Automatic Control System of Waste Heat Power Generation

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Abstract – *China is a large country of cement production and consumption, which produces a large amount of environmental pollution and energy consumption in the production process, which runs counter to the economic development goal of low energy consumption and heavy environmental protection in our country. Cement production generates more than 35% of the thermal energy lost, and if that part of the energy is recycled, it will effectively change the situation. In this paper, the status and mechanism of waste heat power generation are analyzed. Taking waste heat recovery and utilization in the new dry process cement production as the research object, the design and construction of the automatic control system for waste heat power generation are discussed. The measured results show that the system of automatic control effect is good.*

Keywords – automatic control system, cement production, DCS, waste heat power generation.

1. INTRODUCTION

The "green idea" is to realize the transformation of energy-saving, high-efficiency and low-pollution in social life and production. Waste heat power generation is a rapidly developing green energy-saving technology in recent years. It converts productive heat, such as exhaust gas and liquid waste, so as to realize the recycling of wastes and reduce the pollution and energy consumption of waste discharge. At present, the majority of residual heat power generation is still under manual control, which limits its efficiency and effectiveness. Therefore, research on the automatic control system of waste heat power generation has become an important content in this field.

2. WASTE HEAT POWER GENERATION

Waste heat power generation system uses cement rotary kiln to produce flue gas waste heat, and then based on the principle of heat exchange to boil the water within the boiler vaporization. The generated hot steam drives the steam turbine to rotate, and the steam turbine rotates to allow the generator to process the power generation state.This power generation method needs to set up two waste heat boilers. One was placed on the kiln head and the other on the kiln tail. A boiler placed between the last stage of the inorganic preheater and the main kiln exhaust fan is called a SP boiler and a boiler between the electrostatic precipitator and the kiln exhaust fan is called AQC boiler. We also provide a steam turbine. The whole waste heat power generation system generally includes condensing tower, deaerator, wind power equipment, dust removal equipment and so on. Dust removal equipment and wind power equipment belong to the common equipment of waste heat power generation system and cement production line. The electricity generated by the cement waste heat power generation system is mainly supplied to the cement plant for its own production and consumption. So far, the more used power generation technology is the double-pressured steam-turbine waste heat power generation thermal power system. It uses two pressure steam turbines to enter the two temperatures and two kinds of pressure steam to do work. One is a main steam with 320℃, 1.6MPa, and the other is a make-up steam with 155℃, 0.35MPa. Kiln clinker cooler exhaust gas temperature is 400℃, the reverse heat exchange is carried out through the AQC boiler, and the flue gas temperature of the AQC boiler is 90℃, which is discharged after the electric dust removal. The exhaust gas temperature at the kiln tail is 350 ℃, and the upward heat is reversely exchanged by the SP boiler. The main steam with high pressure and temperature and the main steam in the AQC boiler are mixed in the medium-pressure gas collecting cylinder and then enter the steam turbine. SP boiler exhaust gas must meet the raw material drying temperature, which is the cement production process needs. After doing work, the exhausted steam enters the condenser and condenses into water, then enters the vacuum deaerator, which is sent to the economizer for heating after deoxidation. After reaching saturation, it enters the AQC boiler high pressure, low pressure gas bag and SP boiler high pressure gas bag [2].

2.1 The Characteristic Analysis of Boiler Drum Water Level

There are two main factors of boiler drum water level. They are internal disturbance and external disturbance respectively. It is caused by the material imbalance relationship and the heat balance relationship of the drum water level. The dynamic equation is as follows.

$$A_1 A_2 \frac{D^2H}{DA^2} + A_1 \frac{DH}{DT} = \qquad (1)$$

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$$\left(A_W\frac{DU_W}{DT}+K_WU_W\right)-(T_D\frac{DU_D}{DT}+K_DU_D)$$

In the formula:

H = Change of drum water level and water level ratio in steady state;

A = Time constant;

A_W、K_W、T_D、K_D = Time constant and amplification factor of feedwater flow term and steam flow term;

U_W = The ratio of the change of water supply to the maximum steam load, which is usually expressed in formula 2.

$$U_W=\frac{\Delta W}{D_{MAX}} \tag{2}$$

U_D = is is the ratio of steam volume change to maximum steam load, which is expressed by the formula 3.

$$U_D=\frac{\Delta D}{D_{MAX}} \tag{3}$$

If the boiler steam flow is in a stable state, we only consider the external disturbance factors in the study, and the differential equation of the drum water level is as follows.

$$A_1A_2\frac{D^2H}{DA^2}+A_1\frac{DH}{DT}=\left(A_W\frac{DU_W}{DT}+K_WU_W\right) \tag{4}$$

The transfer function can be obtained by differential equation change, as shown in Equation 5.

$$G_1(S)=\frac{H(S)}{U_D(S)}=\frac{K_1}{S(1+A_2s)}-\frac{\varepsilon}{S} \tag{5}$$

Among them, H = water level; U_D= Evaporation volume $\varepsilon=1/A_a$= Reaction speed.

When the steam load suddenly increases, the volume of steam in the steam water mixture increases rapidly, so that the water level will not drop, but it will begin to rise rapidly and then decline after a period of time, that is the phenomenon of false water level. The reasons for this phenomenon are as follows: The first one is that the sudden increase of steam load makes the proportion of water and steam change in the mixture of steam and water, which is the main reason. The second one is the reduction of drum pressure, so that the boiling point of saturated water vaporization decreases and the water level rises, which is the secondary reason. The influence of false water level is also a difficult point for water level control.

2.1 Research on Boiler Drum Water Level Control

The control of drum water level is related to water supply control, steam pressure control and so on. The change process of drum water level under external disturbance is related to steam flow, feedwater flow, feedwater temperature and steam pressure. The control of drum water level has always been a difficult point in boiler control. The existing mature drum water level control methods are single impulse, double impulse and three impulse water level control. At present, the traditional three impulse water level control is the main control strategy for the water level control of the HRSG.

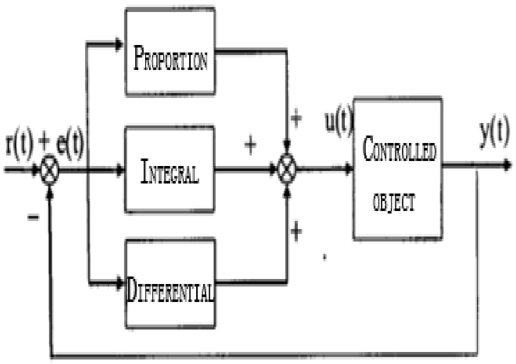

Fig. 1. Schematic diagram of conventional PID control system.

3. DESIGN OF AUTOMATIC CONTROL SYSTEM FOR WASTE HEAT POWER GENERATION

3.1 Algorithm Research of Automatic Control System for Waste Heat Power Generation

Generally speaking, the automatic control algorithm usually adopts the conventional PID control system, which can be divided into two parts, the control object and the controlled object. The specific system principle is shown in Figure 1.

The common formula is shown in formula 6:

$$U(T)=K_P[e(t)+1/T_1\int_0^1 e(t)dt+T_D\frac{de(t)}{dt}] \tag{6}$$

U(T)= Regulator output signal

e(t)= Deviation signal for given quantity and output quantity

K_P= Proportionality coefficient

T= Time constant

In the process of application, it is necessary to control the proportion of integral and differential. At the same time, the setting processing should be carried out for the core content of PID control system. At present, setting is mainly divided into two kinds, one is calculation setting, and the other is engineering setting. In this paper, the PID algorithm is used to calculate the parameters of boiler drum water level control module, and the relevant setting processing is carried out through the pretreatment of the parameters. The filtering processing is carried out by setting the sampling period, and the specific formula is as follows.

$$X_I = \frac{1}{5}\sum_{J=I=5}^{I-1} X_J \quad (7)$$

Among them, X_J = the implementation value of a parameter at a certain moment

The specific boiler drum water level situation is shown in the following table.

Table 1. The situation table of the boiler drum water level.

Influence factor: Feedwater flow	Influence factor: Steam flow	Boiler drum water level	Controller type
5.3 ~ 10.0	5.1 ~ 9.6	The feedwater steam flow is very stable	Conventional PID controller
<5.3 or >10.0	<5.1 or >9.6	Water quantity and steam load change greatly	Manual mode

3.2 The Core of Waste Heat Power Generation Automatic Control System

The focus of the waste heat power generation automatic control system includes four aspects. They are boiler drum level control, turbine protection control, condensate control and deaerator control. For the drum level, it is required to be able to rigorously monitor the drum level, steam flow and feedwater flow. Drum water level control is the main control parameter of these three variables. Once the drum water level exceeds the standard height, it will lead to water vapor separation and produce an effect on water vapor temperature which in turn causes wear on the blades of the steam turbine. Therefore, the design of the system should take three impulses water supply mediation, according to the main and secondary circuits in proportion to the distribution. Turbine is the core equipment of waste heat power generation, so we should ensure its protection and control. The main protection is the turbine speed protection which is used to ensure the turbine work at rated speed, the shutdown protection which turning gear runs immediately after the emergency stop, displacement protection which is used to control turbine axial displacement to avoid overrun, and finally, the turbine hydraulic pressure control. In the case of a water trap, it is mainly concerned with whether the water level of its hot water well is stable or not. Single-loop control can meet this requirement. Deaerator needs to control more parameters, including deaerator water level, temperature, pressure and the action of the mediation valve. The most critical is the reasonable control of the electric valve. PID reaches the purpose of control by setting the pressure value and intake air. In addition, all on-site controls are required to meet at least a 20% increase in volume to facilitate the upgrading and optimization of production processes.

3.3 Hardware and Software Design of Waste Heat Power Generation System

The DCS core of the waste heat power generation system has completed the distributed control of waste heat power generation. The system is mainly composed of engineer station, operator station, field control station and network system. They respectively install control builder F / industrial digiVIS / industrial DCS system for engineer station, operator station and on-site control station. The system uses AC800F redundant controller for all data acquisition, distribution and deployment. The controller contains an independent power supply and communication module, and set the communication redundancy interface to prevent linkage failures which are resulted by any one controller's damage. When configuring redundant interfaces, fast switching of fault controllers is possible, and meanwhile, the operator station displays the corresponding system alarm and locate the damaged controller. Redundant communication is achieved by profibus DP module. I / O modules carry a smart CPU to complete the input and output of the analog quantity and switching value. The application of field bus technology reasonably reduces the cost of intensive field wiring and can quickly diagnose bus faults through centralized arrangement. The number of I / O cards hanging under the controller in the field is related to the hardware support capability, which should be consistent with the actual situation on site and not more than 20% of the hardware support capacity. DCS control cabinet I / O measuring points need more than 1/5 of the standby evenly distributed and reserved for more than 1/5 of the expansion of space, and the control card or the end plate can be increased at any time according to the control needs [6]. In order to facilitate the study, the following is listed as Table 1. Table 2 is the part of the equipment list of AQC boiler and SP boiler [7].

The general steps of the software design of the automatic control system of waste heat are to establish the project tree to define and grade the resources of the system, configure hardware devices, including IP address setting, channel definition and so on, and configure the engineer's program, including task classification, execution cycle and so on [8]. The monitoring and adjusting tasks are programmed by FBF diagram, and the chain control is programmed by LD diagram. The configuration of the operator station is mainly the design of the load process for various picture layouts and parameters [9]. Finally, the system should be debugged to find out whether there are design flaws. The design and layout of the site control station is very critical, which affects the final operation effect of the system. Figure 2 is the processing schematic diagram of temperature and pressure analog quantity input of DCS control [10].

3.4 Testing and Analysis of Automatic Control System for Waste Heat Power Generation

In order to consider the practical effect of the system, after fully debugging the system, a new dry process cement production line is selected to carry out the experiment. During the test, the recording and display of the system parameters can be observed [11], [12]. Also we should try to switch the interface of each system to see whether it runs normally, whether the displayed parameters are abnormal and so on. According to the measured results, the interface of the AP and AQC boiler parameters runs normally, and the interface parameters of the circulating water system, oil circuit system and air and flue gas system are displayed accurately, and the collection and statistics of parameters can be realized. The overall operation effect is relatively stable, and there is no huge fluctuation.

Table 2. Equipment list (part) of AQC boiler.

Name	Type	Number
Profibus communication module	CI1801	2
RTD input module (channel number 8)	AI1830	2
Analog input module (channel number 8)	AI1810	6
TC input module (channel number 8)	AI1835	3
Digital input module (channel number 16)	DI1810	5
Digital output module (channel number16)	DO1810	1
Analog output module (channel number 8)	AO1810	1
Power supply module(24V/10A)	DY810	2

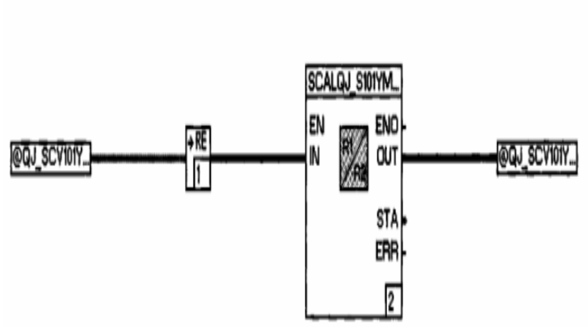

Fig. 2. Processing of analog quantity input of pressure and temperature.

Table 3. Equipment list (part) of SP boiler.

Name	Type	Number
Profibus communication module	CI1801	2
RTD input module (channel number8)	AI1830	2
Analog input module (channel number 8)	AI1810	4
TC input module(channel number 8)	AI1835	2
Digital input module (channel number 16)	DI1810	4
Digital output module (channel number16)	DO1810	2
Analog output module (channel number 8)	AO1810	1
Power supply module24V/10A	DY810	2

4. CONCLUSION

In summary, the waste heat power generation is a kind of energy saving and environmental protection technology with excellent performance, which is suitable for a number of production. The waste gas produced in the new dry process cement production can be recycled by using the waste heat power generation to improve the overall energy utilization rate and reduce the environmental pollution and excessive energy consumption in cement production. For the cement waste heat power generation technology, the improvement of the automatic control ability of power generation system is beneficial to optimize the power generation effect and improve the safety and stability of the production. The core of automatic control system of waste heat power generation is the design of DCS control system. The system is tested and analyzed, and it is found that the system has good performance and high stability. There are no obvious problems. However, the boiler itself has nonlinear variation characteristics in waste heat power generation. Considering the correlation of the parameters can further optimize the effect of the automatic control system.

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