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Experimental Study on Closed Loop Simulated Loading of Proportional Relief Valve

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Proportional relief valve is usually used in the hydraulic experimental platform to simulate the load. The open-loop simulated loading has the characteristics of exiting steady-state error and control accuracy easily being affected by the flow disturbance input, so the pressure closed-loop PID control system is designed in this paper. With adjusting the proportion of the valve orifice area to lessen the differences between target pressure and pressure signal sensor measured, the system can correct real-time the actual pressure to target set value. Experimental results showed that: The dynamic response of pressure closed loop control is fast and anti-interference ability is strong; the steady state error can be eliminated with the signal of the step flow disturbance; For the flow of the sinusoidal and the slope of the interference signal, the system can make the actual pressure value fluctuations in the set point and has strong error correction capability.

1. Introduction

As a simulation of the load element, Proportional relief valve is widely used in the hydraulic laboratory bench. The steady state and dynamic characteristics of a two-stage pressure relief valve with proportional solenoid control of the pilot stage is studied (Maiti et al. (2002)) theoretically as well as experimentally. To study dynamics of a proportional controlled piloted relief valve, Dasgupta and Watton (2005) has made use of Bondgraph simulation technique. Radpukdee and Jirawattana (2009) has used uncertainty learning and a compensation technique to develop a classical sliding mode control for a pressure tracking control of a low-cost electro-hydraulic proportional valve. A simple method to determine optimal pressure curve for sheet hydro-forming is proposed (Hyunbo and Yang (2005)), and the pressure is controlled by a proportional relief valve. The experimental system of valve controlled cylinder is designed by using the proportional relief valve as the simulated loading element, and the performance of the load monitoring and controlling system is studied (Liang et al. (2012)). Chen et al. (2012) designed the hydraulic system of Loading is dynamically adjusted by the pressure of electro-hydraulic proportion relief valve to control the oil pressure in hydraulic cylinder. The simulation of the injection molding process on the injection molding machine is realized (Zheng et al. (2013)) with proportional relief valve in the electro-hydraulic experimental platform. The control performance to simulate the load of the open and close loop is finished (Jia et al. (2013)) on proportional relief valve. Liu et al. (2015) proposed the control strategy, which is the pressure of the closed-loop by adjusting permanent magnet servo motor speed and flow of the open-loop by adjusting the opening area size of proportional relief valve.

Many large mechanical and hydraulic experimental equipments are used the proportional relief valve as a simulation of the load element. Dasgupta et al. (2012) designed the hydraulic test bench. The driving system is the open circuit of variable frequency motor and variable pump, and the loading part is the mode of the proportional relief valve and gear pump. The dynamic characteristic of the hydraulic drive system, which is low speed and high torque, is studied in the paper. Dasgupta et al. (2006) studied on dynamic performance of a servo-valve controlled axial piston motor used in a transmission system. And loading part is the mode of the proportional relief valve and gear pump. Casoli and Anthony (2013) repotted the results of a study focused on the application of gray box modeling methodology on an excavator's hydraulic pump. And the experimental system load is generated by a proportional relief valve. Lovrec et al. (2009) studied the applicability of a low-

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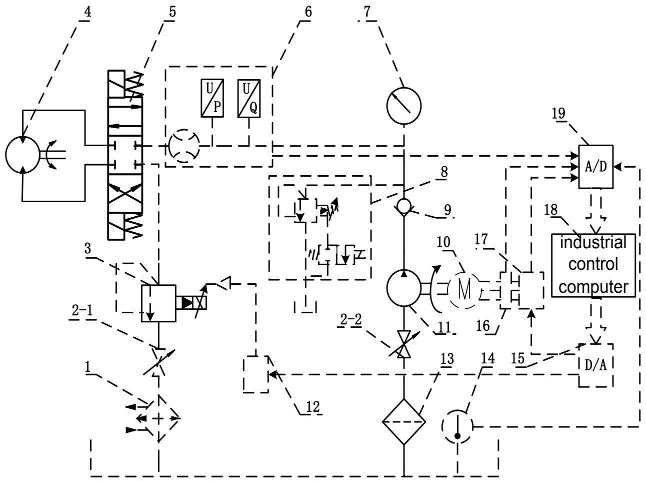
priced drive concept using a speed-controlled induction motor in combination with a constant-displacement pump applied in a load-sensing control strategy. Overloading of the system is prevented by an additional proportional relief valve. Mao (2011) designed a novel pitch control system for a large wind turbine driven by a variable-speed pump-controlled hydraulic servo system. Mao et al. (2009) designed a high response and high energy efficiency electro-hydraulic pump-controlled system driven by a variable rotational speed AC servo motor for achieving high response and high efficiency velocity control in hydraulic injection molding machine.
Based on proportional relief valve, the pressure closed loop PID loading system is designed in this paper. The performance of closed-loop control of pressure is studied under the condition of flow disturbance.

2. Introduction experimental platforms

Schematic diagram of the hydraulic laboratory bench test and control system is shown in Figure 1. Component 10 driven by servo controller 17 is AC servo motor, which can change the speed of the motor. Component 11 is a gear pump. The oil flows through gear pump11, one way valves 9, sensor 6, and three position four way solenoid valves 5, drive hydraulic motor 4 to rotate. Relief valve 8 has two functions, one is to set the maximum pressure of system, and the other is playing a role of the system overflow protection. Proportional relief valve 3 is installed at the outlet of the hydraulic motor 4. Component 12 is proportional amplifying board, which make D/A converter 15′ output voltage into current signal. The displacement of the electromagnet of the proportional relief valve and the opening area of the valve opening is controlled by the current signal. Physical quantities of system measurements are pressure, flow and temperature, which′ voltage signal is sent to the industrial control computer through A/D converter 19.The control signal of the system is input voltage of servo controller 17 and proportional amplifying board12. By controlling these two voltage signals, the flow and pressure of the hydraulic system can be controlled. The physical quantity can be measured and controlled by the LabVIEW program in industrial control computer 18.



1. Radiator 2-1. 2-2. break valve 3. Proportional relief valve 4. Hydraulic motor 5. solenoid directional control valve 6. Combined sensor 7. Pressure gauge 8. Relief valve 9. One way valve 10. AC servo motor 11. Gear pump 12. Proportional amplifying board 13. Filter 14. Temperature sensor 15. D/A card 16. Holier voltage / current sensor 17. Servo controller 18. Industrial control computer 19. A/D card

Figure 1: Schematic diagram of the hydraulic experimental platform

3. Experimental result analyses

Pressure closed-loop PID control principle is shown in Figure 2.The target input pressure is P_i, the actual output pressure is P_o, and the pressure feedback signal is P_f. Controller is traditional PID, the difference between target pressure P_i and the feedback signal P_f is used as PID input, the output of PID is voltage signal. Under magnification Proportional amplifiers converts 1-5V voltage signals into current signal *i* of control the proportional relief valve spool displacement. Current signal *i* changes the size area of the valve port, so as to control the system pressure. When the target pressure P_i is greater than the feedback signal P_f, output voltage of PID increases, the current signal *i* becomes large, and the valve port area becomes small, the actual output pressure P_o becomes large. When the target pressure P_i is less than the feedback signal P_f, the process of adjusting is reversed, the actual output pressure P_o becomes small. The steady-state error can be eliminated with the dynamics adjusting process.

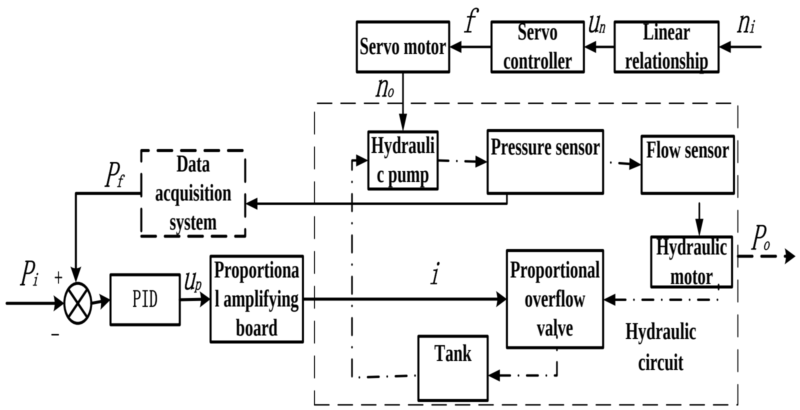


Figure 2: Pressure closed loop control diagram

Figure 3 is the actual flow and pressure response curve when the motor speed is at 1000 r/min and the set pressure is step changed 2 MPa-5 MPa-2 MPa. The PID controller parameters is Kp=0.25, Ki=0.01 and Kd=0. The PID parameter setting values are the same in the following experiments. It can be seen from Figure 3 that when the target pressure 2 MPa-5 MPa-2 MPa is step changed, the measured pressure can has a good response to the change of the target pressure and there is no steady state error. Near 30 s, when the target pressure is step changed 2 MPa-5 MPa, with the load increasing, The amount of the oil compression and internal leakage becomes large, the loss of actual flow increases, the actual flow drops from 0.58 m^3/h to 0.56 m^3/h. Near 50 s, when the target pressure is step changed 5 MPa-2 MPa, with the load decreasing, The amount of the oil compression and internal leakage becomes small, the actual loss of flow decreases, the actual flow increase from 0.56 m^3/h to 0.58 m^3/h. The rise response time of the pressure is about 2 s, and the dynamic response of the closed-loop system is good without the overshoot.

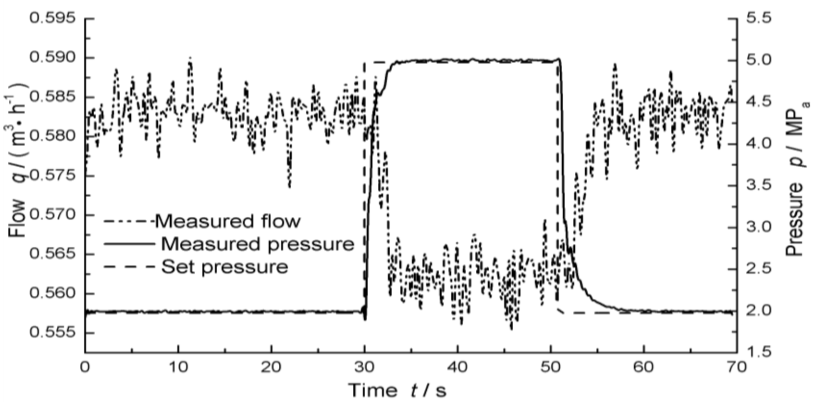


Figure 3: Actual flow and pressure response curve when the motor is at speed 1000 r/min and the set pressure is step changed 2 MPa-5 MPa-2 MPa

Figure 4 is the actual flow and pressure response curve when the set pressure is 2 MPa and the motor speed is step changed at 1000 r/min-1500 r/min-1000 r/min. it is can be seen from Fig. 4 near 30s, when the motor speed is step changed 1000 r/min-1500 r/min, the actual flow increases from 0.558 m^3/h to 0.855 m^3/h. At this time the set system pressure is 2 MPa, and the area size of proportion the valve port is unchanged, so the actual pressure increases from 2 MPa to 2.4 MPa. Because the system pressure is PID closed-loop control, when the actual pressure is larger than the target set, the PID output voltage signal will become small, the proportion of the valve port area becomes large, and the actual system pressure becomes small, until the actual pressure value is adjusted to set the pressure 2 MPa. Near 30s, the process of adjusting is reversed. Thus the actual output pressure P_o can be adjusted to set the pressure 2 MPa. The anti disturbance ability of pressure close loop control is strong, and the robustness is good.

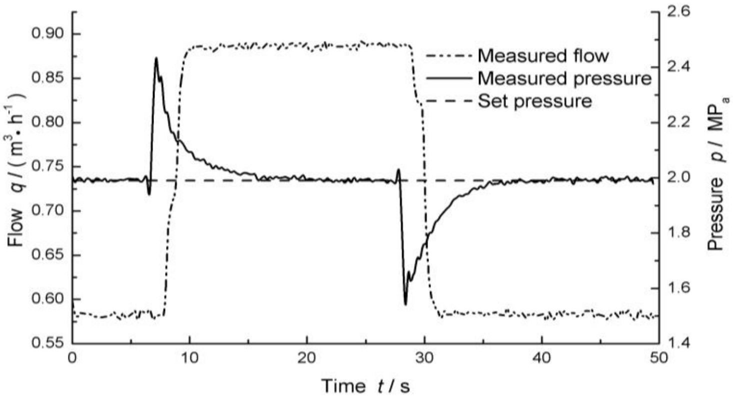
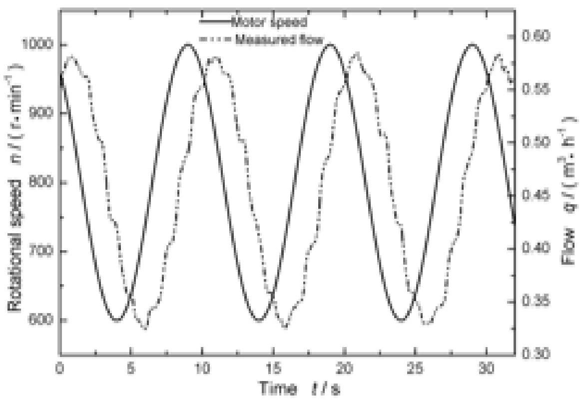
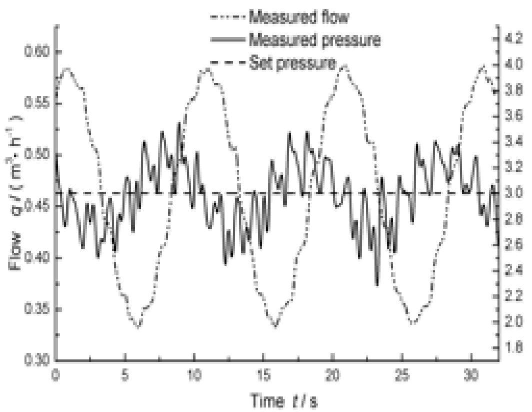


Figure: 4 Actual flow and pressure response curve when the set pressure is 2 MPa And the motor rotational speed is step changed at 1000 r/min-1500 r/min-1000 r/min

Figure 5 is the actual flow and pressure response curve when the set pressure is 3 MPa and the motor rotational speed is sine wave changed (amplitude 200 r/min, the period 10s, the median 800 r/min). It can be seen from Figure 5a when the motor rotational speed of the input is sinusoidal changed, the flow also sinusoidal is changed. System pressure is a closed-loop control, so the actual pressure can be adjusted to set the value around 3 MPa. The frequency response of the system pressure is measured about 1 Hz through experiment. It can be seen from Figure 5a that the actual flow can has a good response to the change of rotational speed. By calculating the amplitude of the rotational speed and flow are corresponding, and it can be seen from figure 5b the cycle of flow is 10 seconds. The phase of actual flow response lags behind pressure, which is caused by flow meter response delay. It can be seen From Figure 5b that the actual pressure can be well maintained at about 3 MPa by PID closed-loop controlling, and pressure PID closed-loop control can corrected the influence of periodic flow signal disturbance input.



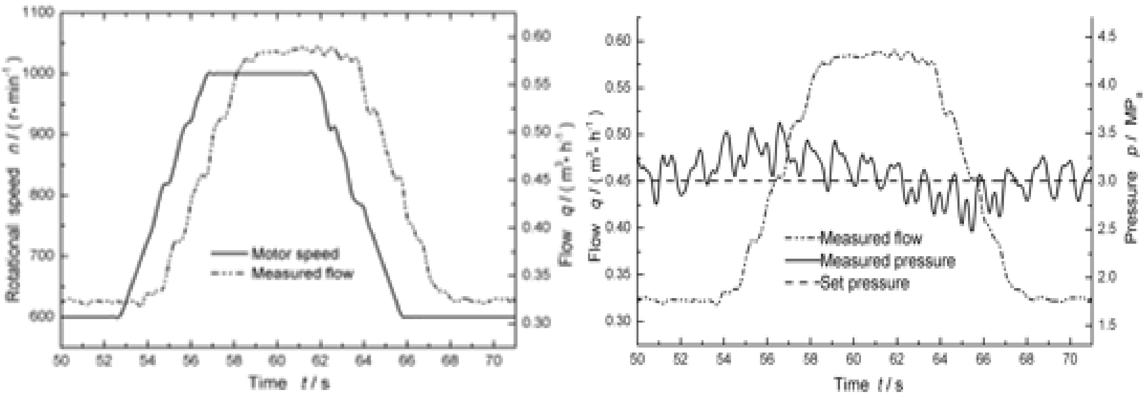
a. Actual flow response curve



b. Actual flow and pressure response curve

Figure 5: Actual flow and pressure response curve when set pressure is 3 MPa and the motor rotational speed is sine wave changed (amplitude 200 r/min, the period 10S, the median 800 r/min)

Figure 6 is the actual flow and pressure response curve when the set pressure is 3 MPa the motor rotational speed is slope signal changed (rotational speed 600 r/min-1000r /min-600 r/min, with a slope of 100). It can be seen from Figure 6a when the motor rotational speed of the input slope signal is changed, the flow is also slope changed. Because of the coupling characteristics in the hydraulic system, the pressure is changed accordingly. The actual pressure can be adjusted to set the pressure around 3 MPa with closed-loop controlling. It is can be seen from Figure 6a that the actual flow can has a good response to rotational speed changes, and the actual flow response lags behind the motor rotational speed about 2 s. The motor is a permanent magnet AC servo motor, so the response of rotational speed is fast. The lag time between the flow and the rotational speed of the motor actually an indirectly reflects the response time of the worm gear flow meter. From figure 6b it can be seen that the actual pressure can be well maintained at around 3 MPa with the PID closed-loop controlling. Pressure PID closed-loop control can correct the influence of the slope flow signal disturbance input.



a. Actual flow response curve *b. Actual flow and pressure response curve*

Figure 6: Actual flow and pressure response curve when set pressure is 3 MPa and the motor rotational speed is slope changed (speed 600 r/min-1000r /min-600 r/min, with a slope of 100)

4. Conclusions

In this paper, the closed-loop PID control experiment is designed. Through the experimental study, the following conclusions are obtained:

1. The experimental results show that the actual pressure of the pressure closed-loop system cannot be affected by the disturbance of the system flow, and the system can correct the actual pressure and output relatively stable pressure. For step and slope flow disturbance signal, the actual pressure can be adjusted to the set pressure value. For sine flow and slope disturbance input, the actual pressure fluctuates around the set pressure value, and the value of the amplitude fluctuations is affected by the flow signal amplitude.
2. It is a superior technology to simulate and study the actual working load in a simple and efficient way with proportional relief valve under the experimental conditions.

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