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Boiler steam pressure control system based on fuzzy control

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Abstract. Industrial boiler steam pressure is an important measure of boiler normal operation. Since there is delay and inertial part, single-loop PID control is difficult to achieve good dynamic characteristics. By analyzing the characteristics of the steam pressure controlled object, this paper presents a fuzzy adaptive PID control based on the cascade control system. Finally, in order to analyze the effect of the control system, mathematical model was constructed by MATLAB simulation to compare fuzzy adaptive PID cascade control with conventional PID control. The results prove that the former has a good control effect.

Introduction

Industrial boiler is an object of being multi-input, multi-output, multi-loop, nonlinear, and interrelated, with many cross-impacts among the controlled parameters, any change of which will affect the others [2]. In these parameters, steam pressure, an important parameter of steam, is an important index to measure the balance of steam production and load equipments steam consumption. Over low or over high steam pressure is all harmful to the metal pipelines and load equipment. Over high pressure will accelerate the metal creep, resulting in the damage to the boiler; while over low pressure will not provide high-quality steam for load equipment. Therefore, controlling the steam pressure is not only the need for safe production, but also the need for Economical combustion.

At this stage, single-loop PID control method is widely used in industrial boiler control system. But it is difficult to obtain good dynamic characteristics, as there is large boiler inertia and large delay. Although scholars have been using fuzzy control and neural network control and other advanced control methods mainly for a single closed-loop control, results have been improved but still not ideal. In this paper, we use fuzzy control to research and simulate, in which the furnace temperature is used as the inner loop control variable to constitute a cascade control with steam pressure.

Dynamic Characteristics of Controlled Steam Pressure

Any changes of the amount of fuel flowing into the furnace during boiler operation will change the furnace heat immediately. But the combustion process is a complex chemical change. And it is inertial to change the furnace temperature. So it is equivalent to first-order inertia form:

$$G_M(s) = \frac{K_M}{C_M s + 1} \tag{1}$$

Where C_M and K_M are combustion-related parameters.

Evaporation can be seen as a part of the volume of heat storage. It is the drum pressure P that is the main parameter which reflected the volume of the heat storage. When the furnace heat Q and the heat taken away by the steam flow D are not equal, drum pressure will change. The relationship can be expressed as[3]:

$$Q - D = C(dp/dt) \tag{2}$$

Where Q—boiler furnace heat in Unit time

D—Steam flow (Expressed by the heat)
C—capacity coefficient of evaporation part of the boiler
dp/dt —Slewing rate of boiler drum pressure by time

STEAM PRESSURE CONTROL SYSTEM DESIGN

The change of Boiler steam pressure is caused by thermal imbalance. And the main factors affecting the thermal balance are combustion heat and steam heat. In order to overcome internal and external interference effect on vapor pressure, the combustion heat inputted to the boiler must follow the changes of steam heat to keep the heat balance in the basic single furnace steam pressure control system [4]. In terms of time, the response of furnace temperature to changes in the amount of fuel is much more advanced than that of the steam pressure. Therefore, we can put the furnace temperature and steam pressure cascade to form the heat load control system. Control block diagram is shown in Fig. 1.

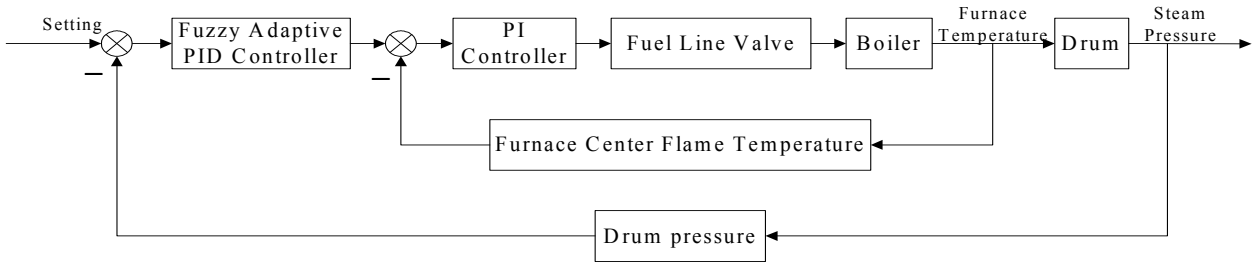

Figure 1 Diagram of steam pressure control system

When the temperature changes in the furnace, the dynamic characteristic of drum pressure is the first-order inertia link with a pure delay, the equivalent delay time is not long.

$$G_0(s) = \frac{e^{-Ts}}{T_0 s + 1} \tag{3}$$

Therefore, adjusting the furnace temperature according to changes of steam pressure can timely and effectively control the steam pressure, and adapt to load.

The Selection of the Master Controller. Master controller works to fix value of control. The main controlled variable is the main indicator of technical operation, allowing the small range of fluctuation, and requiring no static error. Because of the delay and nonlinear of furnace process, the precise mathematical model is difficult to get. Traditional PID control can not solve nonlinear problems, while fuzzy control has good robustness because it does not rely on the system model. Therefore, we use fuzzy adaptive PID controller.

Fuzzy adaptive PID controller can achieve the adjustment of PID control parameters on line. It first finds out fuzzy relationship between the PID and the input error e and error change rate of input ec. Then by using fuzzy reasoning, the controller which has got real-time detection value of e and ec gets the adjusted PID controller parameters to meet different requirements of e and ec on the controller parameters in different situations by searching the fuzzy matrix. In this way, fuzzy control can overcome the nonlinear characteristic of the system, but PID control can overcome possible oscillations and steady state error caused by fuzzy control when the error tends to be zero.

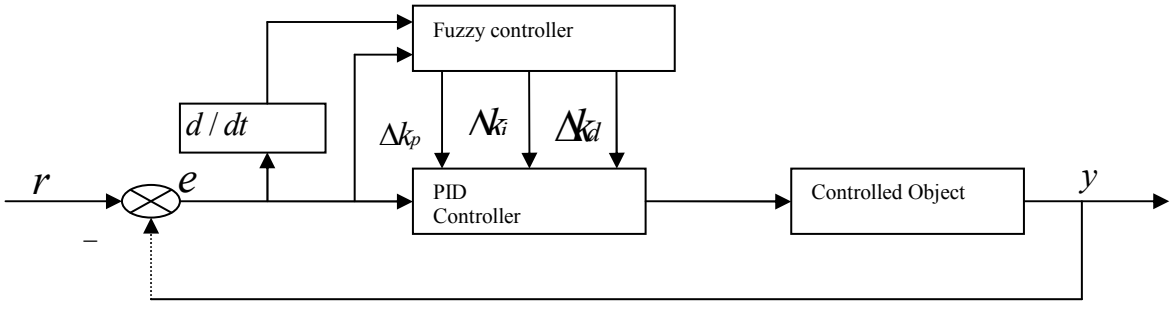

Fig. 2 Block diagram of fuzzy adaptive PID

Fuzzy adaptive PID controller block diagram is shown in Fig. 2.

Fuzzy adaptive PID controller design can be divided into the following steps.

1)Fuzzy controller input and output

There are two-input and three-output in this fuzzy controller. Superheated steam pressure error e and error change rate of steam pressure ec are input variables. And PID controller parameters ΔK_P, ΔK_I and ΔK_D are the controller output variables.

2)The process of fuzzification

Fuzzification process is the determination of the fuzzy memberships of the five variables considering their real-time changes in the scope and values.

{-6,-4,-2,0,2,4,6} is chosen as the domain of discourse of e, ec, ΔK_P, ΔK_I, ΔK_D.Their fuzzy subsets are{Negative Big, Negative Middle, Negative Small, Zero, Positive Small, Positive Middle, Positive Big}, corresponding respectively to{NB, NM，NS，ZE，PS，PM,，PB}.

Triangular is chosen as membership function of input and output variables. The input and output variable membership function curve respectively is shown in Fig. 3.

3)Fuzzy reasoning

In different circumstances, setting principles of e, ec, ΔK_P, ΔK_I, ΔK_D are different.

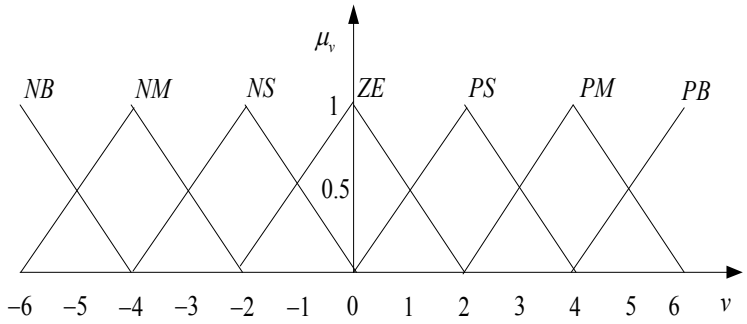

Fig. 3. e, ec, , , membership function

When | e | is large, in order to get good tracking performance and timely error suppression, ΔK_P should be set large but ΔK_D should be small. Meanwhile, in order to avoid a larger overshoot of system response, the integral action ΔK_I is usually taken as 0, which should be restricted.

When | e | and | ec | are of Medium size, in order to get a smaller overshoot, the value of should be smaller. In this case, the value of ΔK_P which has a greater impact on the system should be set small and the value of ΔK_I should be appropriate.

When | e | is small, considering good stability of system, ΔK_P and ΔK_I should get bigger. When | ec | is large, take ΔK_D small in order to avoid system oscillation, otherwise, take ΔK_D large. Considering the system anti-jamming performance, ΔK_D should not be too big or too small.

Correspondingly, the fuzzy rules tables are shown in Tab. I, Tab. II and Tab. III The fuzzy controller applies fuzzy reasoning algorithms of Mamdani and expresses fuzzy relationship by tiny computation rules definitions.

Table 1 ΔK_P fuzzy control rules

e \ ec	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZE	ZE
NM	PB	PB	PM	PS	PS	ZE	NS
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	PS	ZE	NS	NM	NM	NM	NB
PB	ZE	ZE	NM	NM	NM	NB	NB

Table 2 ΔK_I fuzzy control rules

e \ ec	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZE	ZE
NM	NB	NB	NM	NS	NS	ZE	ZE
NS	NB	NM	NS	NS	ZE	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PS	PM	PB
PM	ZE	ZE	PS	PS	PM	PB	PB
PB	ZE	ZE	PS	PM	PM	PB	PB

Table 3 Fuzzy Control Rules

e \ ec	NB	NM	NS	ZE	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZE
NS	ZE	NS	NM	NS	NS	NS	ZE
ZE	ZE	NS	NS	NS	NS	NS	ZE
PS	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PM	PB	PS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

4)The process of fuzzy reasoning

After fuzzy reasoning, output variables obtained are fuzzy values. The master controller output is the setting parameter of fuel flow, which must be a precise control signal within control. Therefore, according to the degree of membership of fuzzy sets and fuzzy control model of parameters, the modified parameters need to be found out and put into the following formulas using fuzzy reasoning matrix.

$$K_P(t+1)=K_P(0)+\Delta K_P(t)=K_P(0)+\{e(t)+ec(t)\}_P \quad (4)$$

$$K_I(t+1)=K_I(0)+\Delta K_I(t)=K_I(0)+\{e(t)+ec(t)\}_I \quad (5)$$

$$K_D(t+1)=K_D(0)+\Delta K_D(t)=K_D(0)+\{e(t)+ec(t)\}_D \quad (6)$$

Here $K_P(0)$, $K_I(0)$, $K_D(0)$ are the initial PID parameters. Through this process, self-adjust PID parameters can be achieved on-line based on actual operating conditions

The Selection of the Deputy Controller. Inner loop works as servo control that the fuel control signal changes with the master controller output signal. In this control loop, the control valve and the transmitter have small delay. Besides, the furnace temperature process has smaller time constant than steam pressure process. As inner loop requires good mobility and there is no error, slave controller should be chosen as PI controller.

Steam Pressure Control System Simulation

In order to verify the superiority of fuzzy control, this paper conducts a simulation of steam pressure control system of conventional PID and Fuzzy PID cascade control system to compare the control effect. During the simulation process, simulation model uses the boiler drum object, which has evaporation of 35t / h. All parts of the mathematical model are as follows [9].

Furnace temperature model: $G_t(s)=\dfrac{3.7}{30s+1}$

Steam pressure model: $G_p(s)=\dfrac{e^{-15s}}{300s+1}$

Interference channel model of steam flow: $G_f(s)=\dfrac{1}{13600s^2+236s+1}$

System simulation is shown in Fig.4.

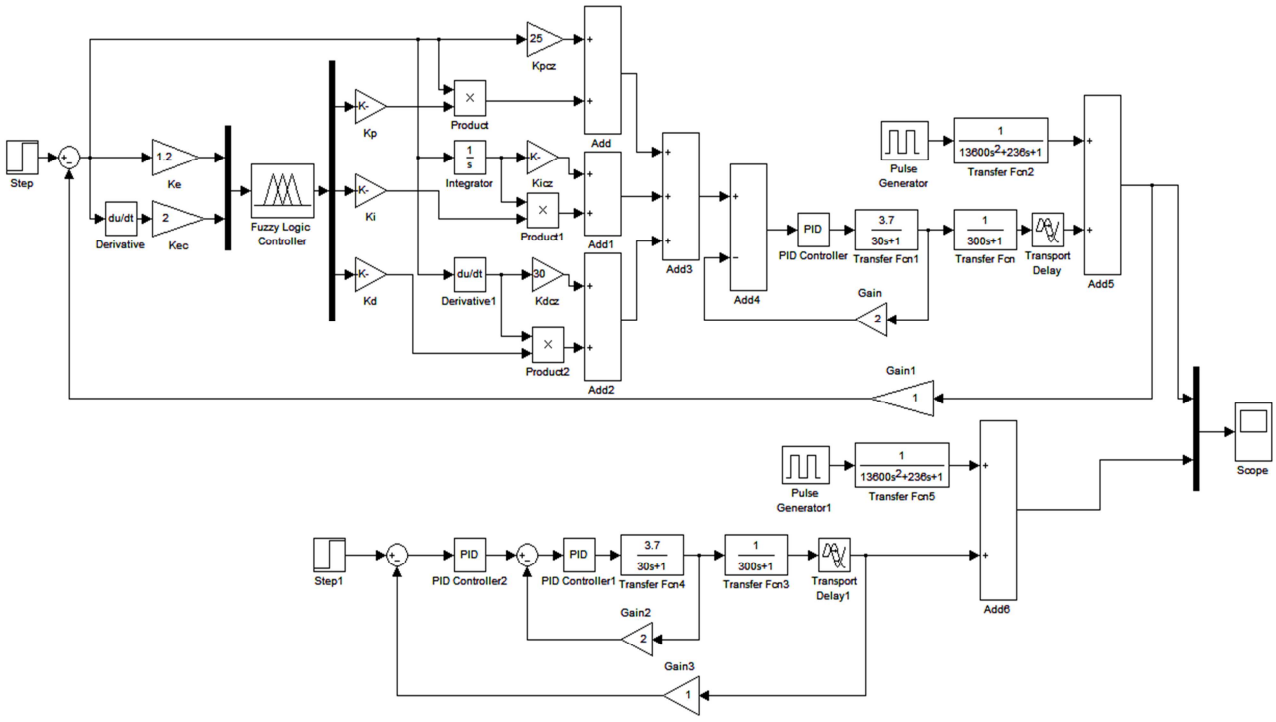

Fig. 4. Simulation diagram of steam pressure

Simulation parameters Ke=1.2, Kec=2, Kp=Ki=Kd=0.05;
Slave controller parameters P: 5, I: 0.2;
Main controller initial parameters P: 25, I: 0.06, D: 30

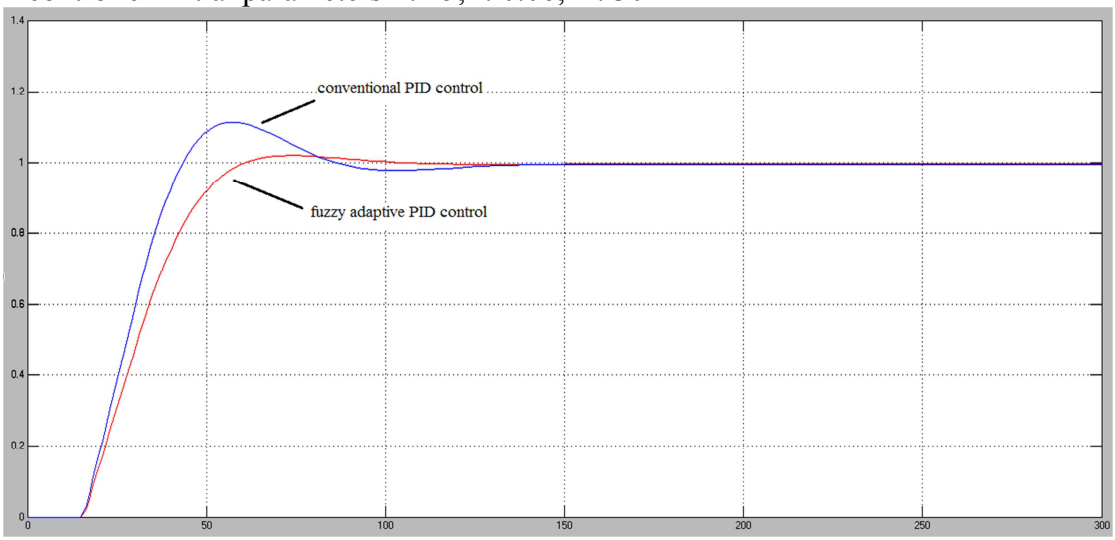

Fig. 5. Step response curve of steam pressure

(horizontal axis represents time t(s), the vertical axis represents steam pressure response r(1 unit))

Simulation result is shown in Fig.5. In the figure, the horizontal axis represents time t(s), the vertical axis represents steam pressure responser(1 unit).

Through the simulation curve analysis, we can acquire the following control system performance.

(1) Compared with conventional PID cascade control, fuzzy adaptive PID cascade control has small overshoot and short settling time, which also enhances the system anti-jamming capability.

(2) The main loop pressure control uses the deviation between steam pressure and setting to adjust fuel flow in order to ensure the stability of the pressure. As furnace temperature signal reflects the fuel disturbance in time, the temperature regulator is introduced to overcome the interference effects. With the disturbance eliminated, the fuel flow disturbance will not cause fluctuation of the main steam pressure.

Summary

Firstly this paper analyzes dynamic characteristics of steam pressure controlled object. Then through the analysis of combustion heat and steam heat interference, cascade control system model is built, in which the main controller is fuzzy adaptive PID control, and the slave controller uses PI control. Finally, MATLAB simulation is operated to emulate the control effect of steam pressure control system. The results prove that the fuzzy adaptive PID cascade control has a smaller overshoot, shorter time to reach steady state and stronger anti-jamming capability.

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