Experiment 6: PID Parameter Tuning for Liquid Level Control System.

1. Experiment objective:

The objective of this experiment is to understand the composition of a single loop control system. Students are expected to design and construct a single loop single tank liquid level control system. They will apply the critical proportional degree method, step response curve method, and tune the PID parameters of the single loop control system. This will help familiarize them with the impact of PID parameters on control system performance criteria. Furthermore, they will utilize a controller instrument for self-tuning of PID parameters and the operation of automatic control.

2.Experiment equipment：

Figure 5-1 shows a single closed-loop control system for an upper tank water level control. It includes a water pump, frequency converter, pressure transmitter, controller I (818 type), main loop regulating valve, upper tank, liquid level transmitter, and controller II (818 type).

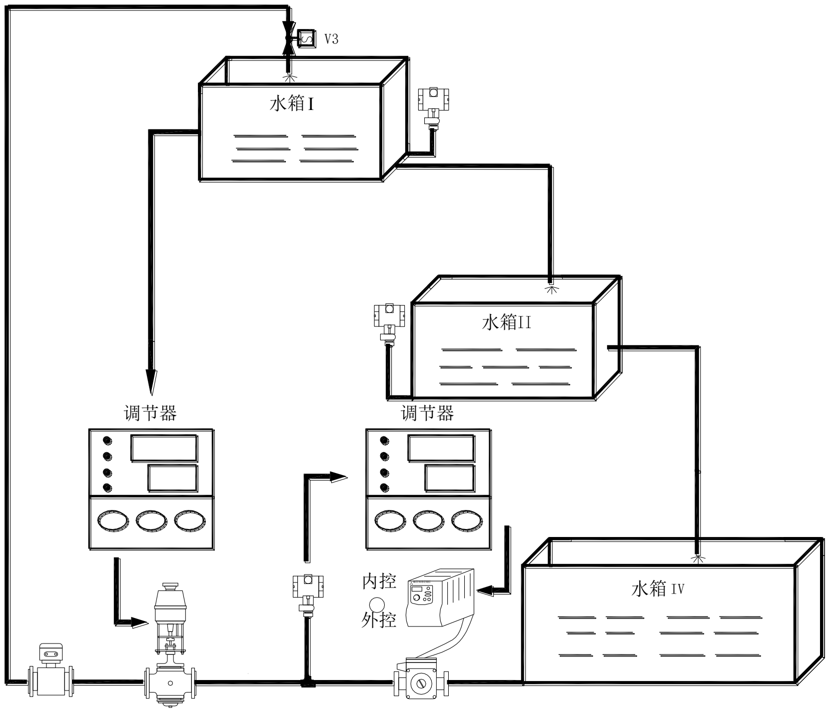

Figure 5-1 Process of the single closed-loop (controller-controlled) flow of the upper water tank

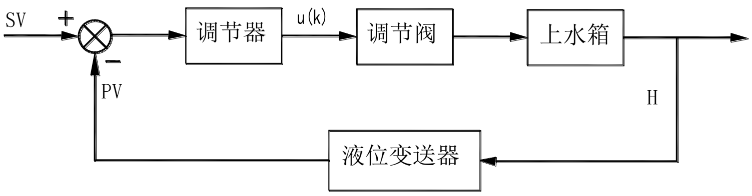

Figure 5-2 Block diagram of the single closed-loop experiment (controller-controlled) of the upper water tank

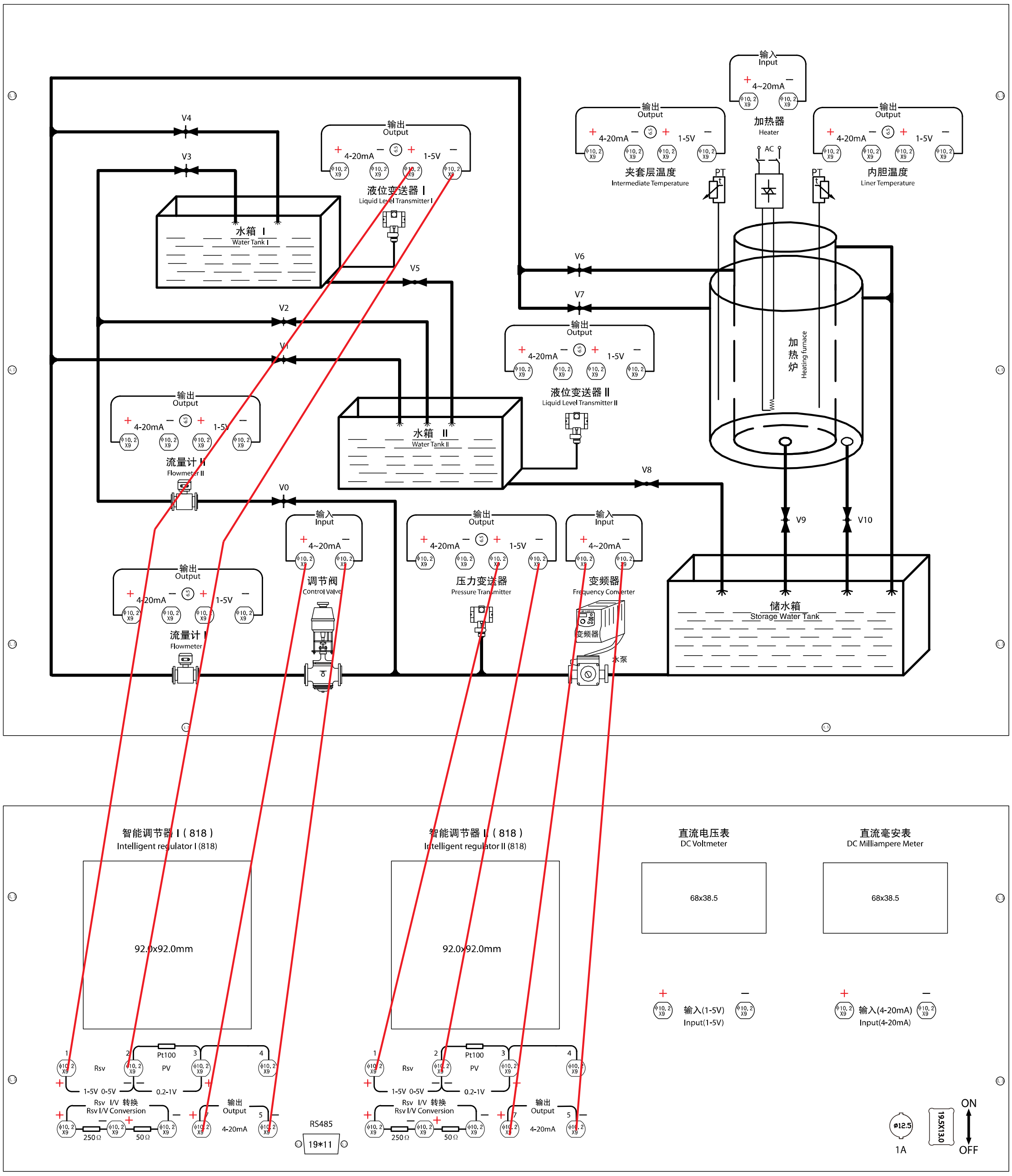

Figure 5-3: Single-loop liquid level control circuit (controller wiring).

3. Experimental Principles:

The single-loop control system, also known as a simple control system, consists of a controlled object, sensor, transmitter, controller, and actuator, forming a closed loop known as a feedback control system.

The single-loop control system is the simplest and most basic type of control system. It is suitable for situations where the controlled object has a small time delay, little variation in load and disturbance, and low requirements for control quality. The design and parameter tuning methods of single-loop control systems serve as the foundation for the design and tuning of various complex control systems.

Key considerations for the experiment:

1. The system should be in a normal working state (equilibrium state) before testing. The initial point of the response curve should be marked on the recording paper, indicating the moment when the step signal starts. This period of time is essential for calculating the pure time delay τ. The testing and recording work must continue until the output parameter reaches a new steady-state value.

2. In the step response curve, attention should be paid to the selection of the operating point and the step amplitude.

3. Each experiment should be conducted at least twice under the same conditions. Only when the tested data is consistent can it be considered valid.

4. In order to perform linear calibration, positive and negative disturbances can be compared, or experiments with different disturbance levels can be conducted.

5. Tuning the parameters of the controller is one of the core aspects of process control system design. Its task is to determine the proportional gain δ, integral time TI and derivative time TD of the PID controller based on the characteristics of the controlled process. In simple process control systems, the tuning of controller parameters is usually based on the decay rate of the system's transient response, ensuring that the system has a certain stability margin.

There are many methods for tuning controller parameters, which can be broadly categorized into two main types: theoretical calculation-based tuning methods. This approach relies on the mathematical model of the system and utilizes control theory techniques such as root locus methods and frequency response methods to determine the numerical values of the controller. This method is not only cumbersome but also overly reliant on the mathematical model, and the resulting data may not be directly applicable. Therefore, theoretical calculation-based tuning methods are rarely used in engineering practice except for theoretical guidance. The second type is engineering tuning methods, which primarily rely on engineering experience and are directly implemented in process control experiments. These methods are simple, easy to understand, and highly practical, thus widely adopted in engineering practice.

The engineering tuning methods for controllers mainly include critical gain tuning method and decay curve tuning method.

(I) Ultimate-sensitivity Method

This is a closed-loop tuning method. Since this method is implemented directly in the closed-loop system without the need for dynamic characteristics of the test process, it is simple and convenient to use and has been widely applied. The specific steps are as follows:

1. Set the integral time T_I of the controller to its maximum value ($T_I = \infty$), set the differential time T_D to zero ($T_D = 0$), and set the proportional gain δ to a relatively large value to put the system into closed-loop operation.

2. After the system reaches a stable state, apply a step disturbance to the setpoint and gradually reduce δ until the system exhibits sustained oscillations with a constant amplitude, referred to as the critical oscillation process as shown in Figure 5-4. Record the value of δ_{cr} (critical proportional band) and the period of oscillation T_{cr} at this point.

3. Based on the recorded values of δ_{cr} and T_{cr}, calculate the parameters of the controller, including δ, T_I, and T_D, using empirical formulas provided in the table.

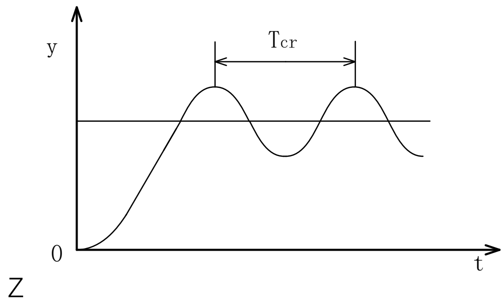

Figure 5-4 Critical Oscillation Process of the System.

Table 5-1 Tuning Parameters using Critical Proportional Band Method.

Setting parameter / Regulation law	δ(%)	T_I	T_D
P	$2\delta_{cr}$		
PI	$2.2\delta_{cr}$	$0.85T_{cr}$	
PID	$1.67\delta_{cr}$	$0.5T_{cr}$	$0.125T_{cr}$

It should be noted that there are certain limitations when using this method to tune the parameters of a controller. For example, some process control systems do not allow for repetitive oscillation experiments, such as the boiler feedwater system and combustion control system, making this method inapplicable. Additionally, for processes with large time constants, it is not possible to achieve undamped oscillations using proportional control, rendering this method ineffective.

From Figure 5-5, it can be observed that the system is critically stable. According to the Nyquist stability criterion, points on the G(jw) curve corresponding to critical stability are defined as |G(jw)|=1. Points within the G(jw) curve indicate stability, i.e., |G(jw)|<1. Points outside the G(jw) curve indicate instability, i.e., |G(jw)|>1. Therefore, on the point of critical stability, we only need to increase the proportional band or decrease the proportional gain in order to achieve |G(jw)|<1, indicating a stable system.

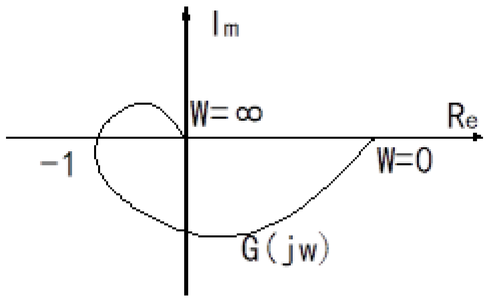

Figure 5-5

(II) Attenuation Curve Method

This method is similar to the Ultimate-sensitivity Method, but it does not require undamped oscillation. The specific steps are as follows:

1. Set the integral time ($T_I = \infty$) of the controller to infinity, the differential time ($T_D = 0$) to zero, and set the proportional band (δ) to a relatively large value. Start the system operation.

2. Once the system reaches a stable state, apply a step disturbance to the setpoint and observe the system response. If the oscillations damp too quickly, decrease the proportional band; if they damp too slowly, increase the proportional band. Repeat this process until an oscillation process with a decay ratio of 4:1, as shown in Figure 5-6, is achieved. Record the value of δ at this point (denoted as δ_S) and the value of T_S (as shown in Figure 5-6). If using the decay ratio of 10:1, the rise time (T_r) can be used instead of the oscillation period (T_S) for calculations.

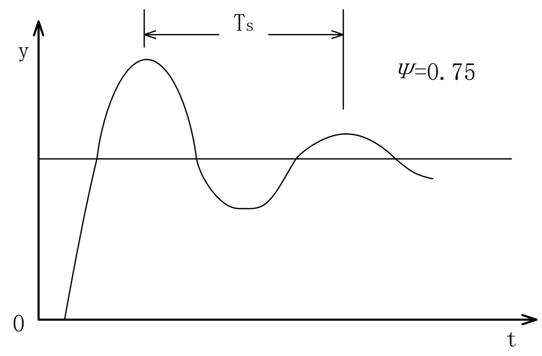

Figure 5-6 the decay oscillation curve of the system

In the figure, T_S represents the decay oscillation period, and T_r represents the rise time of the response.

3.According to the empirical formula given in the table, calculate the parameters of δ, T_I, and T_D.

Table 5-2 calculation formulas for tuning using the attenuation curve method

Attenuation rate ψ	Setting parameter / Regulation law	δ	T_I	T_D
0.75	P	δ_S		
	PI	$1.2\delta_S$	$0.5T_S$	
	PID	$0.8\delta_S$	$0.3T_S$	$0.1T_S$
0.9	P	δ_S		
	PI	$1.2\delta_S$	$2T_r$	
	PID	$0.8\delta_S$	$1.2T_r$	$0.4T_r$

The attenuation curve method is generally applicable to most processes, but its drawback is that it is difficult to determine the decay rate of 4:1, making it challenging to obtain accurate values for δ, T_I, and T_D.

4.Experimental Steps:

Step Response Curve Method

1. Connect the equipment used for the level control loop experiment according to the system diagram.

2. Turn on the main power and power supply for all instruments.

3. Open the inlet valve V4 of the upper water tank, the drain solenoid valve V5 of the upper water tank, and the drain valve V8 of the lower water tank. Close all other valves, with the valve openings in the order of V8 > V5 > V4.

4. Calculate the tuning parameter values.

To set the decay ratio of the transient process to 4:1, you can calculate the tuning parameter values using the "Step Response Curve Tuning Parameter Table" provided below.

Table 5-3 Step response curve tuning parameter table

Setting parameter / Regulation law	δ	T_I	T_D
P	δ_S		
PI	$1.2\delta_S$	$0.5T_S$	
PID	$0.8\delta_S$	$0.3T_S$	$0.1T_S$

5. Set the controller parameters based on the calculated PID parameter values.

6. Operate the pump in a constant pressure water supply mode. Observe the changes in the water tank level curve on the computer.

7. Once the system is stable, apply a step signal and observe the changes in the water level curve.

8. After the system reaches stability again, introduce a disturbance signal and observe the changes in the water level curve.

9. Conduct analysis and processing of the curve data. Analyze and process the recorded curve data from the experiment, and record the processing results in Table 5-4.

Table5-4 Step response curve data processing record table

Parameters / Measurement situation	Parameters of characteristic test		
	K	T	τ
step 1			
step 2			
average			

5. Parameter Settings of Regulator：

This parameter is applicable to the AI818 model of Shanghai Wanxun Instrument Co., Ltd..

When pressure, temperature and liquid level are controlled, this type of regulator can self-adjust ideal parameters. Set the regulator parameter Ctrl=2, and the regulator will enter the self-tuning state. After adjustment, the parameter Ctrl=3.

The parameters to be set for the AI818 model used in this experiment are as follows (those not listed in this table are generally not changed, and the factory default values are adopted):

Liquid level control of upper water tank of 818 regulator

Parameter name	Parameter value	Description	Parameter name	Parameter value	Description
P	30	Retention parameter	dIL	0	Enter the lower limit display value
I	100	Rate parameter	dIH	100	Enter the upper limit display value
D	0	Delay time	Sc		Default
Ctl		Default	oP1		Default

Sn	33	Input specification	CF		Default
dIP	0	Decimal number	run		Default

Liquid level control of upper water tank of 818 regulator

Parameter name	Parameter value	Description	Parameter name	Parameter value	Description
P	30	Differential time (seconds)	dIL	0	Enter the lower limit display value
I	100	Proportional band	dIH	300	Enter the upper limit display value
D	0	Integration time (seconds)	Sc		Default
			oP1		Default
Sn	33	Input specification	CF		Default
diP	0	Decimal number	run		Default

The parameters to be set and other parameters are shown above.

6. Experimental Report:

According to the experimental results, the experimental report is written, and the generalized transfer function is written according to the average values of K、T、and τ.