Application of PID control in hydraulic synchronous system of cleaning equipment

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Abstract: Aimed at the double cylinder synchronization problems arising from the stroke control system of the automatic cleaning equipment, a master-slave hydraulic synchronous control system controlled by servo proportional valve is introduced. In order to reduce the synchronization error of the double cylinders and improve the dynamic performance of the system, a PID control algorithm is adopted in this system. The PID control algorithm and the system simulation model are established by using Matlab/ Simulink tool. Then the simulation analysis of unit step signal of the system is carried out.

1 The introduction
In the stroke control system of cleaning equipment, the hydraulic circuit is the main part. The system adopts synchronous hydraulic circuit to keep the motion of the two actuators consistent. In synchronous hydraulic circuit, due to the different control elements of the structure, performance, and the installation is different, can cause synchronous hydraulic synchronous control circuit occur error (0 ~ 32 mm), which directly affect the positioning accuracy of products on the cleaning station and motion consistency, eventually leading to reach expected effect of cleaning, so the system need to adopt PID control method to ensure synchronous movement of synchronicity.

2 Design of dual cylinder synchronous loop system
For the closed-loop hydraulic synchronous control system, two control methods are generally adopted: master-slave mode and equivalent mode. The vertical synchronous hydraulic cylinder in the cleaning machine can realize signal trigger and steady rise and fall of sprinkler head through synchronous rise and fall of hydraulic cylinder. Due to the asymmetry of center of gravity in the cleaning process, different types of products have different loads in the cleaning process. In addition, problems such as pressure and flow fluctuation of the hydraulic circuit, polarization in the rising process of the jig frame, installation error of the mechanical system, and accumulated error after operation will also occur. In order to solve the above problems, servo valves and proportional flow valves are used in parallel control and master-slave control methods to ensure the synchronization accuracy of the hydraulic system in the downlink process[1]. Servo valves are used in dual-cylinder synchronous operation and double-proportional flow valves are used in the main oil circuit. The working principle is shown in Figure 1.

When the system is running without load, the proportional flow valve 2 and 3 can be adjusted through the input signal of the system, so that the two cylinders in the hydraulic loop system can achieve preliminary synchronization[2]. Due to the inconsistent flow proportional valve, the two
cylinder run to the most high-end and low-end, proportional flow valve cannot satisfy the requirement of the duplex synchronous precision, because in the most high-end and low-end position, a hydraulic cylinder of duplex trigger position sensor to change direction, so must ensure that the duplex synchronous accuracy to maintain the security of system operation. To solve this problem, a control system can be designed, which USES servo proportional valve to

![Fig. 1 Schematic diagram of hydraulic dual cylinder synchronization system](image)

1. Comparison software  
2. Left proportional flow valve  
3. Right proportional flow valve  
4. Way directional control valve  
5. Servo proportional valve  
6. One-way valve  
7. Fluid pump  
8. Overflow valve  
G1. Left hydraulic cylinder  
G2. Right hydraulic cylinder

control the synchronization of two cylinders. When the hydraulic cylinder reaches the specified position, the servo proportional valve begins to work. The hydraulic cylinder G2 is a driven cylinder, and the position sensor detects the position signals of the two cylinders respectively, and then makes a comparative analysis. After the amplification circuit processing, the deviation signal (current) obtained can realize the oil supplement or oil discharge action of cylinder G2, so that the two cylinders can meet the synchronous requirements.

3 PID control method of hydraulic synchronous system

Proportional Integral Differential control, referred to as PID control, is the most mature and applied control method of continuous control system. Its principle framework is shown in Figure 2(a). The essence of PID control is to use the deviation value of input and feedback to carry out comprehensive operation according to the function relation of proportion, integral and differential, and the results obtained are used to carry out output control[3]. In digital control system, PID control is achieved by programming the operation program. PID control algorithm includes position PID control algorithm, incremental PID control algorithm and some improved PID control algorithm. The closed-loop control system is based on Mitsubishi PLC as the control core, so the incremental PID control algorithm is adopted, which is determined by the internal circuit structure of Mitsubishi PLC.
Fig. 2  (a)PID control system schematic diagram  
(b)Hydraulic cylinder synchronous PID control

The mathematical expression of PID control rule is as follows:

\[ U(t) = P \{ e(t) + \frac{1}{I} \int_0^t e(t) \, dt + D \frac{de(t)}{dt} \} \]  

(1)

In a digital sampling system, the differential terms and integral terms in Equation (1) cannot be used directly and must be discretized. The discretization method is as follows: take \( T \) as the sampling period, \( K \) as the sampling ordinal number, then discretize the time corresponding to the sampling time \( KT \) as \( T \), then use the numerical integration of the rectangle method to approximately replace the integral, and use the first-order difference to replace the differential:

\[ U(k) = P \{ e(k) + T \sum_{i=0}^{j} e(i) + D \frac{e(k) - e(k-1)}{T} \} \]  

(2)

In the top formula, \( e(k) \) —Input deviation at the \( K \)th sampling time; \( e(k-1) \) —Input deviation at the \( (K-1) \)th sampling time; \( U(K) \) —PID control output value at the \( K \)th sampling time; \( T \) —Sampling period; \( P \), \( I \), \( D \) —Control parameters; \( D(k) \) —The \( K \)th derivative; \( P \) —The proportional gain.

For the dual-cylinder synchronous control system, its PID control algorithm is shown in Figure 2(b).

4 Parameter setting and simulation of PID controller

4.1 Parameter Settings

When the PID control system is established, the dynamic and static characteristics of the control object are determined. At this point, the control system can achieve the desired control function, depends on the PID control parameters set. The best control effect can be obtained only when the control parameters are matched with the control system. Therefore, the tuning of PID control parameters is very important. In general engineering, PID control parameters are usually determined by trial and error method. The trial-and-error method refers to observing the response curve of the system (such as step response) through closed-loop operation or simulated operation, and then gathering the parameters repeatedly according to the different influences of parameters in the controller on the response curve of the system, so as to achieve a satisfactory response and determine the parameters of the PID control system[5].

Setting the proportional gain \( P \) is the core of the trial-and-error method, the setting method is: Integration Time \( I=\infty \), Differential Time \( D=0 \). The optimum value of the proportional coefficient \( P \) is determined according to the optimization method.
First, setting of the integral time constant I. Set the P value of I as (0.8~0.85). According to the empirical values in Table 1, a larger integral time constant I was selected to observe the curve fluctuation of the regulated quantity. Second, setting of the differential time constant D. For most of the current control systems, the setting of P and I has been able to meet their control requirements, and there is no need to set the differential constant D. But for some lagging physical quantity control, such as temperature control, adding the differential time constant D can greatly improve the dynamic performance of the system[6].

| Physical quantities | Proportional gain P | Integral constant I | Differential constant D |
|---------------------|---------------------|---------------------|-------------------------|
| Liquid level        | 1.25~2.50           |                     |                         |
| Pressure            | 1.4~3.5             | 0.4~3.0             |                         |
| Temperature         | 1.6~5.0             | 3.0~10.0            | 0.5~3.0                 |
| Flux                | 1.0~2.5             | 0.1~1.0             |                         |

4.2 Simulation of PID controller
Taking the speed of hydraulic cylinder as output, the dynamic simulation tool Simulink in MATLAB software was used to simulate and analyze the PID control system. In Simulink module, the system frame diagram as shown in Figure 3 is established.

According to the field trial and error method, the control parameters set were P=2.2, I=0.3 and D=0.3 respectively. After simulation, the state variables obtained were shown in Figure 4(a). It can be seen that the dynamic performance of the synchronous system controlled by proportional valve is greatly improved after PID controller is used. The system adjustment time after PID control is short, so synchronization error and stability error can meet the actual requirements of the system. It can be seen from Figure 4(b) that before the system reaches the stable state, only a small oscillation appears, which reduces the asymmetry of the hydraulic cylinder and the adverse effect of the hydraulic damping on the system.
5 Conclusion

The hydraulic synchronous system uses a closed-loop control with feedback function to reduce errors, so the cumulative errors associated with the cylinder travel will not occur. The incremental PID control algorithm is adopted to improve the servo proportional valve hydraulic synchronous system. Through calculation and MATLAB simulation, it is proved that the improved method can not only improve the dynamic performance of the system, but also reduce the synchronization error.

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