Design and control of load simulator for throttling system of large hydraulic press

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Abstract: In order to improve the precision of the extrusion speed control of the large hydraulic press and improve the quality of the extruding work piece, an experimental system was designed to simulate the throttle system of the hydraulic press. In order to simulate the transient heavy load and the fluctuating load characteristics of the throttle system, two pumps were used to supply the oil in the two chambers of the load cylinder separately, and the pressure of the two cavity of the load cylinder is controlled by two proportional relief valves. The force of the throttle spool driving cylinder can be controlled by controlling the pressure of the two chambers in closed loop, and the load state can be quickly changed. Experiments show that the load simulator can simulate the load form of the hydraulic press very well.

1 Introduction

Load simulator is commonly used in aircraft research [1–3], weapon [4], ship [5] and other laboratory research. The load simulator is usually a passive loading system, that is, when the system is working, the load actuators are driven by the load-carrying object, and the loading object is passively loaded with the load spectrum instruction [6]. The actuators of the carrier simulator are mainly two kinds of hydraulic and electric. The literatures [3, 7–9] use electrohydraulic servo valve as the pressure control element. It can load the small load of the system, and it has the advantages of fast dynamic response and high control precision. The literatures [10, 11] adopt electric loading mode, and applies torsional moment by motor. It has simple structure and is easy to realise high torque and low inertia load. Some scholars also proposed that the proportional overflow valve is used as the pressure control element of the passive hydraulic loading system [12], and the system can easily and effectively load large loads. As the electrohydraulic proportional overflow valve is affected by the flow resistance in the valve spring and the valve body, there is a certain dead zone, and the loading effect is not good when loading the small load. In the dynamic loading system, there is a lot of force caused by the active motion of the bearing object during the dynamic loading process, which seriously affects the loading precision and the control performance of the system. In order to improve the control precision of the load, many scholars have put forward the control strategy [13, 14], in response to the interference of the surplus force, which can be suppressed to a certain extent. Large hydraulic press is an important equipment in the field of our national defence, aeronautics and astronautics, railway transportation and other parts. It plays an important role in the national economic construction and national defence construction. In order to improve the efficiency of the hydraulic press and the yield of the work piece, the Southwest Aluminium Industry Group Co., Ltd. has reformed the system and added the throttle speed regulation system to improve the precision of the extrusion speed control of the hydraulic press. In order to research the speed control strategy of the hydraulic press and further improve its control performance, this paper designs a simulation experimental platform for the throttle system of the hydraulic press. The experimental platform uses the proportional overflow valve as the pressure control element, and the two chambers of the load cylinder are controlled, respectively, by the pressure control element to simulate the actual load of the hydraulic press. The balance relationship between different pressure of the two cavities and the load force of the bearing cylinder can be used to simulate various load forms flexibly and avoid the shortcoming of the dead zone of the proportional overflow valve. At the same time, the response time of the compensation and overflow of the system is short, and the influence of the excess force is greatly reduced and the load simulation requirements of transient load and pressure fluctuation of the throttle system is satisfied.

2 Analysis of load characteristics

Fig. 1 is the structure diagram of the valve, mainly including two parts, the valve body part and the valve core part, respectively. The upper end of the valve core is connected with the hydraulic drive system through threads, so as to realise the opening and closing of the spool. The valve core adopts a cone valve structure, and the parameters of the water valve are shown in Table 1.

The throttling system model includes the throttle valve model and the hydraulic drive system model. The simulation model of throttle system including water valve is shown in Fig. 2. The system parameters are set according to the actual parameters in the industrial field, as shown in Table 2.

The load force of the hydraulic system is mainly the force of the high pressure water to the cone valve. Based on the parameters of the water valve and the model in Fig. 2, the hydraulic cylinder is moved to simulate the opening and closing of the water valve, and the load force of the valve opening and closing is obtained as shown in Fig. 3.

According to the load analysis of the throttle system spool, its load has the following two characteristics:

i. Characteristics of transient and large load: Besides the unstable condition at the initial stage, the load force quickly reaches 20 kN, and this load force is basically maintained behind. The design that the two ends of the valve is asymmetrical causes the valve core to remain at rest (load to the left) when the valve is stationary, thereby maintaining the closing state of the valve port.
ii. The characteristics of load fluctuation, in the process of hydraulic press speed control, the moving water valve core will be affected by inertia force and damping force, and the load of the valve core will change the sine wave at the mean value of 20 kN.

3 Experimental platform scheme of the simulated throttle system

According to the hydraulic principle diagram of the throttle system and the load characteristics of the throttle valve core, a test bench is designed to simulate the throttle system. The experimental platform system can simulate the operating conditions of the valve core of a hydraulic press, and the principal diagram of the hydraulic system is shown in Fig. 4. The whole system consists of two parts, which are spool-drive system controlled by the proportional valve and the load system controlled by the proportional relief valve.

The hydraulic system has the following characteristics.

Table 1 Parameter table of the throttle valve

| Parameters                      | Figure |
|--------------------------------|--------|
| diameter of cone valve, mm     | 48.5   |
| half cone angle, °              | 20     |
| diameter of water diversion hole, mm | 9      |
| diameter of balance cavity, mm  | 90     |
| diameter of balance cavity piston rod, mm | 70     |
| quality of cone valve, kg       | 100    |

Table 2 Parameter table of the throttle hydraulic system

| Parameters                                      | Symbols and units | Figure |
|------------------------------------------------|-------------------|--------|
| rated pressure of the proportional valve       | \( P_{W} \), MPa  | 1      |
| area of action                                  | \( A_{n} \), m²   | 0.011545|
| rated current of the proportional valve         | \( I_{W} \), A    | 0.4    |
| the pressure of the pump                        | \( P_{s} \), MPa  | 3      |
| rated flow rate of proportional valve           | \( Q_{W} \), L/min | 90     |
| volume modulus of hydraulic oil                 | \( E \), MPa      | \( 1.4 \times 10^{3} \) |
| load mass                                       | \( m \), kg       | 100    |
| viscous damping coefficient                     | \( C \), N s/m     | 700    |

Fig. 1 Structure diagram of water valve

Fig. 2 Simulation model of throttle system

Fig. 3 Force of the water valve core

Fig. 4 Schematic diagram of simulator for valve core driving system of hydraulic press

i. The load in the form of top is provided by controlling the overflow pressure of two proportional relief valves in the load cylinder, so as to adjust the working pressure of the two cavities of the load cylinder. The load force is generated to the bearing cylinder by different working pressure of the two cavities.

ii. The use of two load pumps for the two chambers of the load cylinder, independent of each other, can quickly establish transient large load, induce the interference of the surplus force, and avoid air pressure.

iii. The corresponding pressure sensors and displacement sensors are used to monitor the pressure, position and velocity signals.

4 Load experiment

4.1 Experimental conditions.

The physical map of the simulating throttling system is shown in Fig. 5. In order to reduce the scale of the experimental system, and to simulate the transient and wave characteristics of the load, the
rated working pressure of the test system is 10 MPa, the rated flow rate is 14 l/min, the hydraulic cylinder working cylinder is 500 mm, and the hydraulic component model of the experimental platform is shown in Table 3.

The control system of the experimental platform uses 1500 programmable logic controller as the controller, and uses TIA13 as the software platform. A high-speed data communication program is compiled through the programmable controller collected and packed the field data, and the data acquisition frequency of the upper computer WinCC system is 100 Hz. The monitoring system of the experimental platform is shown in Fig. 6.

### 4.2 Experiment result

Due to the movement interference of the bearing object (valve core driving cylinder), the pressure value of the two chambers of the load cylinder fluctuates and the load force will be changed accordingly. Therefore, the PID closed loop control of the two chamber pressure of the load cylinder is designed, and the stable output of the load pressure is realised.

In this experiment, the set value of the non-rod cavity in load cylinder is set as step-change value, sine change value, and the set value of the rod cavity is constant, and the integrated load is finally a step load, and the sinusoidal load. Fig. 7 is the response curve of the step load, and Fig. 8 shows a sinusoidal load response curve with an amplitude of 0.5 MPa and a frequency of 0.5 Hz. Through the experiments of different load spectrums, it is proved that the test bench can fully satisfy the condition of the simulation of the load form of the throttle system of the hydraulic press.

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**Table 3  Main hydraulic components**

| Element name                  | version               | The max pressure, MPa |
|-------------------------------|-----------------------|-----------------------|
| single rod hydraulic cylinder | ATOS CK50/28-500-N90  | 25                    |
| double rod hydraulic cylinder | ATOS CK50/28-250-250-N90 | 25            |
| hydraulic pump               | YUKEN PFE-31016/1DT   | 21                    |
| proportional servo valve      | ATOS DLHZO-TE-040-L71/I | 35              |
| proportional relief valve     | ATOS RZMO-AE-030/100/I | 10               |
| pilot relief valve            | YUKEN SBSG032B3BDC24V | 25                    |

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Fig. 5  Physical map of the experimental platform.
1. Hydraulic pump station; 2. Proportional valve; 3. Proportional relief valve; 4. Load cylinder; 5. Connection to the top cylinder; 6. Driving cylinder; 7. Junction box

Fig. 6  Monitoring system of the experimental platform

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5 Conclusion

i. The load of the hydraulic press is huge, and the load spectrum is clear, but the load precision control is not high. Through double pump, the double proportional relief valve loading system can satisfy the load of the transient step and the load fluctuation, and provide the load conditions for speed control research of hydraulic press.

ii. The loading system with the proportional relief valve to control the pressure of the two cavities of the load cylinder can greatly increase the load pressure by raising the pressure of the non-rod cavity and reducing the pressure of the rod cavity of the load cylinder. On the contrary, the inverse load can be greatly raised by reducing the pressure of the non-rod cavity and increasing the pressure of the rod cavity of the load cylinder. So the loading system scheme can achieve a great change in load capacity and adjust load values quickly and flexibly.

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