Research and Analysis of 300MW Boiler Combustion System Based on Fuzzy Control

Liang Weiping[1],Zhang Jinshuai[1]

1. North China Electric Power University,Department of Automation ,Baoding 071003, China
E-mail:1759482682@qq.com

Abstract: The boiler combustion system is a complex controlled object. According to the industrial production process of the thermal power plant, the boiler combustion control system can be divided into three subsystems: the fuel control system, the air supply control system and the induced draft control system. For the control subsystem of air handling and induced draft, the traditional PID control can achieve satisfactory control effect. This paper does not elaborate, so it focuses on the research and analysis of the fuel control subsystem. Since the fuel control subsystem has large delay, large inertia and can not obtain its accurate model, the conventional PID control can not obtain the desired control effect, so the fuzzy adaptive PID control algorithm combining the conventional PID and fuzzy control theory is adopted. Finally, the system is simulated by Simulink in Matlab, and the simulation results show that the fuzzy adaptive PID not only has good dynamic characteristics, but also has good adaptability, and has received good control effect.

Key Words: Thermal Power Plant; Combustion Control System; Fuzzy Control; Simulink Simulation

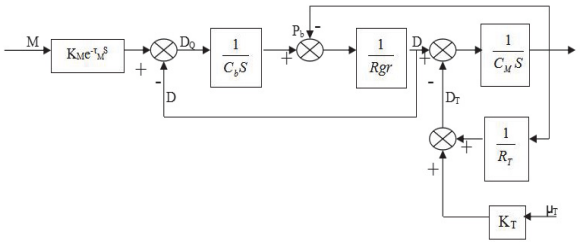
1 INTRODUCTION

Boiler combustion control system is an important component to ensure the safety and economic operation of thermal power plant. On the one hand, through the reasonable control of the boiler combustion system, the important operating parameters are stable in the safe range, which has a positive significance for the personal safety of the thermal power plant staff. On the other hand, it is an important measure to save energy and protect the environment by ensuring that the combustion process of boiler in thermal power plant is always in the optimal state. A coal-fired boiler as an example, suppose that the thermal efficiency is increased by 2%, expected annual power generation can Yuekeduo 3 * 107kw h, with the average price of 0.02 yuan /kw h, an annual additional profit of about 600 thousand yuan. Thus, reasonable analysis and design of boiler combustion system can improve combustion efficiency and make great significance for energy saving and emission reduction.

2 CHARACTERISTIC ANALYSIS OF BOILER COMBUSTION SYSTEM

2.1 The Mathematical Model of the Controlled Object of Main Steam Pressure

Firstly, the mathematical modeling of the controlled object is carried out through theoretical derivation and calculation, and then the qualitative analysis of the dynamic characteristics of the system is carried out, which has certain theoretical reference value and guiding significance for the design and Simulation of the control system. The block diagram of the main steam pressure controlled object is shown in Figure 1[1].



M—Coal feed amount， kg/s； K_M—Ratio coefficient of coal quantity M disturbance to calorific value Q change， kJ/kg； τ_M—The lag time of the coal supply M disturbance to the change of heat amount Q，s；Pb—Drum pressure，MPa；D—Steam flow，m3/s；D_T—Steam turbine consumption，m3/s；μ_T—Steam turbine intake valve opening， %； P_T—Steam turbine intake valve opening，MPa； Cb—Coefficient of thermal storage，kg/MPa； D_Q—Vapor volume absorption of steam water volume per unit time boiler，kg/s； Rgr—Dynamic resistance of superheater，cm2/s； CM—Capacity coefficient of steam pipe， kg/MPa； R_T—Dynamic flow resistance coefficient of steam turbine，MPa/kg·s-1； K_T—Static amplification factor of regulating valve，kg/s；

Figure 1. Block Diagram of Controlled Object of Main Steam Pressure

2.2 The Mathematical Model of the Controlled Object under the Internal Disturbance of the Main Steam Pressure

The quantity of coal M disturbed, turbine load unchanged (i.e. consumption D_T constant), the turbine is equipped with power frequency electric control system, no matter how the pressure of the steam consumption side changes remain unchanged, so the party will not be considered in the D_T diagram.

$$W_{P_T M}(s) = \frac{P_T(s)}{M(s)} = \frac{K_M}{s(R_{gr}C_bC_MS + C_b + C_M)} e^{-\tau_M s} \approx \frac{K_M}{C_b S} e^{-\tau_M s} \ (C_M \approx 0) \quad (1)$$

2.3 The Mathematical Model of the Controlled Object under the External Disturbance of the Main Steam Pressure

(1) Under the disturbance of the opening of the regulating gate of the steam turbine--μ_T

The transfer function of the main steam pressure P_T under the load disturbance is as follows:

$$W_{P_T\mu_T}(s) = \frac{P_T(s)}{\mu_T(s)} = -\frac{K_T(C_kR_{gr}S + R_T)}{R_{gr}R_TC_kC_MS^2 + C_MR_TS + C_kR_{gr}S + C_kR_TS + 1} \approx -\left(\frac{K_TR_{gr}R_T}{R_{gr}+R_T} + \frac{R_T}{R_{gr}+R_T}\frac{R_T}{C_kR_{gr}S+C_kR_TS+1}\right) \ (C_M \approx 0) \quad (2)$$

(2) Under the disturbance of intake volume of steam turbine--D_T

The transfer function of the main steam pressure P_T under the load disturbance is as follows:

$$W_{P_T\mu_T}(s) = \frac{P_T(s)}{D_T(s)} = -\frac{C_kR_{gr}S + 1}{R_{gr}C_kC_MS^2 + C_MS + C_kS} \approx -\left(R_{gr} + \frac{1}{C_kS}\right)(C \approx 0) \quad (3)$$

In summary, under the internal disturbance, the response of the main steam pressure to the fuel quantity perturbation is slow, and the self balancing ability is poor;under the external disturbance, the main steam pressure is fast response of turbine load disturbance, i.e. turbine load--the main steam pressure channel with small inertia, almost no delay.

3 FUZZY CONTROL

3.1 Advantages of Fuzzy Control

In recent years, fuzzy control theory has developed rapidly and has been widely used, mainly because of its advantages compared with conventional PID:

1.A precise mathematical model is not a necessary condition;

2. The fuzzy language is easy to understand and grasp for the field staff who are not very rich in theoretical experience;

3. The fuzzy control system has strong robustness.

3.2 The Basic Principle of Fuzzy Control

The basic idea of fuzzy control is to give the computer some fuzzy language and control rules, so that it has the human fuzzy thinking mode, so as to implement the relevant control strategy for different controlled objects. The block diagram of the principle of fuzzy control is shown in Figure 2, and the process of fuzzy control is approximately as follows:

1. Firstly, the amount of modulated information of the controlled object is obtained, and the information is usually clear. In order to apply these clear quantities to fuzzy control rules for fuzzy reasoning and decision making, it is necessary to convert the clear quantities of these inputs into fuzzy quantities, that is, the gelatinization process;

2. According to the fuzzy control rules which are transformed by the practical experience of technicians and experts, fuzzy inference and decision are made by combining the fuzzy quantity obtained in the last step, and then the fuzzy output is obtained;

3. Finally, the fuzzy output of the last step is converted to the exact quantity, that is, the solution gelatinization process, which can be sent to the actuator for control.

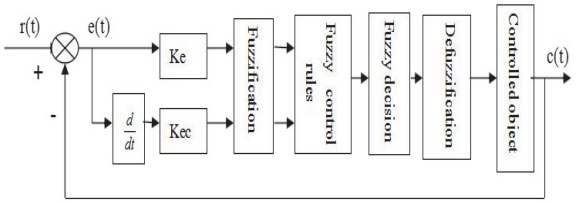


Figure 2. Schematic Diagram of Fuzzy Control

4 Design of Boiler Fuel System

The boiler combustion system is a complex controlled object with high parameters. It has large inertia and pure delay and can not get its accurate mathematical model. The conventional control strategy generally can not meet the control requirements. In view of this complex controlled object, the disadvantages of conventional PID control are very obvious. The PID control parameters tuning of a task is the workload is very large, and the boiler with different operating conditions, the parameters will be changed, so as to achieve the optimal control effect, the PID parameters will change with the conditions of re tuning, this is obviously unrealistic. Fuzzy adaptive PID controller can compensate for the shortcomings of the traditional PID parameter was fixed, the fuzzy adaptive PID controller according to the running condition of the system, the PID controller parameter revision online, in order to achieve the best tuning purposes. Fuzzy adaptive PID can improve the adaptive ability of the conventional PID controller. The fuel control system in this paper adopts fuzzy adaptive PID control[2~8], and the schematic diagram is shown in Figure 3.

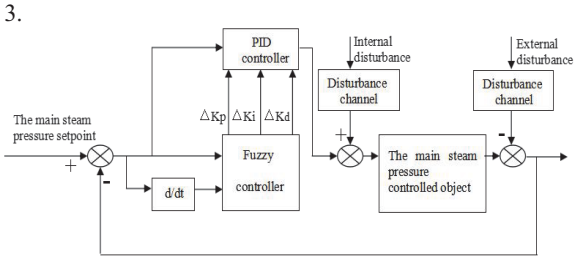


Figure 3. Schematic Diagram of Fuel Control System

4.1 The Structure of Fuzzy Controller

With the introduction of the previous article, this paper selects the most common two dimensional fuzzy controller with the input amount of deviation E and deviation EC, and the output amount of U.

4.2 Fuzzy Distribution of Input and Output Variables

1. fuzzy subset of input and output variables

Combined with the above introduced the fuzzy subset number, although it will make the control effect of a more detailed and accurate, but the control rules can be quite complex; fuzzy subset number is too small, the control effect is very rough, the compromise thought, Fuzzy subsets of this choice of language deviation E and deviation change rate variables EC and output Kp, Ki. Kd are:{NB，NM，NS，O，PS，PM，PB} The meaning of NB，NM，NS，O，PS，PM，PB is negative big, negative medium, negative small, zero, positive small, positive middle, and positive big.All of the domain of the fuzzy set is [-6，6].

2. Fuzzy distribution of fuzzy subsets

The distribution of fuzzy subset is essentially the determination of the shape of fuzzy subset membership function curve. The common membership function curves are Gauss shape, triangle and trapezium. The fuzzy subset of this paper is defined as a triangular membership function, because its shape is simple, easy to analyze, and the reaction is sensitive.

The membership function curve of the fuzzy control used in this paper is shown in Figure 4, and the membership function editor of Matlab can be easily obtained.

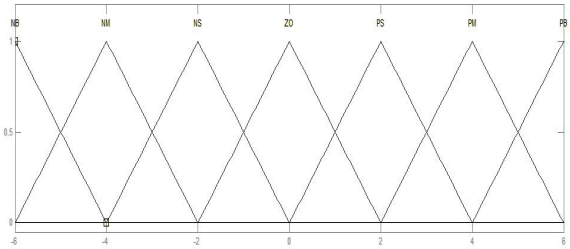


Figure 4. Triangle Membership Function

3. Establishment of quantification factor and scale factor

According to the formula of the scaling factor and the proportion factor in the front, the corresponding modification is made according to the simulation, and the final quantization factors are :Ke=0.35，Kec=60，the Scale factors are :Ku1=0.2，Ku2=0.0002，Ku3=20.

4.3 Establishment of Fuzzy Control Rules

The fuzzy control rule is a fuzzy language rule which is easily recognized by the computer, which is compiled from the theoretical knowledge and practical experience of professional technicians and experts. The computer has the ability of fuzzy reasoning and judgment similar to human beings, and realizes fuzzy control.

The proportional control is to multiplied the error input signal of the controller by a certain proportion as the output control signal of the controller. With the increase of the proportion coefficient, the rise rate of the step response curve of the system increases, and the steady-state error decreases. But the proportion over the general assembly makes the overshoot of the system too large, even causing oscillation and divergence. However, the proportion of the role of too small will enable the system reaction speed is very slow, so we need to choose appropriate proportion, according to the professional and technical personnel and experts experience can be compiled control rules for correction of △Kp, as shown in Table 1.

Table1. Control rule table of △Kp

△Kp E \ EC	NB	NM	NS	O	PS	PM	PB
NB	PB	PB	PM	PM	PS	O	O
NM	PB	PB	PM	PS	PS	O	NS
NS	PM	PM	PM	PS	O	NS	NS
O	PM	PM	PS	O	NS	NM	NM
PS	PS	PS	O	NS	NS	NM	NM
PM	PS	O	NS	NM	NM	NM	NB
PB	O	O	NM	NM	NM	NB	NB

The integral control function is that the output signal of the controller is proportional to the accumulated value of the deviation input signal with time, and its function is to eliminate the static error and improve the control precision of the system. With the increase of the integral action, the oscillation frequency increases and the dynamic deviation decreases. But the integral effect is too large, it will reduce the stability of the control system, make the system overshoot, or even cause oscillation. It should be careful to choose the integral coefficient, control rules correction △Ki as shown in Table 2.

Table2. Control rule table of △Ki

△Ki E \ EC	NB	NM	NS	O	PS	PM	PB
NB	NB	NB	NM	NM	NS	O	O
NM	NB	NB	NM	NS	NS	O	O
NS	NB	NM	NS	NS	O	PS	PS
O	NM	NM	NS	O	PS	PM	PM
PS	NM	NS	O	PS	PS	PM	PB
PM	O	O	PS	PS	PM	PB	PB
PB	O	O	PS	PM	PM	PB	PB

Differential control means the output of controller is directly proportional to the derivative of error input signal. The purpose of differential action is to suppress the change of control volume and improve the stability of control system. The introduction of appropriate differential can inhibit the system error change, prevent the system oscillation or divergence. The differential action over the general assembly makes the system rise slowly and the transition time increases. Correction of △Kd control rules are shown in Table 3.

Table3. Control rule table of △Kd

△Kd E \ EC	NB	NM	NS	O	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	O
NS	O	NS	NM	NM	NS	NS	O
O	O	NS	NS	NS	NS	NS	O
PS	O	O	O	O	O	O	O
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

4.4 Defuzzification of Output Variables

The output of the fuzzy adaptive PID controller is fuzzy, which needs to be gelatinized to the actuator directly. Combined with the previous introduction, this paper uses the weighted average method to defuzzification, As shown in formula (4).

$$u = \frac{\int x\mu_N(x)dx}{\int \mu_N(x)dx} \tag{4}$$

The final parameter of the PID controller is the initial value of the parameter and the algebraic sum of parameter correction, which is calculated by formula (5):

$$\begin{cases} Kp' = Kp + \Delta Kp \\ Ki' = Ki + \Delta Ki \\ Kd' = Kd + \Delta Kd \end{cases} \tag{5}$$

5 Simulation Research of System

In order to prove that the fuzzy adaptive PID control is reasonable, this paper will compare the method of fuzzy adaptive PID control and conventional PID control simulation results of fuel control system, the internal disturbance were added in 200s and 500s (fuel disturbance) and disturbance (load disturbance),The traditional PID parameters are set as follows: Kp=1.2，Ki=0.003，Kd=75，The transfer function of the controlled object is $\frac{2}{27225S^2+330S+1}e^{-80s}$ [9] ,Load disturbance channel transfer function is $\frac{1}{70S+1}$ [9],The main steam pressure is about 17MPa,The simulation results are shown in Figure 5.

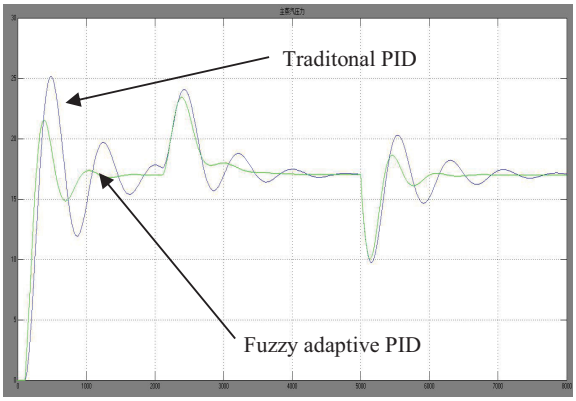


Figure 5. Simulation Result of Fuel Control System

6 CONCLUSION

First, according to the theoretical analysis method, the approximate mathematical model of the controlled object is derived, and the dynamic characteristics of the subsystems are qualitatively analyzed. It can be seen that the controlled object of the fuel control system has the characteristics of large delay and large inertia. Finally, the designed control system is debugged and simulated on Matlab, and compared with the traditional control scheme. Through simulation curves, we can draw the following conclusion: fuzzy adaptive PID control has many advantages, such as fast response, small overshoot and short transition time, which can make the main steam pressure near the set point.

REFERENCES

[1] Wang Jianguo, Sun Lingfang, Zhang Lihui. Automatic control of thermal process in power plant.[M] Beijing: China Electric Power Press, 2009.

[2] Wang Liang. Research on fuzzy and predictive control technology for combustion system of circulating fluidized bed boiler: [D], Harbin: Harbin University of Science and Technology, 2015.

[3] Hu Peng. 480t/h ultra high pressure circulating fluidized bed boiler combustion system fuzzy control application research: [D], Wuhan: Huazhong University of Science and Technology, 2012.

[4] Hui-min Lia，Xiao-bo Wang，Shang-bin Song，Hao Li. Vehicle Control Strategies Analysis Based on PID and Fuzzy Logic Control. Beijing：Procedia Engineering.[J]，2016，137：234~243.

[5] Rahul Patel，Vijay Kumar. Artificial Neuro Fuzzy Logic PID Controller based on BF-PSO Algorithm. Roorkee：Procedia Computer Science/[J]，2015，54：463~471.

[6] Gong Qibin, Xiang Xian Bing. Self tuning fuzzy PID controller design and Simulink simulation. Journal of Chongqing Electric Power College.[J], 2012, 17 (2): 88~92.

[7] Li Peng, Sun Yuzhu, Wang Xiaowei. The technical application of combustion optimization control technology on metallurgical heating furnace. Energy saving and environmental protection.[J], 2015, (15): 98~105.

[8] Li Na, Li Zetao, Zhang He. Economic Research on the boiler combustion system based on improved algorithm. Modern machinery.[J], 2014, (06): 36~42.

[9] Zhang Congbiao. 300MW pulverized coal furnace combustion system modeling and fuzzy control simulation study: [D], Taiyuan: Taiyuan University of Technology, 2014.