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Design and Realisation of Level Cascade Control System for Double-capacity Water Tanks

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Abstract: As a typical representative of process control, double-capacity water tank level control is a common automation control system used to control the level of two water tanks to achieve level stability and control, which is widely used in various fields of industrial production. In actual production, the accuracy and control effect of liquid level control directly affects the production cost of the factory, economic benefits and even the safety factor of the equipment. Therefore, in order to ensure safety and convenient operation, it is necessary to research and develop advanced level control methods and strategies. The sub-loop of serial stage control has a fast control effect, which can effectively overcome the influence of the perturbation into the sub-loop and improve the dynamic characteristics of the object, therefore, this paper adopts the serial stage control algorithm to achieve the constant value control of the liquid level of the double-capacity water tank and compare it with the conventional PID control algorithm, and the realisation results show that the serial stage control has a good ability to inhibit the secondary perturbation, and it can effectively improve the system's rapidity and accuracy.

Keywords: Double-capacity water tank, Cascade control, PID.

1. Introduction

With the continuous improvement of modern industrial automation level, the stability, accuracy and reliability of the liquid level control system has put forward higher requirements. Level control system plays a vital role in many industrial applications, in which the double-capacity water tank level cascade control system as an important form of control system, is widely used in water supply systems, chemical production, environmental protection facilities and other fields[1]. The purpose of this paper is to discuss the design and implementation of double-capacity tank level cascade control system to meet the needs of industrial production for level control accuracy and stability.

The design and implementation of double-capacity water tank level cascade control system is of great significance for industrial production. Through the application of the system, it can achieve accurate control of the tank level, improve the level management efficiency in the industrial production process, and ensure the safe and stable operation of the production system. At present, although there have been many studies on the level control system, there are still some problems in the practical application, such as low control accuracy, poor stability, slow response time. Therefore, in-depth research and optimisation of the double-capacity water tank level cascade control system is needed to improve the performance and stability of the system. This paper focuses on the design process and implementation method of the double-capacity water tank level cascade control system, which adopts the water tank level process control system and the host computer configuration software to achieve the control of the double-capacity water tank level. Through the experimental method to establish the mathematical model of the double-capacity water tank system, using the basic PID control and serial control of the tank level control system, the two control schemes for parameter calibration and put the system into operation.

2. Modelling

The process of establishing a teaching model is to simplify and abstract the intricate practical problems into a reasonable mathematical structure, the mathematical model of the controlled object is an important basis for designing the process control system, determining the control scheme, analysing the quality indicators, adjusting the regulator parameters, etc[2]. In this paper, we adopt the experimental method for the establishment of mathematical model for the double-capacity water tank.

2.1. Characteristics of the object

The second-order double-capacity level control object is composed of two water tanks connected in series, so it is called double-capacity object, and the overall structure is shown in Fig. 2.1. The level of the lower tank H2 is the main parameter, and the level of the upper tank H1 is the subparameter, the output of the main regulator is the given value of the subregulator, the main loop is a fixed-value control system, and the sub-loop is a follower control system. The level signal detected by the level sensor of the lower water tank is compared with the given level value and sent to the main regulator, and after PID operation, its output is the given value of the vice regulator, which is compared with the level signal detected by the level sensor of the upper water tank and then sent to the vice regulator, and after PID operation, its output controls the opening of the electric regulating valve to control the size of the inlet water flow rate, so as to control the level of the water tank. Changes in the amount of incoming water Q1 first make the level of the upper tank H1 changes, inflow Q1 on the controlled variable H2 of the influence of the process is more indirect and complex, which also exposes the weakness of the single-loop control is poor, and the superiority of the control of the series control system can make up for these shortcomings and make the outflow of H2 tends to stabilise. The purpose of the series control system is to make the system have good dynamic and steady state performance, to ensure the control quality of the main controlled quantity, and to realise non-differential regulation. When there is a disturbance in the sub-loop, because the time constant of the main controlled object is larger than that of the subcontrolled object, the sub-loop has already made a quick response when the main controlled quantity is not reflected, which eliminates the influence of the disturbance on the main controlled quantity in time. In addition, if the perturbation acts on the main controlled object, due to the existence of the sub-loop, the time constant of the vice-controlled object is greatly reduced, which speeds up the response of the system and improves the dynamic performance[3-4].

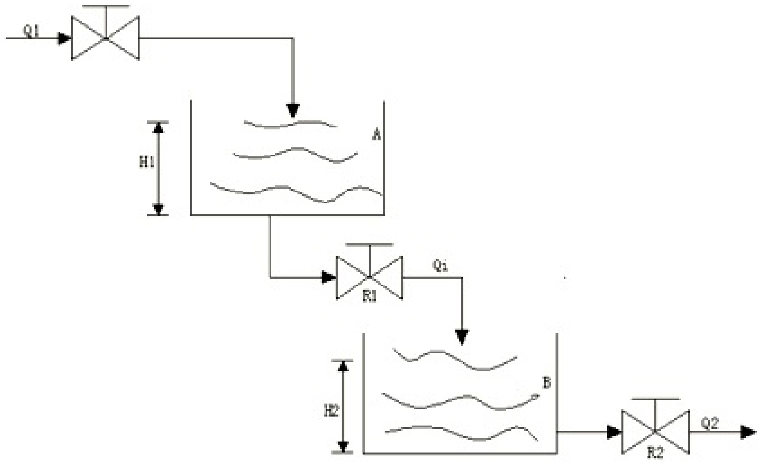

Figure 1. Second-order double-capacitance level control object

According to the principle of single-capacity tank characteristic test, it can be seen that the mathematical model of double-capacity tank is the product of two single-capacity tank mathematical model, that is, the mathematical model of double-capacity tank can be described by a second-order inertial link[4-5]:

$$G(s)=G1(s)G2(s)=\frac{k_1}{T_1 s+1}\cdot\frac{k_2}{T_2 s+1}=\frac{K}{(T_1 s+1)(T_2 s+1)} \quad (1)$$

Where $K = k_1 k_2$, is the amplification factor of the double-capacity tank, and T_1 and T_2 are the time constants of the two tanks, respectively.

Serial control system is a double-loop system, essentially two regulators in series, through their co-ordination, so that a regulated quantity accurately maintained for a given value. The double-capacity tank level serial control system structure is shown in Figure 2.

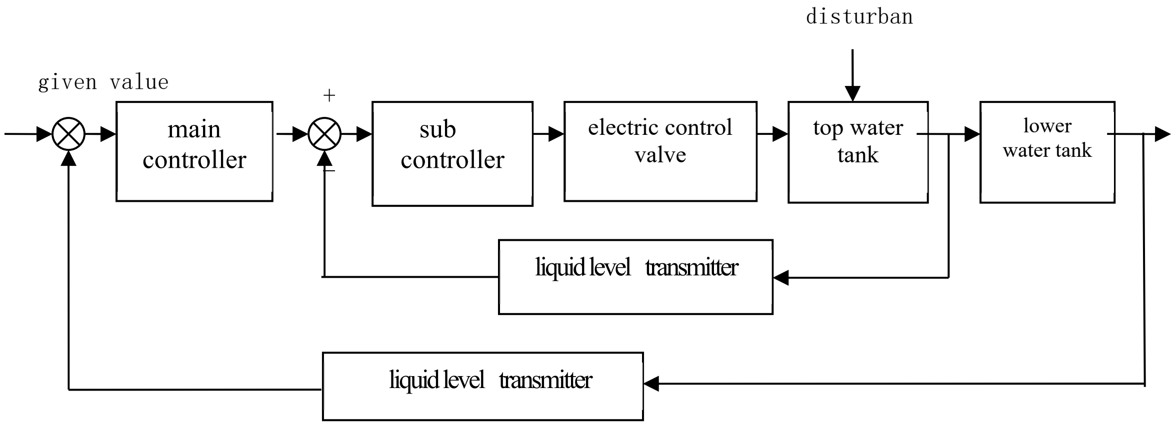

Figure 2. Structure of double-capacity water tank cascade control system

2.2. Modelling of the object

In the experiment, a step signal is input to the upper water tank to make its level leave the original equilibrium state. After a certain adjustment time, the tank level re-entered the equilibrium state. Using the curve fitting method of MATLAB, the experimentally measured data were fitted, and the transfer function of the water tank was calculated through the tangent method, resulting in a MATLAB curve fitting diagram shown in Figure 3:

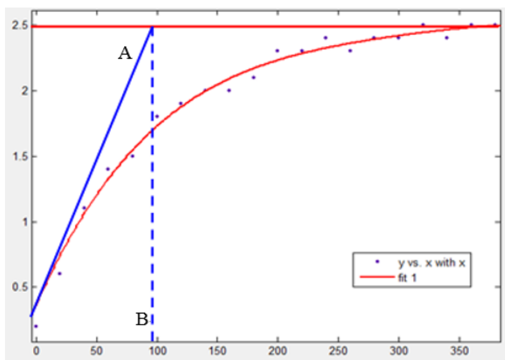

Figure 3. Fitted curve of the upper tank

In the experiment, the design of the above step response curve using the tangent method to calculate the tank parameters K and T. When the response curve in the input quantities to produce a step in the instant, the slope of the curve to reach the maximum, and then gradually converge to stability, the slope K for the P (t) in the t = 0 derivatives, P' (0) = 0.02061, so as to do tangent to the intersection of the steady state value of the A point, A point in the mapping on the horizontal axis of the value of the B point for the T. Response value is 30, the static amplification factor is the ratio of the steady state value of the step response curve to the value of the step perturbation, so the transfer function of the upper tank is shown in the following equation:

$$y = \frac{0.083}{98.7s+1} \tag{2}$$

According to the curve using tangent graphing method to calculate the characteristic parameters of the lower tank, the step response perturbation value of 30, static amplification factor, the same reason can be obtained for the lower tank transfer function:

$$y = \frac{0.097}{244.2s+1} \tag{3}$$

According to the above characteristic parameters, the upper and lower tank transfer function to the double-capacity tank transfer function is:

$$y = \frac{0.083}{98.7s+1} \times \frac{0.097}{244.2s+1} \tag{4}$$

2.3. PID control algorithm

In engineering practice, the most widely used regulator control law for the proportional, integral, differential control, referred to as PID control, also known as PID regulation. PID control is the deviation of the proportion (Proportional), integral (Integral) and differential (Differential) through a linear combination of the three constitute a control quantity, used to control the system of controlled variables to achieve the desired value or stable in the desired range. PID controller is based on the error of the system, the use of proportional, integral, differential calculated control quantities for control[6]. The PID control algorithm can be expressed as follows:

$$U(t) = Kp[e(t) + \frac{1}{Ti}\int_0^t e(t) + Td\frac{de(t)}{dt}] \tag{5}$$

3. Experimental Results

The experimental device is shown in Fig. 3.1, which mainly includes double-capacity water tank, intelligent instrument, monitoring computer and sensing transmitter, and regulating valve. The control system through the magnetic pump to make the liquid to achieve a cycle and through the adjustment of the regulating valve, can make the liquid level to maintain in the set value, so as to achieve the stability of the liquid level control.

Figure 4. Physical diagram of the experimental setup

In order to verify the superiority of the serial control system of the double-capacity water tank, two different control systems will be used in the experiment, one is the control system with sub-loop control, i.e. serial control system, and the other is the single-loop control system without sub-loop control. Firstly, the single-loop control system experiment will be carried out. The set value of this experiment is set to 10, firstly, the system switch is opened to manual mode, the valve opening OP=30, and when the liquid level reaches about 9 cm, it is switched to automatic mode, and the system response waveform is observed. In the process of system parameter adjustment, we use the empirical trial and error method, according to the analysis of the waveform, the final adjustment of the PI parameters are: proportional amplification coefficient is 13, the integration time is 72. The red curve represents the set value, and the green curve is the system output response curve. The single-loop control system output waveform is shown below:

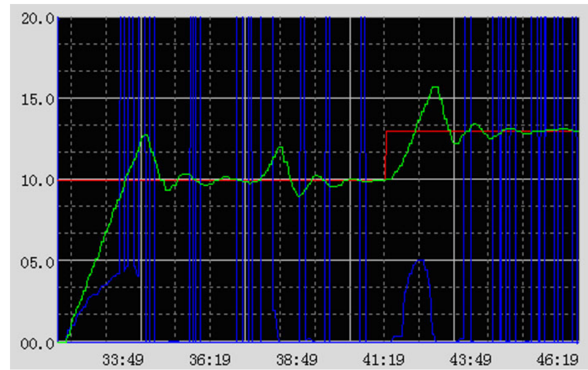

Figure 5. Single-loop control system step response diagram

As can be seen from the above figure, the liquid level for the first time to reach the set value of about 110 seconds, overshooting about 30%, to reach equilibrium in about 5 minutes, after adding a perturbation, the output waveforms are again more pronounced oscillations, and the overshooting amount is larger. Finally, after adding a step perturbation signal, the output waveform fluctuates greatly, and the system adjustment time is longer, the control performance of the system needs to be further improved. Then series control system experiments are conducted. Under the same PID parameters, the sub-loop is added and the sub-loop is proportionally controlled. In the case that the main loop proportionality is 13 and the integration time is 73, the sub-loop proportionality is 50, and the output waveform of the serial control system is shown below:

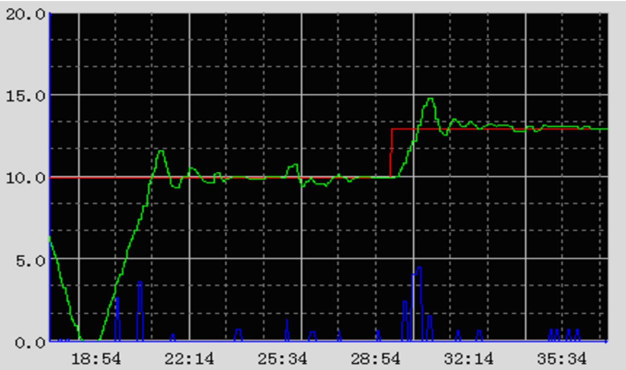

Figure 6. The output waveform of the serial control system

The red curve represents the set value, and the green curve is the system output response curve. As can be seen from the above figure, the system for the first time to reach the set value of about 70 seconds, overshooting about 17%, to reach equilibrium in 4 minutes, and then add a perturbation, the overshooting amount of 8%, relatively small, and it took 2.5 minutes to reach equilibrium, and then finally add a step perturbation signal, compared with a single-loop control system, the overshooting amount of a significant reduction, less fluctuations in output waveforms, and a reduction in the adjustment time. From the above two sets of experiments, it can be clearly seen that the output waveform of the series control system fluctuates smoothly and can reach the set value quickly, and the waveform after adding perturbation signals and step signals is also very little affected, and it can be seen that the output waveform of the series control system is very smooth and can reach the set value quickly. So， it can be seen that the serial control system is more superior in terms of rapidity, stability and accuracy, which is more in line with the actual requirements of production.

4. Conclusion

The double-capacity water tank level cascade control system takes the level of the tank as the controlled quantity, firstly, the characteristics of the tank is analysed and its mathematical modelling is established, and then the experimental device is used to obtain the double-capacity water tank step response waveform, and finally, the control system performance is analysed through the output response curve. The experimental results show that the double-capacity tank level series control performance is good, the series control system can effectively reduce the amount of overshooting, reduce the oscillation frequency, shorten the regulation time, and anti-interference ability is strong, with good dynamic and steady-state performance, which can provide useful references for the researchers and practitioners in related fields.

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