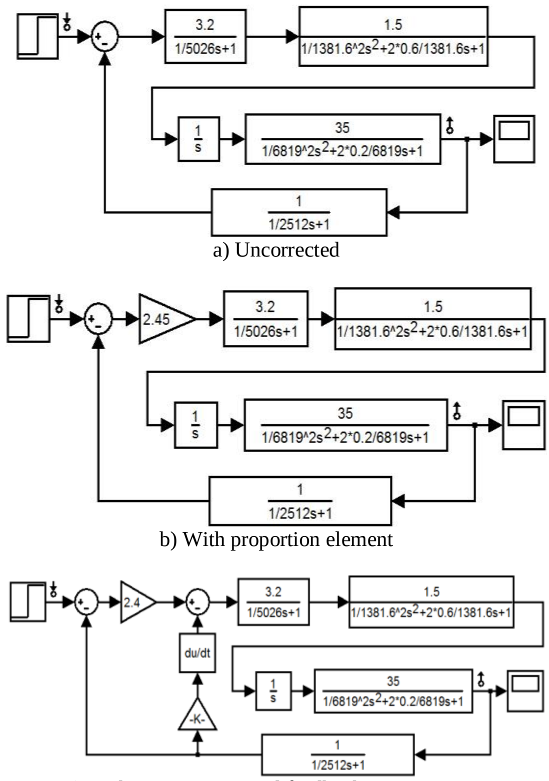


Fig.3 Overall model of three-stage servo valve

## CONTROL STRATEGY RESEARCH ON THREE-STAGE ELECTRO-HYDRAULIC SERVO VALVE

Control strategy is an important content of three-stage electro-hydraulic servo valve, and its merits directly relate to the dynamic performance of it. This paper applies two control strategies: proportional control and speed feedback compensation method to improve system performance.

The simulation model of uncorrected servo valve is shown as figure 4(a). Adding a proportion component before the servo amplifier will form a proportion control system (as (b)), which could reduce control error and increase the response speed; on the basis of the proportional control increases a speed closed-loop feedback link, it can constitute a proportion-speed feedback compensation system, as shown in figure c, it not only can enhance the dynamic response, but also improve the steady-state accuracy

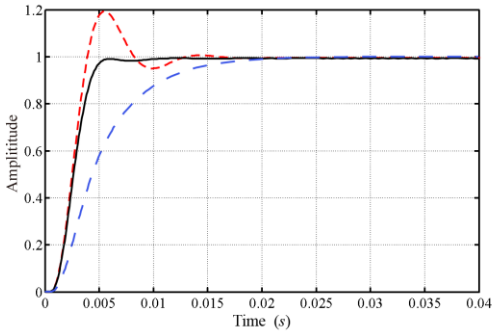


a) Uncorrected
b) With proportion element
c) With proportion-speed feedback compensation
Fig.4 Sinmulink model of system

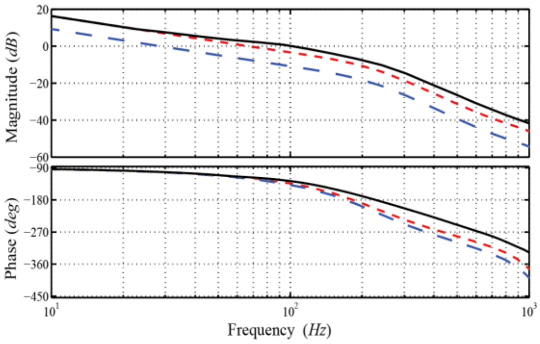
By adjusting the corresponding control parameters and simulating the three systems, their step response, open-loop and close-loop bode diagrams can be get, as shown in figure 5 respectively(the blue dotted line presents response of uncorrected system, red dotted line presents that with proportional controller, and the black solid line is that with proportion-speed compensation controller). From the figures we can see that without correction, the rise time is 0.012s, amplitude margin is 15.4dB, phase margin is 70°, amplitude frequency width is about 38Hz, and phase frequency width is about 62Hz. It's clear the system response is very slow.

For proportional control, the rise time is shortened to 0.0035s with a larger overshoot, amplitude margin is 19.34dB, phase margin is 62°, amplitude frequency width is 165Hz and phase bandwidth is 95Hz. It's obviously, after proposing a proportion element, dynamic performance of the system has greatly promoted, the amplitude frequency width increases nearly three times, but there is still room for continued improvement.

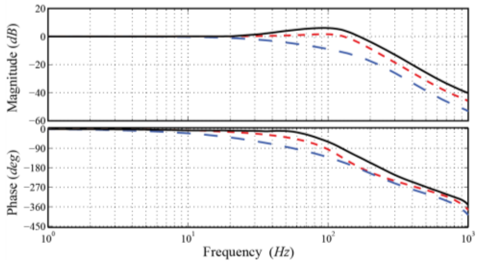
In the proportion-speed compensation control system, the rise time is 0.004s with no overshoot, amplitude margin and phase margin is 8dB and 60° respectively, and the amplitude frequency width and phase frequency width is 200Hz and 140Hz respectively. Obviously, with the speed feedback loop, the dynamic performance of three-stage servo valve has promoted very significantly.



a) Step Response



b) Open-loop Bode diagram



c) Close-loop Bode diagram

Fig.5 Simulation results

## CONCLUSION

Based on the mathematical modeling of three-stage electro-hydraulic servo valve, this paper has carefully carried on the simulation analysis and research to the proportional and proportion-speed feedback compensation control strategy, verified the fact that compared with proportional control, proportion-speed feedback compensation control not only can significantly enhance the dynamic response and expand the bandwidth of the system, but also makes the system more stable.

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