

Deaerator system pressure and liquid level PID regulation control strategy

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Abstract. Excessive oxygen content in the feed water of industrial boilers will cause oxidative corrosion on the metal surface, resulting in grooves or even thinning of the metal tube wall, resulting in trachoma until it is completely damaged. Therefore, the quality of the deoxidation effect greatly impacts the service life of industrial boilers and directly affects the economic benefits of enterprises. Automatic equipment and PID parameter adjustment are used to improve the deoxygenation performance of the deaerator system, making the oxygen content of the water in the industry meet the standard, thereby reducing the oxidation and corrosion of pipelines and prolonging the practical life of the equipment. This article mainly introduces Shanxi Yaxin Energy Group Co., Ltd. and Xinneng Technology Co., Ltd. 's 220-ton CDQ coke oven with co-production 120T SS98 high-temperature and high-pressure steam boiler, supporting a set of XNC-130 deaerator produced by Lianyungang Huagang Power Equipment Co., Ltd., the design output is 130t/h, the working pressure is 0.03MPa, the working temperature is 104 °C, the design pressure is 0.3MPa, the design temperature is 120 °C, the water tank volume is 50m³, and the material Q345R. The system uses Siemens PLC, Rosemount pressure transmitter, regulating valve and other equipment combined with PID control algorithm to achieve pressure and liquid level adjustment and the best deaeration effect.

Keywords: Deoxidation effect, Automatic equipment, PID parameter adjustment.

1. Introduction

With the wide application of deaerators in industrial boilers, its importance has become increasingly prominent [1-5]. Boiler feed water contains oxygen, nitrogen, carbon dioxide and other gases. The high temperature and high-pressure environment will cause oxidative corrosion to the boiler feed water pipeline, body, and other ancillary equipment, attracting widespread attention from many industrial enterprises and thermal power companies [6]. Excessive oxygen content will cause the metal inner wall to bulge and thin, and trachoma will appear until it is completely damaged. Therefore, the deoxidation quality dramatically impacts the lifetime of industrial boilers and the profit of enterprises. Deoxidation of boiler water is one of the critical components of the evaluation criteria in the industry. The Ministry of Electric Power promulgated GB1576-2001 "Water Quality Standards for Industrial Boilers" and "Supervision Regulations for Safety Technology of Deaerators in Power Stations". These regulations put forward some standards for the oxygen content of deaerators; that is, the oxygen content of low-pressure deaerator feed water should be less than 15µg/L, and the oxygen content of the feed water of the high-pressure deaerator should be less than 7µg/L [7].

In recent years, Shanxi Xin Energy Group Co., Ltd. [8] has responded to the government's call for environmental protection and energy saving. The company abandoned the traditional wet quenching method and invested in a 220T CDQ coke oven, which generates heat energy to drive a 120T/h high-temperature and high-pressure steam boiler. The steam produced is used to support a 35MW generator set and for heating in-plant use. High-temperature and high-pressure steam boilers have extremely high requirements for water quality. The XNC-130 deaerator produced by Lianyungang Huagang Power Equipment Co., Ltd. [9] is selected. The deaerator aims to remove the harmful gases dissolved in the water, especially oxygen, and prevent these harmful gases from entering the boiler system and causing corrosion of the thermal equipment, thereby affecting the regular operation of the boiler system. Currently, the deaerator is using the thermal deaeration method. Under certain pressure, when

water temperature increases, the solubility of the gas will decrease, and vice versa. The total pressure of the steam-water mixture on the surface of the deoxygenated water contains the partial pressure of the steam. When the water temperature rises, the partial pressure of the water vapour on the liquid surface will increase, and the partial pressure of other gases near the corresponding liquid surface will decrease. When the water temperature rises to boil, the partial pressure of the steam will be close to the total pressure on the liquid surface. At this time, the partial pressure of other gases on the liquid surface will be close to 0, and these gases will be completely removed from the water. Thermal deaeration requires that the pressure in the deaerator should be maintained at 0.02~0.025MPa. When the temperature is 104°C, almost all the dissolved oxygen molecules in the deaerated water will be removed, and the oxygen content is approximately zero; however, the temperature should not exceed 107°C.

This design project's control object is the deaerator. The Siemens PLC system combined with the PID control algorithm is used to design the pressure and liquid level control system [10].

2. Overall structure

2.1 System design requirements

This system designs a deaerator pressure control system and a liquid level control system. It can collect the data of the pressure transmitter and transmit it to the CPU after AD conversion, and then apply the PID controlling algorithm to control the electric regulating valve to stabilize the liquid level and pressure.

2.2 System design flowchart

The overall system scheme of this paper is shown in Figure 1 and Figure 2.

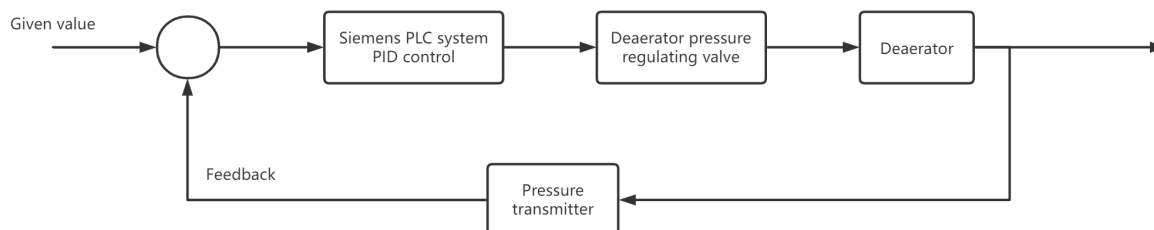


Figure 1. Block diagram of pressure control

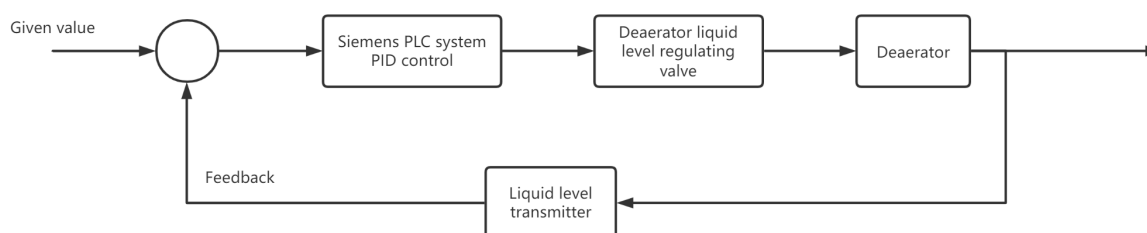


Figure 2. Block diagram of level control

Siemens PLC system PID controller is the core part of this system. It is mainly responsible for the acceptance of pressure transmitter and electric regulating valve position signal, and after processing the output control electric regulating valve opening. At the same time, when the deaerator pressure exceeds the alarm value, an alarm signal will be issued.

The electric control valve regulates the pressure and flow rate. It receives AO signals from the CPU, compares them with the signals from the feedback mechanism, and controls the motor to reduce the error. The feedback signal is generated by a potentiometer connected to the motor using a speed-shifting device.

The pressure transmitter detects the pressure change of the deaerator in real-time and transmits the data to the CPU through an AI safety gate. After going through the PID algorithm, the CPU sends the corresponding AO valve output.

2.3 The choice of Siemens PLC controller

Siemens PLC400 system was selected.

Siemens PLC400 system features high processing speed, powerful communication performance and excellent CPU resource margin. There is also a FIFO (first in, first out) buffer to save the errors. It is also integrated with HMI (human-machine interface) service, and the I/O expansion function is strong, which enables it to achieve distributed structure and redundant control.

2.4 The choice of PLC programming software

Siemens Step7 V5.6 software was selected.

Siemens Step7 V5.6 is the standard software used to create programmable logic control for SIMATIC S7-300/400 station. It is one of the most comprehensive engineering software for demanding controller tasks which can help users solve engineering problems intuitively and efficiently. It can be programmed using ladder diagram logic, function block and statement table. It has a short debugging time and downtime. It can use the integrated system to diagnose issues to localize the errors efficiently, which prevents engineering design from needing to configure the system diagnosis manually. Moreover, diagnostic information is automatically updated through the Engineering System (HWCN) when new hardware components are introduced. It is also Easy to learn and can provide users with powerful technical support during the product's life cycle.

2.5 The choice of the configuration software

Siemens WINCC V7.5 software was selected.

Siemens WINCC V7.5 is a scalable process visualization system (SCADA) that has efficient functions to control automated processes. It can handle a wide range of tasks, from simple single-user systems to distributed multi-user systems with many servers; it can also provide cross-site solutions, including Web clients. One of the unique features of WINCC is its complete openness. It can be easily combined with user programs to create HMI solutions that accurately meet real-world requirements.

2.6 The choice of the pressure transmitter

The type 3051 pressure transmitter from Beijing far east Rosemont is selected for pressure and liquid level.

The pressure transmitter model is 3051CG3A22A1BM5HR5B4, and the range is from 0 to 100 kPa.

The liquid level differential pressure transmitter Model is 3051CD2A22A1BM5HR5B4, and the range is 23.544 ~ 0.519 kPa.

2.7 The choice of the electric regulating valve

The 371 series intelligent electric straight-stroke single-seat control valve from Anshan Tooling Automatic Control Instrument Co., Ltd. is selected.

The model is 371LSC-99 AC380V; it has an output force of 10000N, and the itinerary is 60mm.

2.8 Calculation of liquid level differential pressure

The process conditions are shown in Table 1 and Figure 3.

Table 1. Process conditions

No.	Items	Parameters
1	Maximum liquid level	$H_{max} = 1.2m$
2	Normal liquid level	$H_{com} = 0m$
3	Minimum liquid level	$H_{min} = -1.2m$
4	Measuring range	$H = 2.4m$
5	Medium density	$\rho = 977.96kg/m^3$
6	Cold water density	$\rho_0 = 1000kg/m^3$
7	Flange opening height difference	$h = 2.4m$

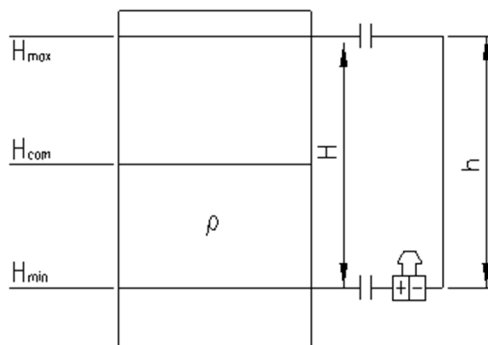


Figure 3. Liquid level diagram

The calculation of the maximum pressure P_{max} is:

$$P_{max} = \rho \times H \times g = 977.96 \times 2.4 \times 9.81 = 23.025kPa \quad (1)$$

The calculation of the negative migration of differential pressure transmitter is:

$$B = \rho_0 \times H \times G = 1000 \times 2.4 \times 9.81 = 23.544kPa \quad (2)$$

The range of differential pressure transmitter is -23.544~-0.519kPa.

The display scale of differential pressure transmitter is -1.2m~1.2m.

Figure 4 and Figure 5 are the photos of the valve and the pressure transmitter.



Figure 4. Picture of the regulating valve equipment.



Figure 5. Picture of pressure transmitter equipment.

3. System hardware design

In this system design, the Siemens PLC400 redundant system is used. The following are details of the system hardware design.

3.1 Measuring point selection

The parameters of the measuring point are shown in Table 2.

Table 2. Information about the measuring point

No.	type	Measuring point name	Signal type	Unit	Variable tag
1	AI	Deaerator pressure	4-20mA	KPa	PT-35202B
2	AI	Deaerator level	4-20mA	KPa	LT-35202B
3	AO	Deaerator liquid level control valve given	4-20mA	%	LV-35202B
4	AI	Deaerator liquid level control valve feedback	4-20mA	%	LVI-35202B
5	AO	Deaerator pressure regulating valve given	4-20mA	%	PV-35202B
6	AI	Deaerator pressure regulating valve feedback	4-20mA	%	PVI-35202B

3.2 The hardware configuration

Specific hardware configuration selection required for level and pressure adjustment of deaerator. Table 3 shows the hardware configuration settings.

Table 3. Hardware configuration settings

No.	Items	Parameters
1	CPU	414-5H PN/DP; (6ES7414-5HM06-0AB0)
2	Analog input module	SM331; AI8X12 bit; (6ES7331-7KF02-0AB0)
3	Analog output module	SM332; AO8X12 bit; (6ES7332-5HF00-0AB0)
4	Interface module	IM153-2; (6ES7153-2BA10-0XB0)
5	Temperature safety barrier (thermal resistance)	MTL5573
6	Analog input safety barrier	MTL5541
7	Analog output safety barrier	MTL5546Y

3.3 Network and hardware structure diagram

The network design is shown in Figure 6. The hardware design is shown in Figure 7.

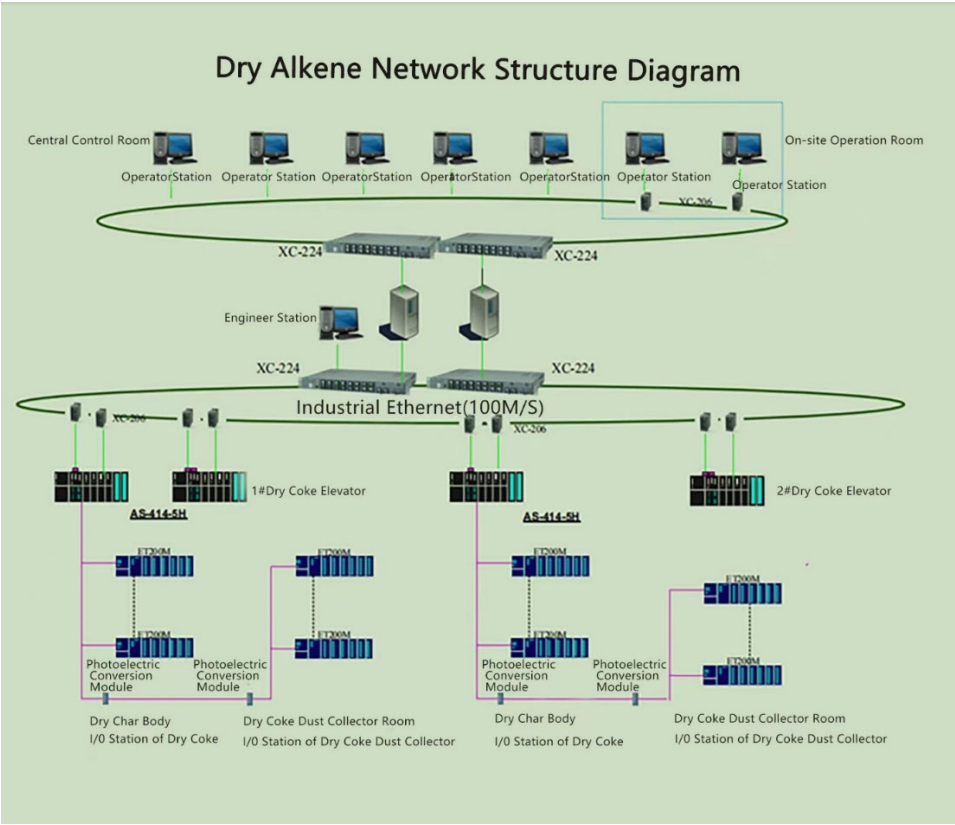


Figure 6. Network system diagram

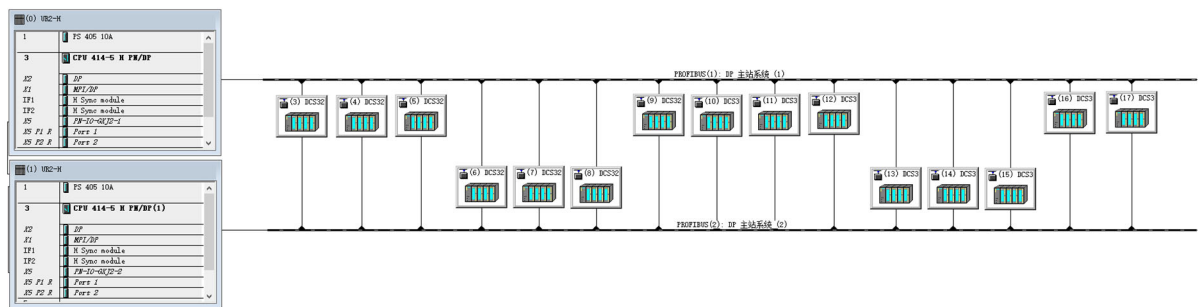


Figure 7. Hardware system diagram

3.4 Hardware device wiring

3.4.1 Analog input module

Wiring diagram for SM331 module is shown in Figure 8.

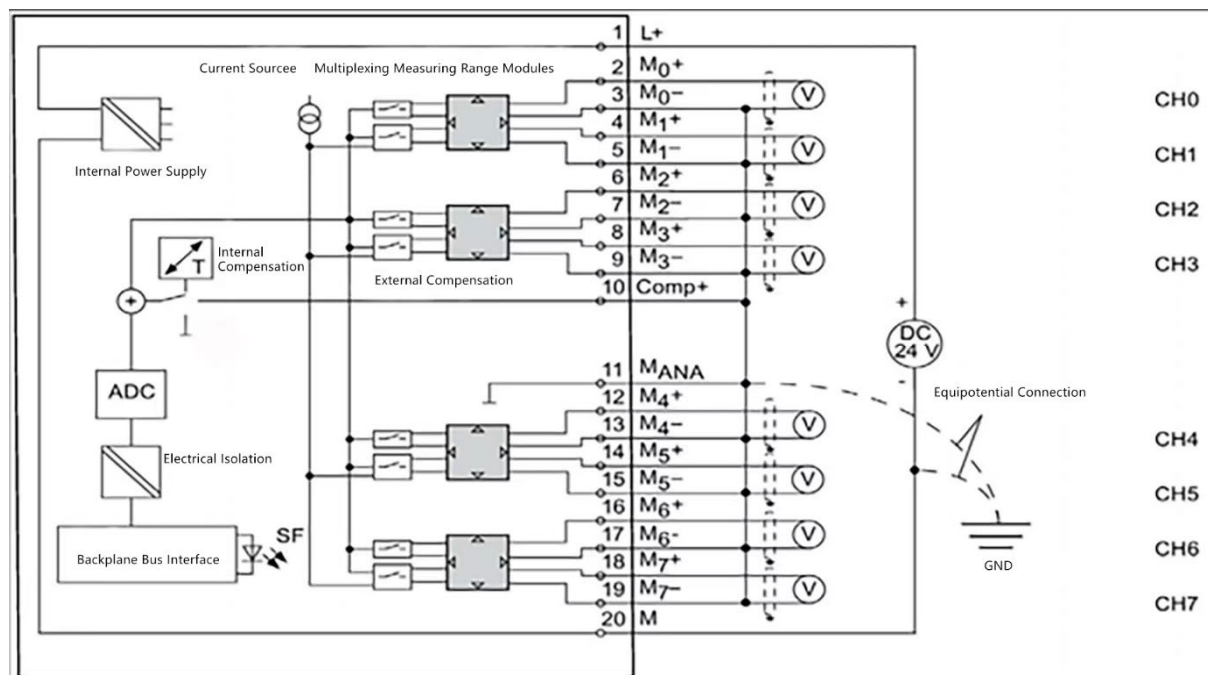


Figure 8. Analogue input module wiring

3.4.2 Analog Input Safety Barrier

Wiring diagram for MTL5541 module is shown in Figure 9.

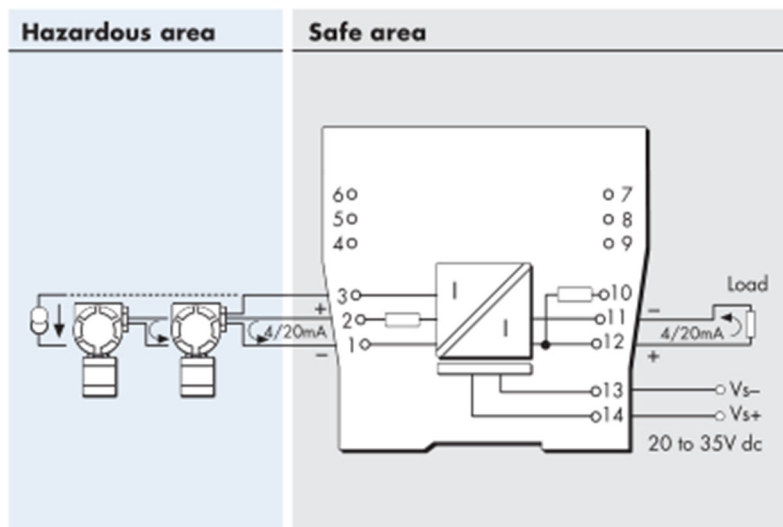


Figure 9. Analogue input safety barrier wiring

The wiring method of the pressure/differential pressure transmitter is a 2-wire system requiring power distribution. When wiring, the positive pole of the transmitter is connected to the safety barrier terminal 2, and the negative pole is connected to the safety barrier terminal 3. The safety barrier terminal 11 is connected to the MX- on the analogue input module SM331, while terminal 12 is connected to MX+ (x corresponds to CH). According to the diagram, the safety barrier and module are connected to power and the ground.

The feedback of the electric control valve is an active 2-wire wiring method. The positive pole of the feedback is connected to terminal 3 of the safety barrier, and the negative pole is connected to terminal 1.

3.4.3 Analog output module

Wiring diagram for SM332 module is shown in Figure 10.

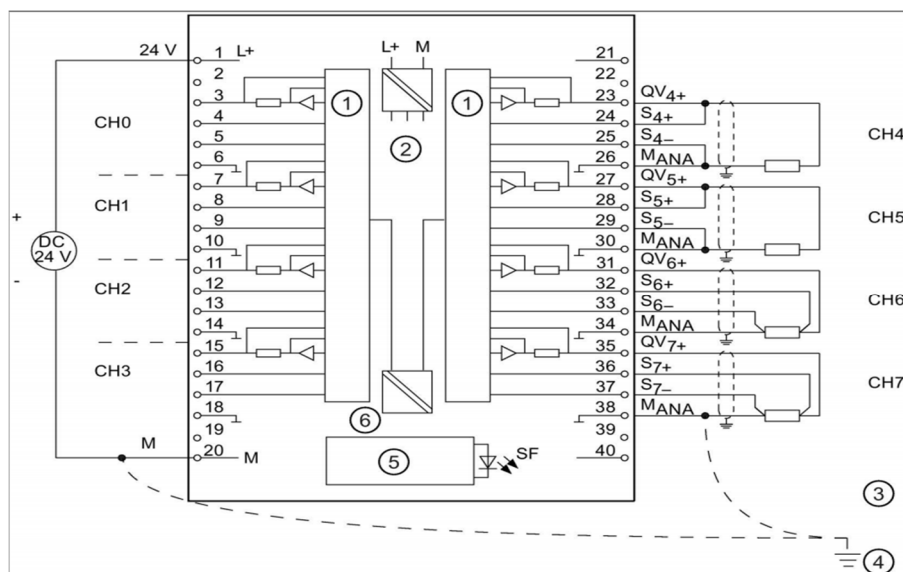


Figure 10. Analogue output module wiring

3.4.4 Analog output safety barrier:

Wiring diagram for MTL5546Y module is shown in Figure 11.

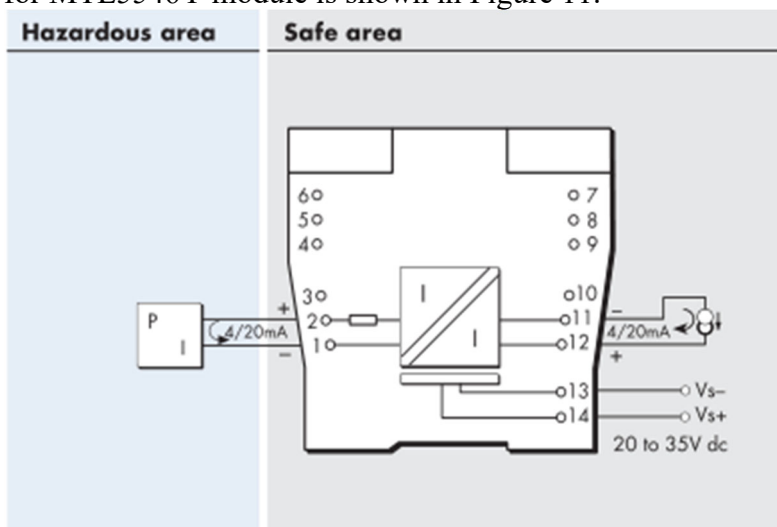


Figure 11. Analogue output safety barrier wiring

The control valve uses active 2-wire wiring. The positive pole of the control signal of the regulating valve is connected to the safety barrier terminal 2, and the negative pole is connected to the safety barrier terminal 1. The safety barrier terminal 11 is connected to the MANA on the analogue output module SM331, and terminal 12 is connected to QV_x+ (X corresponds to CH). According to the diagram, the safety barrier and module are connected to power and the ground.

3.4.5 Wiring schematic diagram of electric straight-stroke single-seat control valve

The Wiring schematic diagram for the 371LSC-99 valve is shown in Figure 12.

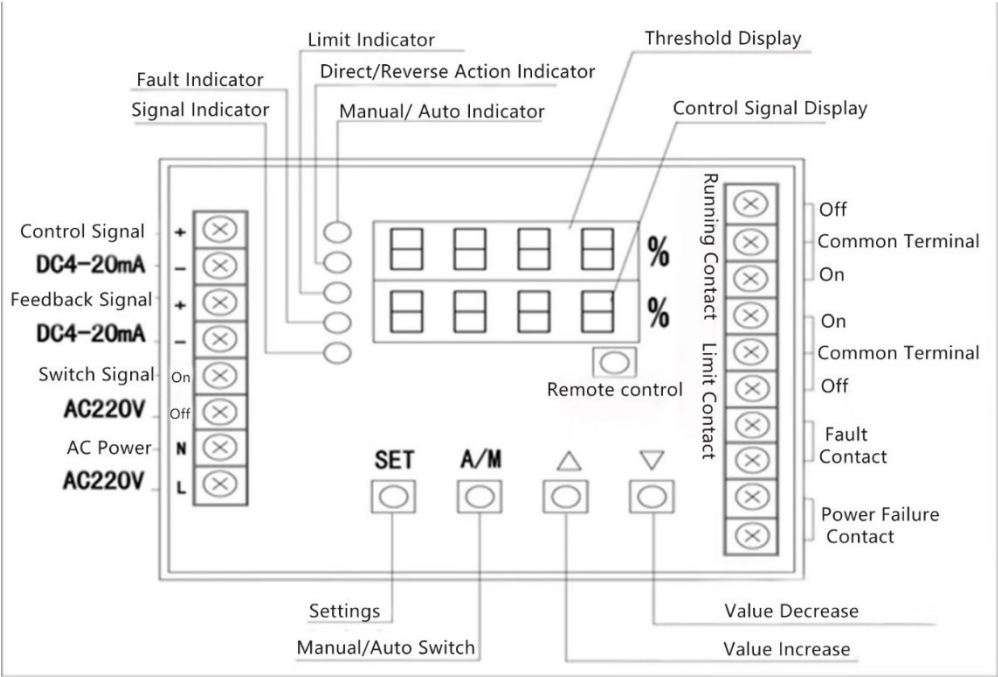


Figure 12. wiring diagram of the valve

4. System software design

4.1 Step7 Background block FB selection

The PID background block is programmed in VC programming language.

4.2 PID control function block

The FB background block is used for programming.

4.3 Configuration screen diagram

4.3.1 WINCC variable management

Variables for pressure control are shown in Figure 13.

GX12/PV_35202B.FB_IN	FloatToFloat	GX12	DB439,DD284	
GX12/PV_35202B.GAIN	FloatToFloat	GX12	DB439,DD292	
GX12/PV_35202B.LMIH	FloatToFloat	GX12	DB439,DD352	
GX12/PV_35202B.MAN	FloatToFloat	GX12	DB439,DD288	
GX12/PV_35202B.MAN_ON		GX12	DB439,DD880+270.2	
GX12/PV_35202B.PV	FloatToFloat	GX12	DB439,DD376	
GX12/PV_35202B.RANG_H	FloatToFloat	GX12	DB439,DD0	
GX12/PV_35202B.RANG_L	FloatToFloat	GX12	DB439,DD4	
GX12/PV_35202B.SP	FloatToFloat	GX12	DB439,DD372	
GX12/PV_35202B.SP_E_O		GX12	DB439,DD880+270.6	
GX12/PV_35202B.SP_INT	FloatToFloat	GX12	DB439,DD276	
GX12/PV_35202B.TD	LongToSignedDword	GX12	DB439,DD300	
GX12/PV_35202B.TI	LongToSignedDword	GX12	DB439,DD296	
GX12/PV_35202B.UNIT		GX12	DB439,DD880+8	

Figure 13. Pressure control

Variables for level control are shown in Figure 14.

GX12/LV_35202B.FB_IN	FloatToFloat	GX12	DB440,DD284	
GX12/LV_35202B.GAIN	FloatToFloat	GX12	DB440,DD292	
GX12/LV_35202B.LMN	FloatToFloat	GX12	DB440,DD352	
GX12/LV_35202B.MAN	FloatToFloat	GX12	DB440,DD288	
GX12/LV_35202B.MAN_ON		GX12	DB440,DD880+270.2	
GX12/LV_35202B.PV	FloatToFloat	GX12	DB440,DD376	
GX12/LV_35202B.RANG_H	FloatToFloat	GX12	DB440,DD0	
GX12/LV_35202B.RANG_L	FloatToFloat	GX12	DB440,DD4	
GX12/LV_35202B.SP	FloatToFloat	GX12	DB440,DD372	
GX12/LV_35202B.SP_E_O		GX12	DB440,DD880+270.6	
GX12/LV_35202B.SP_INT	FloatToFloat	GX12	DB440,DD276	
GX12/LV_35202B.TD	LongToSignedDword	GX12	DB440,DD300	
GX12/LV_35202B.TI	LongToSignedDword	GX12	DB440,DD296	
GX12/LV_35202B.UNIT		GX12	DB440,DD880+8	

Figure 14. Level control

4.3.2 WINCC flow chart

The overall flow chart is shown in Figure 15.

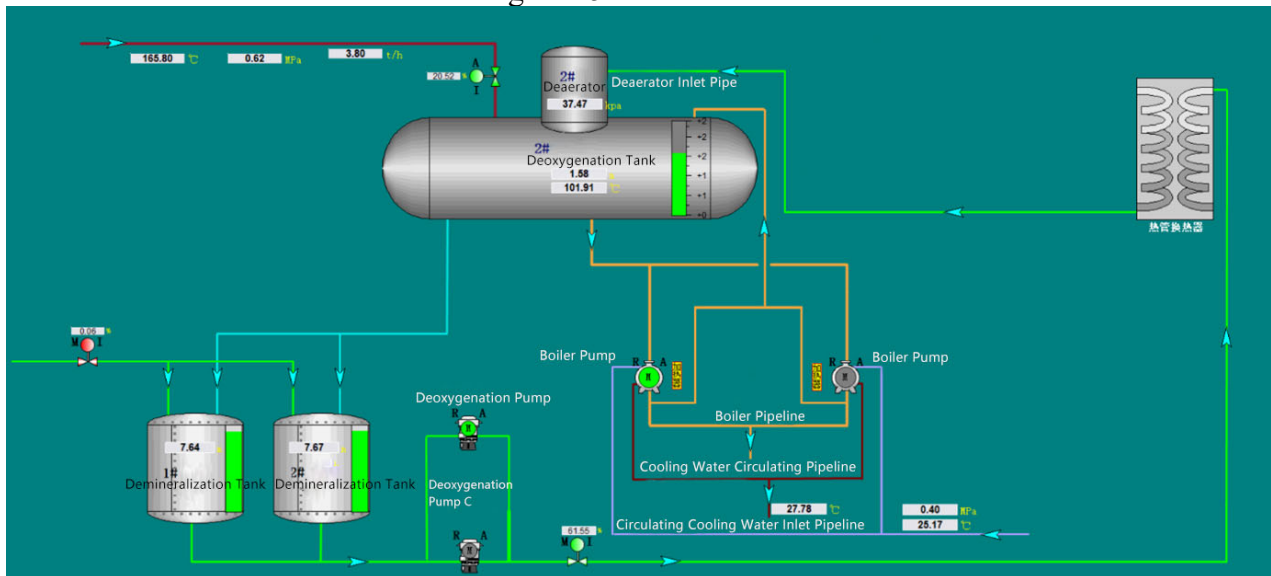


Figure 15. Configuration diagram

4.4 PID parameter setting and curve recording

PID parameter settings for pressure is shown in Table 4.

Deaerator pressure behavior is shown in Figure 16.

Table 4. PID parameter setting for pressure control

P	0.800	Process setpoint	37.00 KPa
I	22	Process feedback value	36.89 KPa
D	10	Output value adjustment	43.30 %

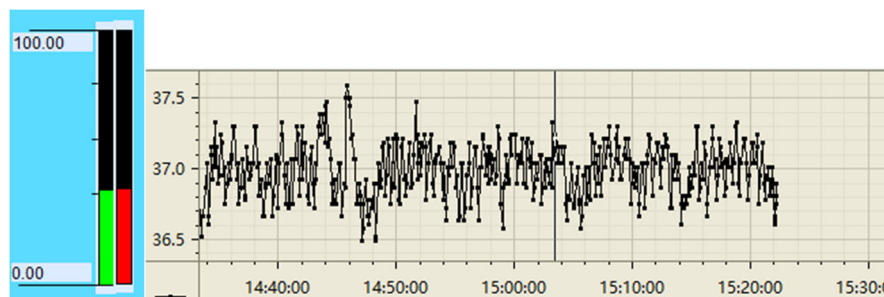


Figure 16. The change of pressure over time

PID parameter settings for water level are shown in Table 5.

Deaerator water level behavior is shown in Figure 17.

Table 5. PID parameter setting for water level control

P	60.00	Process setpoint	2.00 m
I	400	Process feedback value	1.54 m
D	10	Output value adjustment	60.00 %

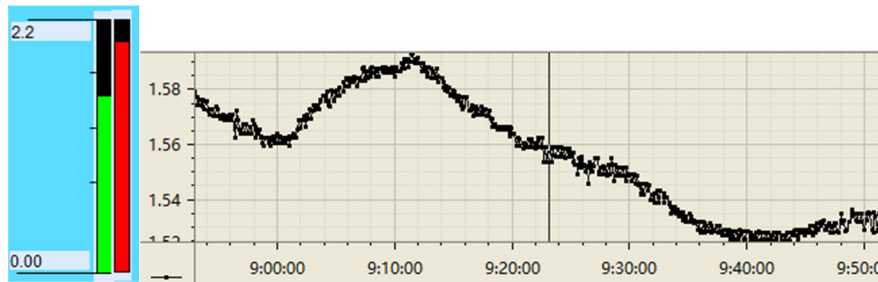


Figure 17. The change of water level over time

5. PID parameters settings

PID parameters are adjusted based on the actual situation and the following rules [11-14].

5.1 General rules for parameter adjustment:

The proportional P makes the response faster, the differential D makes the reaction faster, and the integral I makes the reaction slower, according to the control law of each parameter. The control system's performance will be improved by more significant P and D within a specific range. The fundamental principles for adjusting each parameter are as follows: raise the proportional gain P, lower the integral time constant T_i , and raise the differential time constant T_d when the output does not oscillate.

5.2 The method of PID controller parameter tuning:

1. Theoretical calculation setting method.

This approach primarily uses the mathematical model of the system to calculate the controller parameters theoretically. PID settings obtained with this method are typically not directly usable and need to be altered and modified using engineering practice.

2. The engineering tuning method

This strategy, applied directly during the control system test, primarily relies on experience. The engineering tuning technique is well-known in the field and is simple to master.

The crucial proportional approach, the response curve method, and the decay method are three engineering tuning techniques that are widely applied.

While each of these three approaches has its own benefits and drawbacks, the critical ratio approach is now the most popular. Following are the processes involved in utilizing this technique to modify the PID controller's parameters:

(1) Pre-select a short sampling period that allows the system to work.

(2) Only increase the proportional control signal until the critical oscillation occurs in the system's step response to the input. Record the proportional amplification factor and critical oscillation period.

(3) The PID controller parameters are obtained by formula calculation under a certain degree of control.

5.3 General steps for parameter adjustment:

1. Determine the proportional gain P.

The integral term and differential term of the PID should be removed before calculating the proportional gain P, which leaves the PID as a pure proportional adjustment with $T_i=0$ and $T_d=0$ in most cases.

Set the input between 60% and 70% of the system's maximum permissible value, then gradually raise the proportional gain P from 0 until the system begins to oscillate.

Conversely, gradually reduce the proportional gain P until the system oscillation stops. At this point, note the proportional gain P and set the PID's proportional gain P to 60%–70% of the current value.

2. Determine the integral time constant T_i .

Set a higher initial value for the integral time constant T_i after determining the proportional gain P . Then, progressively reduce T_i until oscillation occurs in the system, and then gradually increase T_i until the system no longer oscillates. At this point, note the T_i and adjust the PID's integral time constant T_i to be 150%–180% of the present value.

3. Determine the differential time constant T_d .

In most cases, the differential time constant T_d is superfluous and can be set to 0. Apply the same procedure used to determine P and T_i when setting the value of T_d and take 30% of the value after oscillation ceases.

Finally, test the system under both load and no-load conditions, and then adjust the PID parameters until the specifications are reached.

6. Conclusion

This project is based on the Siemens PLC system for research and design. It realizes the data acquisition of pressure transmitter, liquid level transmitter, PID algorithm and electric regulating valve control system. Mainly completed the system scheme design, hardware circuit design and detailed description of the software, and finally completed the debugging and operation of the system. With the progress and development of society, more and more theoretical studies and analyses have shown that sustainable economic growth needs to be supported by restrained and modest industrial production. In terms of energy consumption, this design analyzes the liquid level and pressure regulation of the deaerator in automatic refinement. The efficiency of electricity consumption, and the maintenance rate of water equipment, boilers and pipes have been greatly reduced, and the replacement rate of equipment damage has also been significantly reduced, maximizing the capital investment of power plants and enterprises. It plays a significant role in constructing a conservation-oriented society.

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