Research on mechanical compensation power recovery hydraulic pump-motor test system

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Abstract. In this paper, an online closed-loop control mechanical compensation power recovery scheme is designed. This solution is based on PID algorithm to control the displacement of the loading motor to match the optimal system loading flow; At the same time, the variable control method of the loading hydraulic motor is improved to make the variable characteristics of the hydraulic loading motor better. Based on this scheme, a simulation model was built and analyzed in MapleSim. Finally, the effectiveness of the scheme was verified by experiments.

1. Introduction
The mechanical transmission ratio in the conventional mechanically compensated power recovery test system needs to be designed according to the displacement of the hydraulic motor, the hydraulic pump and speed. The flow matching between the hydraulic pump and the motor usually requires manual matching by the tester, which has certain limitations. This paper uses the overflow flow of the overflow valve as the feedback signal to control the displacement of the loading hydraulic motor, and automatically complete the flow matching of the tested hydraulic pump and the loading hydraulic motor. Under the condition of meeting the requirements of system loading pressure, the flow of high-pressure oil through the overflow valve is minimized and the power recovery is maximized [1]. The mechanical power recovery hydraulic pump-motor test system developed in this paper has been tested and verified. The power recovery scheme can effectively control the overflow flow of the system overflow valve. The recovery efficiency is 63.3, which meets the design requirements.

2. Power recovery program
In order to improve the power recovery efficiency of the system, the system adopts a double output shaft motor to drive the pump and the motor separately to reduce mechanical transmission loss. At the same time, a hydraulic flowrate sensor is added to the loading circuit of the overflow valve. The flowrate sensor and the variable hydraulic motor establish a closed-loop control to realize the control of the minimum overflow flow of the overflow valve, and finally achieve the purpose of improving the power recovery rate of the system. Load hydraulic motor displacement control block diagram shown in Figure1 [2].
FIG. 1 Block diagram of hydraulic motor displacement control

The principle diagram of the mechanical compensation power recovery system is shown in Figure 2. The variable hydraulic pump 10 and the variable hydraulic motor 12 are connected by a double output shaft variable frequency motor 11. The overflow valve 9 is used to load the system. The flow rate sensor 8 at the inlet of the overflow valve 9 is used to monitor the flow of the overflow valve in real time and feed it back to the variable control mechanism of the variable pump or variable hydraulic motor to control the displacement of the variable hydraulic pump or variable hydraulic motor. The torque difference in the system is compensated by the variable frequency motor, and the test speed of the test piece is controlled by adjusting the speed of the variable frequency motor. The oil supply pump 1 of the tested pump and the oil supply pump 13 of the tested motor are used to supply oil to the tested hydraulic pump and the tested hydraulic motor to prevent dry grinding and damage of the tested components due to insufficient oil [3].

FIG. 2 Schematic diagram of hydraulic system

3. **Power recovery system simulation modeling and analysis**

MapleSim is a multi-domain system modeling and simulation tool. The simulation software is based on symbol-numerical hybrid computing technology, and can effectively handle various complex mathematical problems involved in the development of engineering system models. MapleSim provides a wide range of predefined model libraries and toolboxes, including mechanical library, transmission library, hydraulic library, electrical library, control design toolbox, etc. Researchers and engineers can use a wide range of analysis tools to gain insight into their systems, while reducing model development time and generating high-fidelity, high-performance models [3].
The simulation model of the power recovery system built according to Fig. 2 is shown in Fig. 3. The main simulation parameters are shown in Table 1. The double output shaft motors respectively drive a variable pump and a variable motor, and use the overflow valve to load the system. The overflow flow of the overflow valve is used as the input signal of the PID controller to control the displacement change of the variable pump, so that the overflow flow of the overflow valve is a fixed value[5].

Table 1: Main components simulation parameters

| Icon element | parameter types            | value     |
|--------------|----------------------------|-----------|
| fluid properties | density/kg/m^3 | 850       |
|              | volume modulus/Pa       | 8 × 10^8  |
|              | Viscosity/m^2/s         | 1.8 × 10^{-5} |
| variable motor | Maximum displacement/ml/r | 400       |
|              | Volumetric efficiency/%  | 0.95      |
|              | Mechanical efficiency/%  | 0.88      |
| Variable pump | Maximum displacement/ml/r | 400       |
|              | Volumetric efficiency/%  | 0.95      |
|              | Mechanical efficiency/%  | 0.88      |
| overflow valve | Opening pressure/MPa       | 20        |
|              | Closing pressure/MPa      | 20.5      |
|              | Overflow flow rate/L/min | 20        |
| PID controller | proportional coefficient | 0.4       |
|              | Integral coefficient     | 0.5       |
|              | Differential coefficient | 0.1       |

The simulation time is set to 10s, and the displacement of the motor is increased from 0ml/r to 200ml/r within 0s~10s. The simulation parameters of the main components are shown in Table 1: As the principle of power recovery is the same when testing the pump and when testing the motor, the motor is used as the tested component and the pump as the loading component for simulation. The simulation results are shown in Figure 4~Figure7. The overflow flow curve of the overflow valve in the power recovery system is shown in Figure 4. The overflow flow of the proportional overflow valve can be set to 20L/min, the pressure adjustment of the overflow valve is stable, and the pressure can be maintained constant even when the flow fluctuates. In the process of increasing the input displacement of the motor, the PID controller has a good control effect on the overflow flow. The overflow flow of the overflow valve reaches the set value of 20L/min within 0.48s. With the change of the input displacement of the motor, the overflow flow of the system has been kept constant and the fluctuation is small, indicating that the PID control algorithm can effectively control the change of the overflow, and the flow fluctuation is ±0.3L/min.
The flow rate of the loading pump changes with the flow rate of the tested motor as shown in Figure 5. It can be seen from the figure that the flow of the loading pump and the flow of the motor under test show a good following effect. Figure 6 shows the power recovery efficiency curve when the input displacement of the tested motor is increased from 0 to 200ml/r within 0~10s. It can be seen that as the input displacement of the tested motor increases, the system recovery efficiency will also gradually increase, when the input displacement of the tested motor is 200ml/r, the recovery efficiency of the system is 65.8%. The magnitude of the system overflow value largely determines the power recovery efficiency; therefore, the relationship between the system overflow and the power recovery rate is simulated when the input displacement of the tested motor is 200ml/r, the speed is 1500rpm, and the system pressure is 20Mpa. It can be seen from Figure 7 that as the overflow of the overflow valve increases, the recovery efficiency of the system gradually decreases. When the overflow rate of the overflow valve is 20L/min, the recovery efficiency of the system is 65.8%; when the overflow rate of the overflow valve is 50L/min, the recovery efficiency of the system is 60.4%.

The above simulation results show that: when the system pressure is 20MPa, the test speed is 1500rpm, the system overflow is 20L/min, and the tested motor input displacement is 200ml/r, the maximum power recovery efficiency is 65.8%, and the PID algorithm is used to control the system overflow. The flow control accuracy has reached ±0.3L/min, achieving the expected design goal; the overflow flow of the overflow valve has an impact on the power recovery efficiency of the system, and reducing the set overflow of the overflow valve can improve the power recovery efficiency of the system. But if the overflow flow is too small, other components of the test system will interfere with the overflow flow, and the system pressure will be unstable.

4. Power recovery test verification
The variable pump model A4CSG200 was selected as the tested pump, and the variable motor model loaded was A6VM500EP2. According to the displacement range of the A4CSG200 variable pump, set the displacement range of the A6VM500EP2 variable hydraulic motor to 0~250ml/r, and set the test speed to 1000rpm, test pressure is 20MPa. In the actual test, it is found that when the overflow flow of the overflow valve is lower than 15L/min, the system pressure is unstable, so the minimum overflow flow of the overflow valve is set to 20L/min. Figure 8 shows the result curve of the test when the variable method of the tested motor is internal control.
In Figure 8, the red line is the flow of the pump, the blue line is the flow of the motor, and the black curve is the overflow of the overflow valve. It can be seen that the flow following curves of pumps and motors are not stable enough, and the fluctuation range of the overflow flow of the overflow valve reaches ±4.6L/min, which affects the power recovery effect of the test bench. Analysis of the structural principle diagram of the A6VM500EP2 variable motor shown in Figure 9 shows that the reason for this situation is that the A6VM500EP2 variable motor uses internal control variables, that is, the control pressure required by the variable is the main oil circuit pressure of the motor [6]. The pressure of the main oil circuit will affect the stability of the motor displacement, which leads to the above problems. For this reason, through the analysis of the schematic diagram and multiple tests, the internal oil circuit of the motor is finally improved as follows: the two one-way valves of the internal control oil circuit are removed and the oil circuit is cut off, and from the G port Connect a stable external control pressure oil source to reduce the influence of the control oil source on the displacement of the hydraulic motor.

After many tests and improvements, the above-mentioned improved variable motor is used for testing, and the power recovery test curve of the obtained pump motor is shown in Figure 10. The final flow follow-up curve of the pump motor is shown in Figure 10. Since the minimum displacement of the loading motor for the test is 40ml/r, the following curve of the pump motor is drawn from 40ml/r. The red line in the figure is the flow rate of the pump, the blue line is the flow rate of the motor, and the black curve is the overflow flow rate of the overflow valve. The entire test process time is 20s. It can be seen from the figure that as the flow rate of the pump under test gradually increases, the flow rate of the loading motor also gradually increases as the flow rate of the pump increases. During the entire follow-up process, the loading motor variable mechanism has well controlled the motor displacement under PID control, and the flow difference between the pump and the motor is maintained within a fixed range. In other words, the overflow flow rate of the overflow valve is 20±0.96 L/min, which is much lower than the overflow flow rate under the internal control condition. The recovery efficiency curve during the test is shown in Figure 5.9. It can be seen that as the flow rate of the pump under test increases, the recovery efficiency of the entire system gradually increases. When the tested pump flow rate is 250L/min, the recovery efficiency of the system reaches the maximum value of 63.3%. Therefore, when the displacement of this type of variable pump is 250ml/r, the speed is 1000rpm, and the test pressure is 20MPa, the system's power recovery rate is 63.3%, that is, the motor only needs to provide 36.7% of the extra power to the test bench. Due to factors such as pipeline pressure loss and motor mechanical efficiency during the actual test, the test result is slightly lower than the simulation result.
5. Conclusion
This paper designs a closed-loop mechanical compensation power recovery program that adjusts the displacement of the loading motor on-line to make the overflow of the loading relief valve a constant value, and uses MapleSim software to model and simulate the power recovery rate. The test method of power recovery of pumps and motors was also studied. The test found that the hydraulic motor adopts external control pilot pressure to obtain better control effect than internal control pilot pressure. The test system has stable pressure and fast response speed. The power recovery rate of the final test system can reach 63.3%, reaching the expected development goal. It has certain reference value for the design and application of power recovery system.

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