

# Boiler level measurement and control system

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## Abstract

This paper develops a boiler level control system to measure and control boiler level easily. This level control system applies PID control algorithm in SIEMENS S7-300PLC, uses ladder diagram and statement table programming, and completes variable connection and screen editing in MCGS monitoring system. The PLC boiler level control system is completed by establishing the system mathematical model, designing the level control algorithm, and verifying the simulation. Through debugging, modifying parts of the parameters, the control effect of the control system achieve satisfied expectation.

*Keywords:* Automatic control, liquid level, PLC, MCGS

## 1. Introduction

Boiler as a kind of power energy equipment has been widely used since the 18th century. The main monitoring parameters of the boiler control system are liquid level, pressure and temperature, etc. For complex ones, it is also necessary to consider the air-to-coal ratio and water make-up capacity. These things have an important impact on boiler safety, stability and environmental protection. With the continuous development of intelligent control, the boiler liquid level control is becoming more and more perfect, but still faces the following two problems. 1) The control system is easy to diverge and oscillate. 2) The economy of the control system is very poor. The boiler liquid level control system designed in this paper adopts the PID control algorithm of Siemens S7-300PLC, and completes the variable connection and screen editing in the MCGS monitoring system. Through experimental verification, good results have been achieved.

## 2. Boiler Level Analysis

The control object of the boiler is a steam boiler, and its structure is similar to that of a single-capacity water tank in an ordinary boiler. The structural frame is shown in Fig. 1.

As shown in Fig 1, the input variable of this object is water supply, and the control variable is liquid level.



Fig.1. The composition of the single tank object

According to the material balance, the following relationship exists between input variables and control variables ( $\frac{dV}{dt}=q_i - q_o$ ). Since  $V=A \cdot H$  gets  $A \frac{dh}{dt}=q_i - q_o$ . Since the outlet flow can be approximately expressed as

$q = \frac{h}{R}$  gets  $A \frac{dh}{dt} = q_i - \frac{h}{R}$ . The overall input and output model is Formula 1.

$$T \frac{dh}{dt} + h = Kq_i \quad (T=AR, K=R) \quad (1)$$

Where  $h = h_0 + \Delta h$ ,  $q_i = q_{i0} + \Delta q_i$ . ( $h_0, q_{i0}$  is the value of the balance state). Because of  $h_0 = 0$ . The input and output model of data changes is shown in formula 2.

$$T \frac{d\Delta h}{dt} + \Delta h = K\Delta q_i \quad (2)$$

In the control system, we often adopt the latter, and do not use special letters to indicate this amount of change. The result of Laplace transform<sup>1</sup> on the above formula is as formula 3.

$$TsH(s) + H(s) = KQ_i(s) \quad (3)$$

This transfer function itself is the transfer function of a step object. If an object input function is equal to the magnitude of the amplitude value and the function is the transfer step object input equal to a, then the transfer step input response of the step object is  $Q_i(s) = \frac{a}{s}$ . The step response function formula of a single tank is formula 4.

$$h(t) = L^{-1} \left[ \frac{K}{s(Ts+1)} \right] = L^{-1} \left[ \frac{Ka}{s} - \frac{KaT}{Ts+1} \right] = Ka \times L^{-1} \left[ \frac{1}{s} - \frac{T}{Ts+1} \right] = Ka(1 - e^{-\frac{t}{T}}) \quad (4)$$

The step response of a single tank is shown in Fig. 2.

The response curve of the boiler liquid level during water supply is shown in Fig. 3.

If it is a simple water tank, we add water to the water

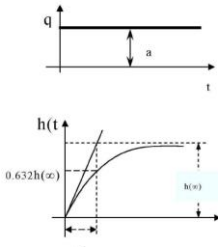


Fig.2.Step response of single tank

tank. If the water supply is constant, the water level should rise linearly with a certain slope, as shown in

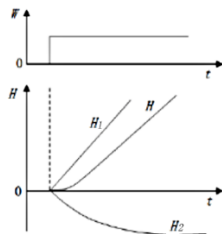


Fig.3.Variation curve of boiler drum liquid level during water supply

Figure H1. However, the boiler is a heating system. When water enters the steam drum, the liquid level of the boiler will be lowered. When the water vapor encounters condensation, the density of the water increases as the temperature drops. We use pressure sensors, and the actual height of the high-density liquid level will be smaller than predicted. That is, the condensed water is H2, and then after superimposing it with H1, the actual liquid level value is obtained as shown in Figure H. Based on the above analysis, the water level cannot rise in a straight line with a constant slope, and there must be a certain lag. It is equivalent to a combination of an integral link and a delay link in the system. The transfer function is as formula 5.

$$\frac{H(s)}{W(s)} = \frac{k_0}{s} e^{-s\tau} \quad (5)$$

Where  $k_0$  represents the frequency and change speed of the water level when the feedwater flow under a certain amount changes as a unit;  $\tau$  represents the delay.

### 3. PID Control

Through the analysis of the above characteristics, we use PID algorithm to achieve precise level control. For this reason, we choose PLC in the controller. Compared with a single chip, PLC adopts a modular design<sup>4</sup>, which can greatly reduce external wiring, make it more convenient and quicker to use, and have higher control accuracy.

#### 3.1. PID

PID can also be said to be a control algorithm based on closed-loop proportional, integral, and derivative. The control system continuously compares the set value with the actual process variable, and adjusts the control variable through the PID algorithm<sup>1</sup>. This control variable can adjust the process variable. Makes the set value and the process variable continuously reduce until it is 0. The control quantity is constantly updated, and the PID algorithm formula is used to determine the control quantity at the next moment. Its basic formula can be expressed as formula 6.

$$M_n = K_c * e_n + K_i * e_n + M_x + K_D * (e_n - e_{n-1}) \quad (6)$$

Where  $K_c$  is the proportional gain coefficient, which is multiplied by  $e_n$  to obtain the proportional control value.  $e_n$  is the deviation at the nth time of PLC sampling,  $e_{n-1}$  is the deviation at the n-1th time of PLC sampling;  $K_i$  is the integral term coefficient ;  $K_D$  is the coefficient of the

differential term;  $M_x$  is the value before the integration;  $M_n$  is the calculated value at the nth time of the PID.

$$e_n = (sp_n - pv_n) \tag{7}$$

$$K_i = K_c * T_s / T_i * (sp_n - pv_n) \tag{8}$$

$$K_D = K_c * T_D / T_s * (PV_{n-1} - pv_n) \tag{9}$$

Where  $sp_n$  represents the system given value at the nth time;  $pv_n$  represents the process variable at the nth sampling time;  $PV_{n-1}$  represents the process variable at the n-1 th sampling time;  $T_s$  represents the sampling time interval;  $T_i$  represents the integration time;  $T_D$  Represents the derivative time.

There are three PID adjustment modules in Siemens PID module, and different function blocks correspond to different scenarios. The function blocks FB41 "CONT\_C", FB42 "CONT\_S" and FB43 "PULSEGEN" correspond to different functions, we need to choose according to actual needs. In this research, what we need is a positional PID, so we use the FB41 function block.

### 3.2. Control system algorithm

The position-based PID adjustment adopted by the FB41 "CONT\_C" module, and its PID control algorithm structure<sup>5</sup> is shown in Fig. 4.

CYCLE:TIME:PID sampling period, generally set to 200MS; SPINT:REAL:PID set value;

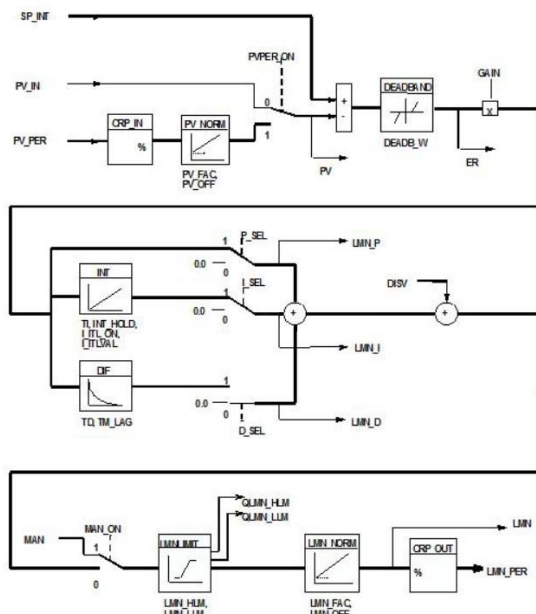


Fig.4.PID Function Block

PVIN: REAL: PID feedback value (also called process variable);

PV\_PER:WORD: Unnormalized feedback value, valid by PEPER-ON selection; (not recommended) MAN: REAL: manual value, valid by MAN-ON selection: GAIN: REAL: proportional gain; TI: TIME: integral time ; TD:TIME: differential time;

TM LAG: TIME: I don't know. I haven't used it. It is related to differentiation:

DEADBW: REAL: Dead zone width: If the output oscillates with a slight amplitude near the balance point, you can consider using the dead zone to reduce sensitivity

### 3.3. MCGS

MCGS<sup>5</sup> configuration software is composed of several important parts, and their positions are different, and their functions are also different. The specific process is as follows: (1) User window: Set the performance of other windows. (2) Main control window: Here you can configure the simulation screen and the parameter adjustment screen, which can define the parameters and reflect the process quantity in real time. (3) Equipment components: Here we build a channel to connect the real-time data converted from A/D and D/A in the monitoring system to the channel correspondingly. We read and write the real-time data in SF41 through the main control window, and display the set volume, process volume, manual volume, etc. in the corresponding read and write mode. The manual and automatic buttons are in the form of a combination of two labels, and the two buttons are reversed according to the button action to realize automatic conversion when pressed. The main control screen is shown in Fig. 5.

The parameter adjustment screen is shown in Fig. 6.

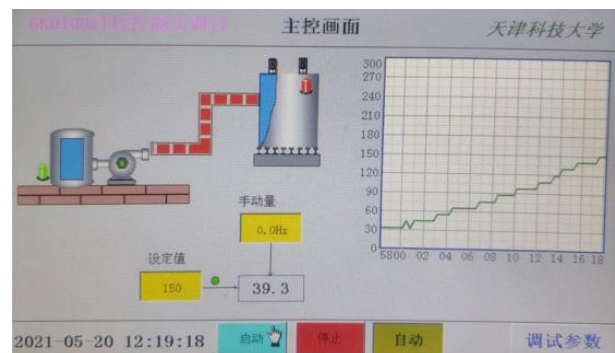


Fig. 5.Main control screen

The functions of the control system are as follows: Input

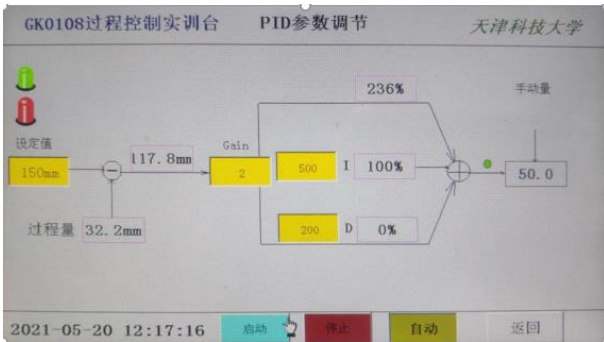


Fig.6.System parameter interface

the set value of the boiler, and the system will control the inverter according to the set value, and then control the liquid level. From Fig.4, we can clearly observe the boiler liquid level change. When the water level value of the water storage boiler is lower than the lower limit, the lower limit alarm light will light up and the motor will automatically stop. It can be seen from Fig.5 that when the liquid level reaches the set value, the total control quantity, namely the frequency of the inverter, will gradually decrease until it reaches zero. When the liquid level reaches the set value, the water level will be slightly higher than the set value due to the water in the pipe, but the liquid level will still be sent out. Therefore, the liquid level will drop. When the liquid level is lower than the set value, the PLC detects that the liquid level is too low. Then start the motor to feed water again, so that the boiler liquid level reaches a dynamic equilibrium.

**4. Equations**

The thesis introduces the research and theories of liquid level control technology based on Siemens, and focuses on the calculation algorithms and basic theories of various systems and functional blocks in the liquid level control software. Through software programming, hardware connection, sensors, frequency converters and motors, a complete set of liquid level monitoring system is combined. This paper can provide a certain theoretical basis for actual industrial production.

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