International Journal of Hybrid Information Technology
Vol. 9, No.7 (2016), pp. 51-60
http://dx.doi.org/10.14257/ijhit.2016.9.7.06

# Research and Design of Automatic Control System of Hot Water Boiler Based On PLC

Xu Hui-jun

*Electrical and Information College,Northeast Agricultural University，Harbin, 150030, China*
*105718776@qq.com*

***Abstract***

*In this paper, there are three scheme of PLC+ PC control program have been put forward for l0T/h hot water boiler. The multi variable, nonlinear, uncertain complex process automatic control is realized, and the thermal efficiency of the hot water boiler is improved. Each boiler in the system is controlled by the respective PLC, the public part is controlled by a set of PLC, an industrial control computer as an engineer station, an industrial control computer as an operator station, field bus Profibus-DP network was comprised by Industrial control computer, PLC. Fameview software was designed to achieve the redundant control of the upper monitor of the two boiler.*

***Keywords****: hot water boiler, PLC, Fameview, Profibus-DP*

## 1. Introduction

The number of boilers and the number of manufacturers in our country are the first in the world [1]. Boiler is an important part of the power equipment of all kinds of industrial enterprises [2]. This needs to change in the boiler control technology, and need to design a new type of hot water boiler control system that is cost-effective, easy to use and maintenance [3-4]. Therefore, the automatic control of hot water boiler improves the safety, reliability and economy of the boiler operation.

With the increasing of network communication function, the interconnection of the PLC and the PLC and computer, can form a large scale control systems, in the hanging online universal computer, online configuration, programming and downloading, online monitor the whole production process, which already has a form of distributed control system (DCS), consider price and reliability advantages of PLC, so that it can compete with traditional DCS control system[5-6]. In summary, with the decline in the cost of PLC and the increase of the performance, the general PLC+PC has been able to meet the requirements of small boiler control, and cost-effective.

## 2. The Totality Analysis of the Hot Water Boiler Control System

### 2.1. Control Task

The function of the hot water boiler is to produce hot water with a certain pressure and temperature parameter, which can meet the demand of the external load[7]. In order to meet the requirements, and ensure the safety and economic operation of the boiler body, the control system of the boiler is required to have the functions of automatic detection, automatic program control, and automatic protection and so on[8]. To this end, the main control task of the boiler is:

1. To keep the water level of boiler drum in the range of regulation and the stability of the water supply;

ISSN: 1738-9968 IJHIT

2. Keep the furnace negative pressure within the specified range;
3. Stable hot water temperature and pressure;
4. Maintain the economy of combustion and the safe operation of the boiler.

Completion of the above tasks need to monitor the four regulation: water supply, blast volume, air volume, fuel. The four main Regulated quantity: pot water level, furnace negative pressure, outlet water temperature, outlet water pressure. These regulating amount and the amount of adjustment are actually interrelated and mutually restricted, so it is difficult to determine the size of a single quantity. In practical operation, the solution is to set up a few relatively independent regulation system to simplify the adjustment process. In the medium and small sized hot water boiler, as long as doing some adjustment to two relatively independent regulating objects can basically meet the basic requirements of the general user, that is, the water process control and combustion process control.

### 2.1.1. Automatic Control of Water Supply for Hot Water Boiler

The basic task of the water supply of hot water boiler is to control the water quantity under various load conditions, to make the amount of the water supply and hot water sent to maintain a balance[9]. The high or low water level has great influence on the safe operation of the boiler and the production process. Too high level may lead to Full water accident, when the water level is too low, it will destroy the water cycle, and burned some heating surface, even seriously, will cause explosion, so how to maintain the stability of the boiler water level is very necessary, which can also see the necessity of water control[10].

This system is used for heating, so water is composed of two parts: return water of a heat supply network and replenishment of water, so water supply control also includes two parts:

1. Circulating pump control

Boiler pipe network system regulate the water flow by changing different circulating pump start and stop, the circulation pump system is composed by 3 sets of circulation pump. It is mainly responsible for the heating return water recovery to the boiler, circulating pump by the soft starter control the start and stop[11].

2. Replenishment pump control

By changing the speed of the water supply pump, the water level in the boiler pipe network system can be kept within a certain range. The control mode of the combination of deviation control and PID control is adopted to adjust the water supply. Deviation control set backwater pressure range, when backwater pressure actual value not in the set range, increase or decrease the replenishment pump operation units, until the backwater pressure meet the requirements so far. PID control on the basis of deviation control on the return pressure to fine tune. Replenishment pump system according to the real-time data of the backwater pressure set value with the acquisition of backwater pressure, through the PID algorithm will return water pressure control value near the setting value, so as to determine the make-up water pump speed, to change the return water pressure. The improved PID control algorithm and parameter tuning method are adopted in the control.

### 2.1.2. Automatic Control of Combustion Process of Hot Water Boiler

According to the combustion theory, the fuel burning in the furnace and heat in the hot air can be roughly divided into 6 parts, that is:

$$Q_{in}=q_1+q_2+q_3+q_4+q_5+q_6$$

In the formula $Q_{in}$—Total heat of the furnace;

$q_1$— The heat absorbed by the working medium;

$q_2$—Heat loss in exhaust gas;

$q_3$—Gas incomplete combustion heat loss;

$q_4$—Solid incomplete combustion heat loss;

$q_5$—Heat loss of furnace body;

$q_6$—Physical heat loss of ash.

 

The q2, q3 and q4 are the main parts of various heat losses, and they are changed with the change of excess air coefficient α. Its relationship is shown in Figure 1. There are one of the best α 0 existed Combustion process, in which a value near the fuel can be fully combusted, the heat loss is the minimum, said is the best combustion zone; less than this value, chemical incomplete combustion and mechanical loss of incomplete combustion began to increase, said for the insufficient air area; greater than this value, although the fuel is burned completely, but because the air flow too much, resulting in lower temperature, exhaust gas loss increase, reduce efficiency, said air high excess region.

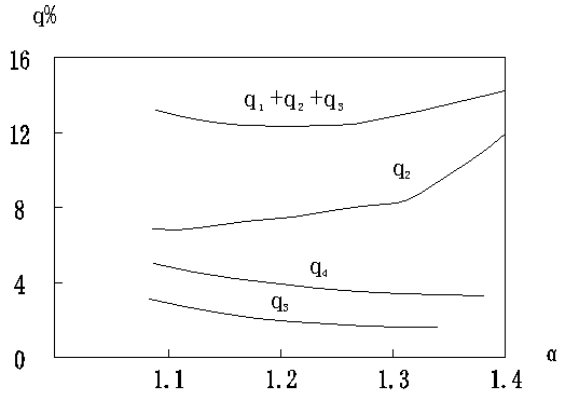


**Figure 1. Relationship between Heat Loss Andα**

As shown in Figure 2, when the load is low, fuel quantity and air quantity became very small, the momentum flow reduced (for an oil fired boiler, oil atomization variation), the fuel and air mixing is not good, caused by incomplete combustion, so the low load is to improve the excess air ratio. So the simple ratio control does not guarantee the best combustion state in any case[12]. To this end, it is necessary to add the "air fuel ratio" correction function to achieve the optimal control.

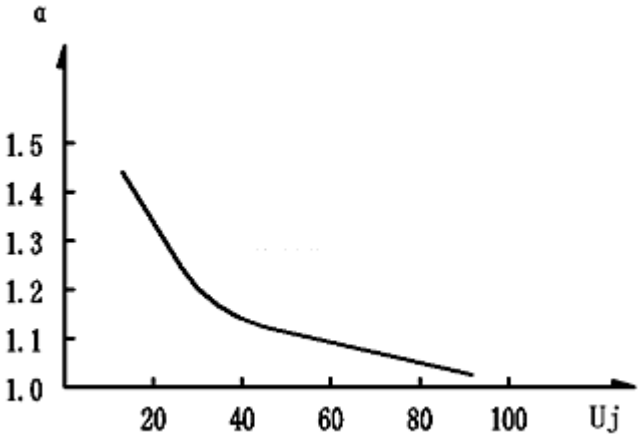


**Figure 2. Relationship between Excess Air Coefficient and Load**

The combustion control of the boiler is directly related to whether the pollution to the environment, whether the energy saving and whether it can bring benefits to the enterprise. Therefore, the boiler combustion control automation was paid much attention for many years. When the boiler load changes, all the changes will be changed, and when any adjustment, it will also affect the other adjusted amount. The combustion process control is mainly to meet the needs of the load, and to ensure the safety of the combustion of the economy and the

 

boiler operation, and therefore often use the three circuit, six parameters of the adjustment method.

## 3. System Hardware Design

### 3.1. Control Task

This system uses Advantech IPC and PLC (S7-300 PLC) of the upper and lower computer control structure. Among them, PLC is responsible for the control and analog signal acquisition and adjustment of the hardware switch I/O, and the global data communication is carried out by Profibus -DP. Industrial control machine is used to modify the parameters and set, manual / semi-automatic / automatic control, online monitoring, data storage and query, *etc*. The industrial control machine is connected with PLC through Profibus -DP to communicate with each other. The overall structure of the system is shown in Figure 3:

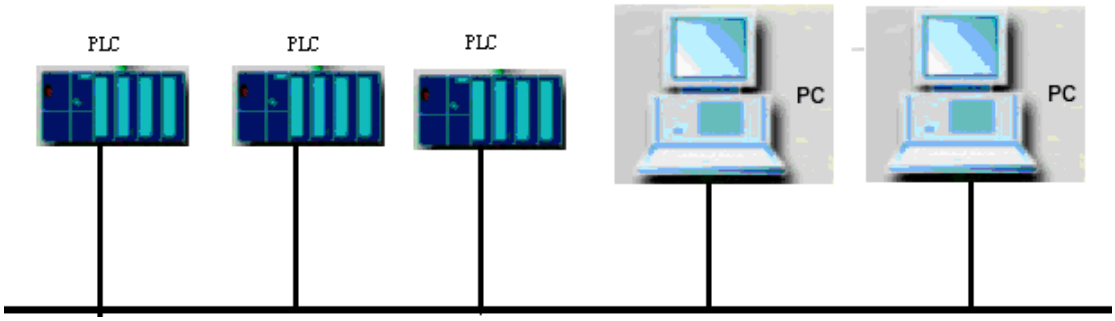


**Figure 3.System General Structure**

### 3.2. Input and Output Hardware Design

According to the system analysis, the project designs the hardware connection of digital input, digital output, thermocouple input, thermal resistance input, 4-20mA current input and 4-20mA current output.

#### 3.2.1. Digital Input

The digital input consists primarily of grate, blower, induced draft fan, circulating pump, dust and slag dragging machine automatic hand signal, fault signal, the running signal. The use of digital input module SM321DI16*24VDC, the specific wiring as shown in Figure 4.

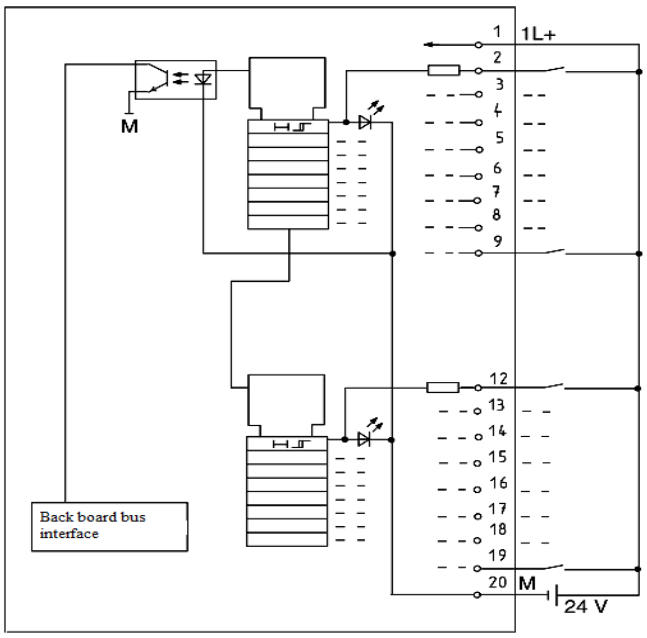


**Figure 4. SM321DI16*24VDC Terminal Wiring Diagram of Digital Quantity Input Module**

### 3.2.2. Digital Output

Digital output includes grate, blower, induced draft fan, circulating pump, dust collector, fishing slag machine and return the parent tube discharge pressure control *etc*. Using digital output module SM322DO16*24VDC/0.5A.

### 3.2.3. Thermocouple Input

Thermocouple Input mainly includes the furnace exit temperature, convection tube bundle inlet flue gas temperature and the temperature of the flue gas outlet. Using analog input module 331AI SM 8 x TC, the specific wiring as shown in Figure 5.

### 3.2.4. Thermal Resistance Input

Thermal resistance input mainly include smoke temperature, dust exit smoke temperature, outlet temperature, inlet water temperature and room temperature, *etc*. Using analog input module 331AI SM 8 * RTD.

### 3.2.5. 4-20mA Current Input

4-20mA current input mainly includes the pressure (second line), flow, oxygen content, current, voltage, motor speed, *etc*. Using analog input module 331AI8 SM * 12 bit.

### 3.2.6. 4-20mA Current Output

4-20mA current output includes grate, blower and a draught fan speed regulator output. Using analog output module SM 332 AO 4 x 16.

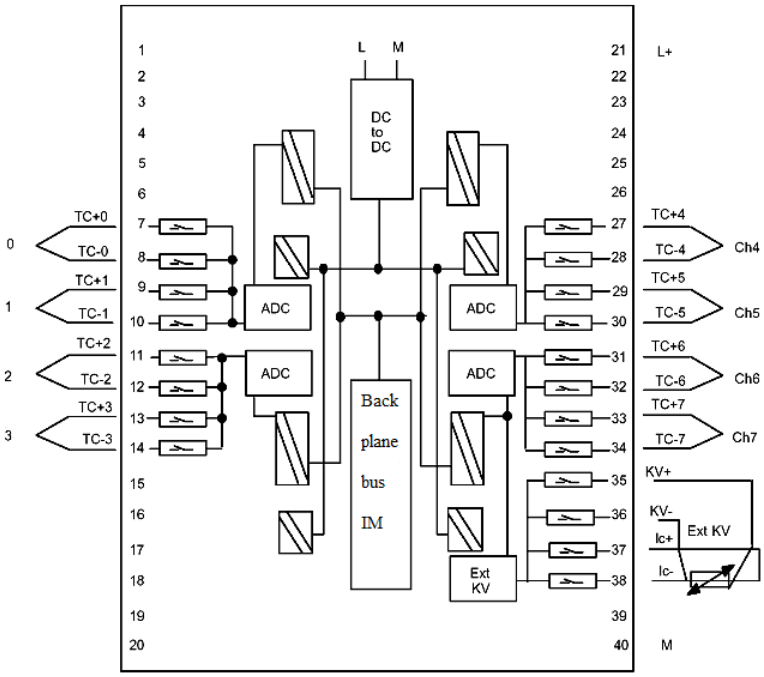


**Figure 5. Sm 331ai 8 × TC Terminal Wiring Diagram of Analog Input Module**

### 3.3. System Power Supply and Grounding

All the control loop of the system adopts the unified power supply line, supplying power to the boiler control system, by separate power through 5000vA line ups, without any power equipment. And other electrical appliances, in the control room, such as lighting system, air conditioning, *etc*. are not connected to the power supply system.

The grounding of the system has been an important part of the system design, and the correct grounding is the key to the successful operation of the control system. The purpose of the control system grounding is to improve the performance of the system in order to secure and restrain the interference. The system is set up in two categories: security ground and shielding ground.

## 4. System Software Design

### 4.1. PLC Software Design

#### 4.1.1. Feed Water Control

The water used by the system are mainly two sources, for the one hand from the heat recovery, through the circulating pump sent to the copper pot and other aspects directly through the replenishment pump according to supply water to the system requirements. According to the control principle of deviation control and PID control, the PID control function of frequency converter is realized. Block diagram as shown in Figure 6

 

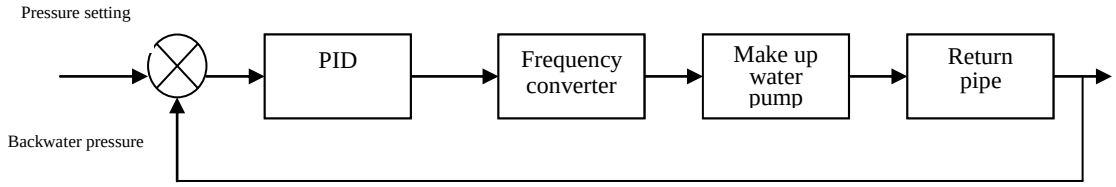


**Figure 6. Feed Water Control**

#### 4.1.2. Combustion Control

The basic task of the automatic control of the boiler combustion process is to make the fuel burn to meet the needs of the load, and to ensure the safety and economic operation of the boiler. Combustion control system is mainly stabilize the boiler water temperature, always keep it near the setting value; ensure the economy of the boiler combustion process; regulation of blast volume and air guide, furnace pressure to keep within a certain pressure range.

#### 4.1.3. Interlock Control

In boiler control, in order to ensure the safe operation of the boiler, when the event of a failure, there must be an immediate alarm and related protection, and trigger the associated equipment to achieve automatic chain.

### 4.2. Fameview Design

#### 4.2.1. Fameview Project Design

Using FameView to make master screen "hot water boiler automatic control system", screen can display the real-time data of the boiler operation: indoor temperature, furnace negative pressure and temperature at the exit of furnace, water supply valve opening *etc*., dynamic display of induced draft fan, a fire grate, a circulating water pump and control the running state of the fan, a fire grate, *etc*. the object. The key parameters of the system can also be set in the parameter setting screen.

Fameview can also be used to produce historical curve, the curve function can be used to observe some important variables of real-time changes, such as export water temperature, furnace negative pressure, oxygen content, *etc*..

### 4.3. System Communication

In the automatic control system of the hot water boiler, a Profibus-DP network is formed by the Profibus-DP field bus, in which the Profibus-DP field bus control system is composed of the following.

1. First class master station

This system uses three PLC as the first class master station, The PLC of the system is the SIEMENS S7 series S7-300 model, CPU313-2DP of S7-300 has this integration of the built-in Profibus-DP interface. So it can be directly connected to the Profibus-DP field bus. If the interface is not available, it can also be configured Profibus-DP communication processor module, such as CP342-5 communication processor can also be connected to the S7-300 Profibus-DP as the master station

2. Second class master station

The second class master station are used to complete the system configuration, parameter setting, programming, on-line detection, data acquisition and storage. In this system, there are two Advantech IPC, via PROFIBUS DP network card CP5611 A2 on the

 

other hand and PROFIBUS DP field bus is connected, the network card with PROFIBUS DP interface. One of the two industrial control computer PC is installed STEP7 software for software programming, another is installed Fameview software for monitoring, operation.

3. Passive station

The distributed I/O with Profibus-DP interface, sensor, driver and PLC can be used as passive station, which must meet the needs of the field equipment to control when selecting from the station. Of course, the interface between the station and the bus should be considered. If the station does not have a Profibus-DP interface, it can be considered to use the distributed I/O to device. In this system, as a sensor, frequency converter, *etc*.

## 5. System Debugging and Running

After four steps, the system is power off, the system is electrified, the system is electrified, and the system is debugged. Control system can be officially put into operation. Parameters such as inlet temperature, water temperature difference, coal consumption, exhaust temperature and circulation water are all counted, parameters are in the optimum range of combustion. Table 1 is the automatic control and manual operation of the main parameters of statistical average.

**Table 1. Main Parameters**

| Parameters | Manual operation（average） | Automatic control（average） |
|---|---|---|
| water outlet temperature（℃） | 95 | 90 |
| water inlet temperature（℃） | 64 | 57 |
| coal consumption（Kg/h） | 1437 | 1252 |
| exhaust temperature（℃） | 155 | 123 |
| circulation water（T/h） | 133.3 | 117 |

Statistics from the boiler operation shows that since the hot water boiler control system designed in this paper has been put into operation, the total coal saving ratio of the boiler is about 12.9%. Calculating the boiler coal efficiency as follows: a hot water for the 10T/h of the boiler manual operation needs coal-fired 30T per day, assuming a boiler under normal circumstances, the average annual input production time is 180 days. Considering the price of coal is about 400 yuan /T calculated two boilers benefit annual coal is 30T * 180 days * 400 * 0.129 * 2=55.728 million yuan.

## 6. Concluding Remarks

Hot water boiler control system has a lot of advantages, such as, the perfect function, advanced and reasonable structure, low energy consumption, flexible expansion, easy to maintain, and the reliability is high, not only can improve the level of industrial automation, the maximum improve production efficiency, also can be the operation, management and other production activities contact together, gradually realize plant management and control integration, achieve production flexibility and adaptability. Through the practice of this project, it is proved that this kind of form in the control of medium and small sized hot water boiler is completely feasible, and it is very useful for many domestic small and medium sized boiler control system.

 

## References

[1] Y. Guo, "Boiler Control System Based on Profibus-DP Network", International Mechatronics Technology, vol. 3, no. 23, **(2016)**, pp. 26 ~ 27.
[2] J. Hu, "SIEMENS S7-300PLC Application Tutorial", China Machine Press, **(2007)**, pp. 23 ~ 49.
[3] Jiekong, "Technology Co., Ltd. Fameview User Manual", Jiekong Technology Co., Ltd press, **(2007)**, pp. 1 ~ 520.
[4] K. Liu, "Head First SIEMENS S7-300PLC", Beijin University Press, **(2007)**, pp. 25 ~ 30.
[5] F. Liu, "Status Quo and Existing Problems of Boiler in China", Journal of Beijing Institute of Planning Labour Administration, vol. 13, no. 3, **(2005)**, pp. 42 ~ 45.
[6] X. Mei and Z. Yang, "The Application of Frequency Converter in The Control System of The Mixed Gas Heating Boiler", vol. 06, no. 2, **(2006)**, pp. 106 ~ 109.
[7] Y. Yang, "The Development Trend of PID Parameter Tuning", Journal of Jiaozuo Institute of Technology, vol. 16, no. 5, **(1999)**, pp. 369 ~ 371.
[8] K. Zhang, "Rapid Quantitative Evaluation of Boiler Operation Economy", Shaanxi Electric Power, vol. 34, no. 3, **(2006)**, pp. 25 ~ 26.
[9] S. Zhang, "The Theory and Application of Modern Programmable Logic Controller", Science Press, **(2006)**, pp. 17 ~ 18.
[10] F. Fang,J. Liu and W. Tan, "Nonlinear inversion-based output tracking control of a boiler-turbine unit", Control Theory and Applications, vol. 12, no. 5, **(2005)**, pp. 390 ~ 393.
[11] Kotka, "Neural network for Prediction of superheater fireside corrosion in atmospheric fluidized hed eomhustion", vol. 10, no. 5, **(1998)**, pp. 114 ~ 153.
[12] X. Liu, J. Liu and P. Guan, "Neuro-fuzzy generalized predictive control of boiler steam temperature", Control Theory and Applications, vol. 5, no. 1, **(2007)**, pp. 83 ~ 88.

 

 