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Comparative study of single-loop control and cascade control of third-order object

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Abstract

For third-order system can describe most of the controlled objects in nature, this paper designs a third-order object control system which contains three tanks. In the control system, Simatic S7-200 PLC is employed as the hardware controller. And the single-loop control system and cascade control system are established respectively in order to compare their control characteristics. Through comparing and analyzing with two control methods, experiment results show that cascade control system has better performance than single-loop control system no matter where the disturbances get into control system.

*Keywords:*third-order level cortrol system;cascade control;single-loop control;

1. Introduction

Water level controlling has a wide range of application in various fields, such as liquid storage tanks, feed tanks, product tanks, intermediate buffer containers, boiler and other equipments [1, 2]. It's the most important goal for liquid level control system to keep the liquid level which is handled by unit equipment fluctuating within the range of process allowed.

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To comparative study of single-loop control and cascade control of third-order object, the control experiments are done on THSA-1 experiment system platform which is composed of three water tanks connected in series, Siemens PLC, electric magnetic valve, pressure sensors, analogue converter, pumps and other peripheral equipments. Siemens PLC [3] is a hardware control platform, through which we can design the controller of two control methods with programming. Composition of equipments is shown in Fig 1.

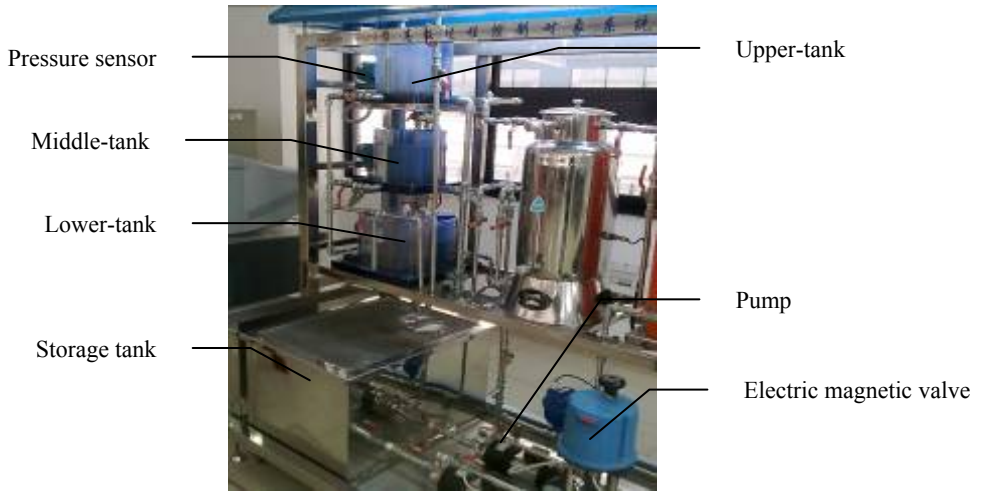

Fig. 1 Composition of equipments

In order to compare two control methods, the experimental method of this paper is to control liquid level of lower-tank following the setting point timely and having no steady-state error finally [4, 5]. Single-loop control, which has the characteristics of simple structure and is easy to implement, is often used in the industrial production because it can solve large numbers of constant value control problem. Considering the above-mentioned characteristics, at the beginning of experiments, using the method of single-loop control to achieve a satisfy response of the plant (liquid level of the lower-tank).

2. Single-loop control system of third-order object

Single-loop control only uses one pressure sensor to collect the single of liquid level of the lower-tank, and then the single is transmitted to the controller after A/D conversion, which can control the liquid flow entering the upper-tank through changing the opening of electric magnetic valve. Finally, liquid flow will have an influence on the liquid level of the lower-tank indirectly. Block diagram of single-loop control is shown in Fig 2.

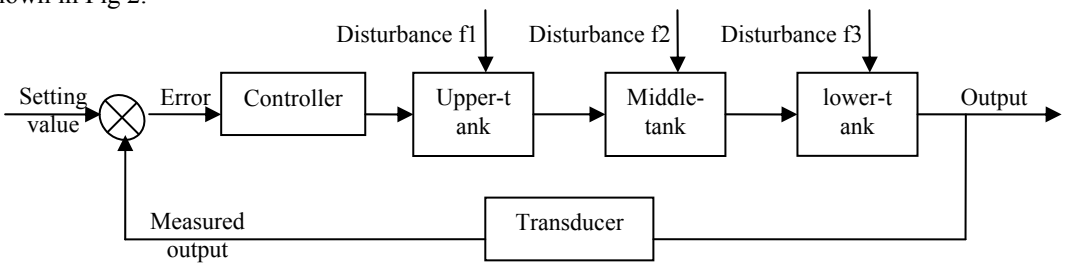

Fig. 2 Block diagram of single-loop control of liquid level

As seen in Fig 2, each tank can be described by first-order inertia, so the mathematical model of third-order three-tank water level control object is written as following [6]:

$$W_0(s) = \frac{K_0}{(T_1 s+1)(T_2 s+1)(T_3 s+1)} \quad (1)$$

Where, T_1, T_2 and T_3 are the time constant of upper-tank, middle-tank and lower-tank respectively, K_0 is the amplification factor of process.

3. Cascade control system of third-order object

Compared with single-loop control, cascade control has a significance difference. There are two more loops in the structure because vice-loops are added. The block diagram of cascade control of object in this paper is shown in Fig 3.

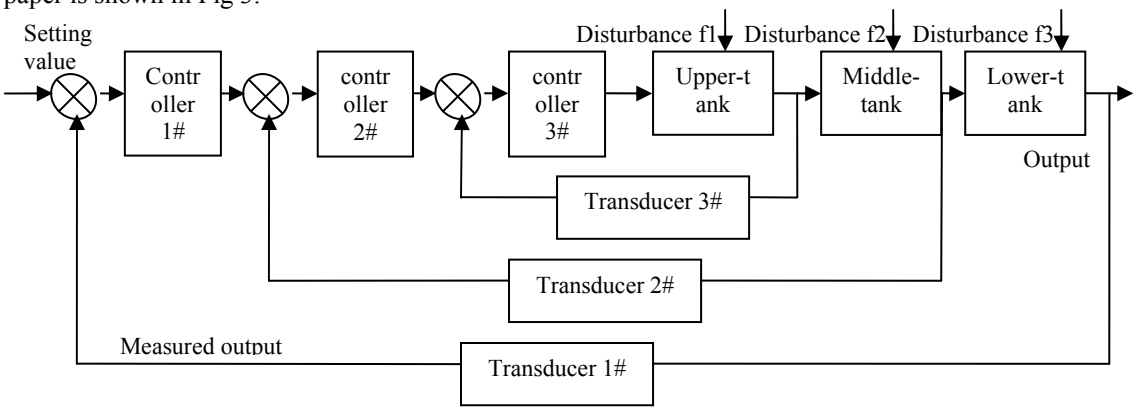

Fig. 3 Block diagram of cascade control of liquid level

According to Fig 3, there are three loops in the diagram. In each loop, there is a transducer by which the single is transmitted to the controller to control the opening of the valve that can change the liquid level of the lower-tank finally through controlling the liquid flow.

4. Comparing with two control methods

4.1. Comparing and analyzing without disturbance

First, the single-loop control and cascade control is used to control the liquid level of the lower-tank without the disturbance respectively. After adjustment and optimization of the PID parameters, a set of response curve is shown in Fig 4.

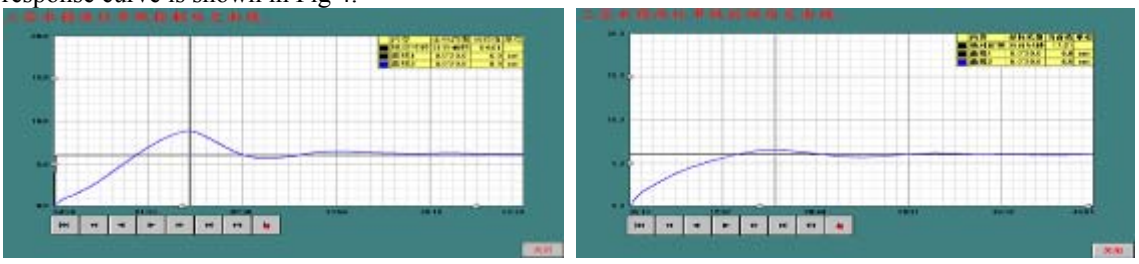

Fig. 4 (a) Response of liquid level under the single-loop control (without disturbance); (b) Response of liquid level under the cascade control (without disturbance)

Comparing with Fig 4(a) and Fig 4(b), better performance of the controller is achieved based on the cascade control, while the fluctuation in the level is within ±9% and steady state is reached with less than 12 min.

Cascade control improves the dynamic performance through adding vice-loops to the structure of control system, because adding vice-loops reduces the time constant of the equivalent accused process.

4.2. Comparing and analyzing with disturbance happened in the Middle-tank

Second, consider the disturbance happened in the Middle-tank (Disturbance f2). A set of optimal PID parameters are designed that is similar to the above method. A set of response curve is shown in Fig 5.

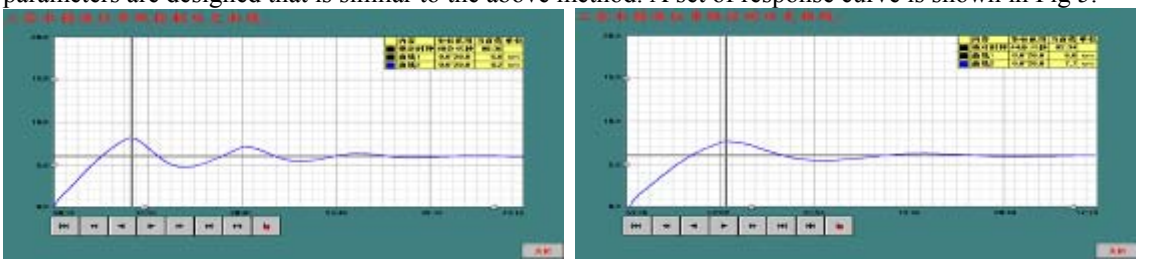

Fig. 5 (a) Response of liquid level under the single-loop control (with disturbance f2); (b) Response of liquid level under the cascade control (with disturbance f2)

Comparing with Fig 5(a) and Fig 5(b), the response of single-loop control system is unsatisfied, which has the large oscillations and is uneasy to reach to the steady state. While under the cascade control, the system also can achieve the steady state in a short time although having an overshoot which is allowed in the industrial production.

The situation where disturbance happened is much closer to the controlled parameter, the influence is more obvious. To cascade control, the overshoot is smaller and transient response is faster because the vice-loop plays the rule of filter methods for the disturbance, which improves the ability to overcome the secondary disturbance greatly.

4.3. Comparing and analyzing with disturbance happened in the Middle-tank and Upper-tank

Third, consider the disturbance happened in the Middle-tank and the Upper-tank (Disturbance f2, f3) at the same time. Fig 6(a) shows the response of liquid level under the single-loop control, while Fig 6(b) shows the response of liquid level under the cascade control.

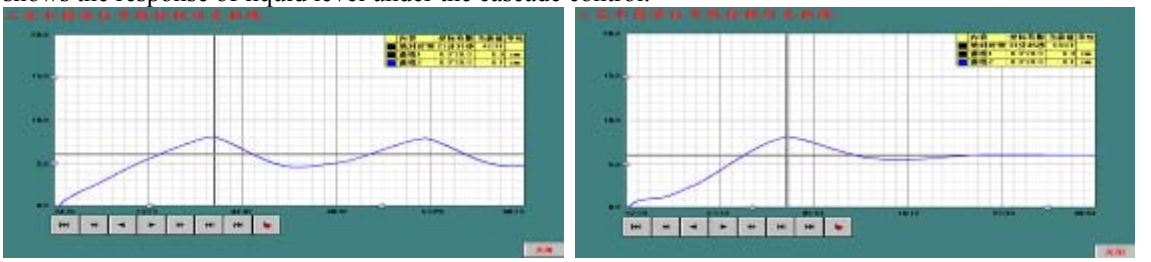

Fig. 6 (a) Response of liquid level under the single-loop control (with disturbance f2 and f3); (b) Response of liquid level under the cascade control (with disturbance f2 and f3)

Comparing with Fig 6(a) and Fig 6(b), the response of single-loop control system is unstable, which is unable to reach the steady state after adjustment and optimization of the parameters. Because having the

ability to overcome multiple disturbances, the response of cascade control system has the better performance. The overshoot is about 25% and steady state is reached with less than 21 min.

Through the above experiments, it is not hard to know that the effect of control method based on cascade control is better than the single-loop control method whether absence of disturbance in the loop or not. The reason why cascade control can improve the control quality is that adding some vice-loops to the structure which can overcome multiple disturbances effectively [7].

5. Conclusion

This paper compares the single-loop control system with cascade control system while they are all employed to control third-order object, which is influenced by different factors and disturbs. Single-loop control system can't get the satisfy response curve when there exists disturbs closer to the controlled parameter. However, to cascade control system, before the disturb make an influence on the level of lower-tank, the upper-tank and middle-tank can transmit the singles of level changes to the other two controllers, whose outputs can control the opening of electromagnetic valve in time, so it can reach the pre-control effect. Analyzing the structure of the cascade control, the inner loop has the rough adjustment effect, while outer loop have the precise adjustment effect. Inner loop can overcome disturbances effectively and improve the control quality. So cascade control system has better performance than single-loop control system no matter where the disturbances get into control system or not.

Acknowledgements

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