A REVIEW ON MODERN APPROACH TO THE FUZZY LOGIC BASED BOILER DRUM LEVEL CONTROLLER

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Abstract - Based on the analysis of dynamic characteristics of the drum water level, a control strategy of the drum water level in a CFB using fuzzy logic boiler is presented in this paper. Compared the effectiveness of fuzzy control with the general PID on the model of the drum water level in a CFB boiler and the simulation results show that the scheme provides the control system the stronger robustness and better control quality, and improves its dynamic and static performance index.

Keywords – Fuzzy control; Drum water level; A self adjusting defuzzification

I. INTRODUCTION

The drum water level is the main index in the running for circulating fluidized bed (CFB) boiler, it indirectly reflects the balance relation between boiler load and water supply. If the water level is too low, the change speed of the water amount is quicker because of the less amount of water inside the drum, higher load and the fast speed of water evaporation. It will cause all the water in the drum vaporize, resulting boiler burn and explode if it can not be controlled in a timely. However, if the water level is too high, it will affect the separator of steamwater of the drum, causing the phenomenon of steam with liquid, resulting the damage because of the fouling of the superheated wall, at the same time, with the sharp drop of temperature for the superheated steam, which as the power of the turbine, moreover it will damage the turbine blades. Therefore, drum water level is too high or too low, which will all result in the serious consequences, and we must take a strict control. At present, we use drum water level control system adopting double-impulsive and three-impulsive control mode in order to overcome the “false water level”, which introduce feed forward control element based on the conventional single-loop PID control and constitute feed forward-feedback control system. However, the automatic control system of drum water level generally can be put into use automatically in the circumstance of the relatively stable load, relatively fixed coal and boiler’s combusting relatively steady. But it will require skilled operators manually to control when the system dynamic characteristics have a substantial change [1]. In addition, the transfer function of feed forward channel of the control system is unable to overcome the disturbance of the drum steam flow if simply adopting the pure ratio [2]. Based on above-mentioned, the paper proposes a self adjusting PID fuzzy controller to control the drum water level after the full analysis for the dynamic properties of the drum water level.

II. DYNAMIC CHARACTERISTICS OF DRUM WATER LEVEL

The drum water level in a CFB boiler is affected by the balance relationship between water-supply volume and evaporation volume, at the same time it is affected by the volume ratio change of the steam and water in the mixture of the steam and water in the circulation pipe. The reason of reflecting the water level change in boiler has a lot, the influence to drum water level caused by the disturbance of steam flow and water supply explained as follows.

A. The effect to the drum water level caused by the disturbance of steam flow

With the steam usage suddenly increased and bubble in swelling the water rapidly increased for the same fuel, it will cause the entire water level elevate and engender raising of the water lever, which is called the phenomenon of false water level. The step response curve of the water level changes under the disturbance of the steam flow is shown in Fig. 1. At the beginning stage, the water level will not decrease, but increase firstly then decrease because of the phenomenon of false water level when the steam flow suddenly increase (Conversely, the water level decrease...
firstly then increase when steam flow suddenly decrease)[2-8]. The actual change of water level is $H$ when steam flow increase suddenly, which is the superposition of the $H_1$ and $H_2$. $H_1$ represents water level change not considering the bubble volume change under water and $H_2$ represents water level change only considering the bubble volume change under water, that is:

$$H = H_1 + H_2$$  \hspace{1cm} (1)

It is described by the transfer function as:

$$\frac{W(D(s))}{H(s)} = \frac{\epsilon}{s} + \frac{K_D}{Ds+1}$$  \hspace{1cm} (2)

where $\epsilon$ is the soaring speed of the step response curve at the effect of the steam flow; $K_D$, $T_D$ denote magnification and the time constant of $H_2$ causing the water lever change.

![Fig.1 Step response curve of water level under the disturbance of steam flow water supply]

Drum volume under the water will somewhat decrease because supply-water temperature is lower saturation water when supply water flow increases and draws part of the heat from the original saturation water. Water level change reflects entirely water level rises perpendicularly because of increase of storage capacity when change procedure of drum volume under water balances gradually[9-13]. Therefore, the actual water level will present a period of initial inertia phase rather than increasing immediately at the beginning. When step change in water-supply flow happens, the dynamic characteristics of drum water level is shown in Fig.2, which equivalents to composition of an integral element and a first-order inertial element described with transfer function.

$$\frac{Ww(s)}{Vw(s)} = \frac{\epsilon}{s(T_2s+1)}$$  \hspace{1cm} (3)

Where $\epsilon$ denotes change speed of water level with watersupply changing unit flow, $T_2$ is time constant of water level.

Above described dynamic characteristics of drum water level shows that the dynamic characteristic of controlled object is changing constantly according to the different
operating conditions, which requirements adjuster should be with self-adaptive capacity of corresponding change parameters.

![Fig.2 Step response curve of water level under the disturbance of water supply](image)

**III. SELF-ADJUSTING PID FUZZY CONTROL OF DRUM WATER LEVEL**

The fuzzy control is an intelligence control system to control complex system based on analogizing human ways of fuzzy thinking, which applies fuzzy sets, fuzzy linguistic variables and fuzzy logic inference knowledge. Fuzzy control with the advantage of quick response, small overshoot, short transition time and so on need not require know mathematical model of object beforehand. The self-adjusting PID fuzzy control uses fuzzy controller with the good characteristics replace of the conventional PID controller, which adjusts PID parameters on-line in terms of fuzzy relationship, i.e. fuzzy control rules, of PID three parameters with error E and change of error EC, therefore which shows a dynamic and static performance[14-19]. A self-adjusting PID fuzzy control system structure of cascade three-impulsive drum water level is given in the paper, shown as Fig.3.

![Fig.3 Self-adjusting PID fuzzy control diagram of drum water level](image)
We make a simulation research to the control system for the problem. At first, we designs controller with the proportion coefficient $K_p$, integral coefficient $K_i$ and differential coefficient $K_d$ by means of fuzzy logic toolbox.

A. Design of the self-adjusting PID fuzzy controller of drum water level

We choose error $E$ and change of error $EC$ between actual water level of system ($H$) and the given water level ($R$) as the input parameters, which satisfies the requirement of error $E$ and change of error $EC$ to PID parameters of self-adjusting at different time [30–32]. At the same time, we choose $-5$, $-4$, $-3$, $-2$, $-1$, $0$, $1$, $2$, $3$, $4$, $5$ as the universe of discourse of fuzzy input $E$, $EC$ and output $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ and choose PL, PM, PS, ZE, NS, NM, NL, seven languages as the linguistic variables. The membership function for $E$, $EC$, $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ are expressed by triangle curve, as shown in Fig.4.

![Fig.4 Membership function scheme of input and output](image)

Fuzzy control rules are the summarization to the theoretical knowledge and practical experience of the experts. We can conclude the self-adjusting requirement of controlled process to parameters $K_p$, $K_i$ and $K_d$ according the effect of the parameters $K_p$, $K_i$ and $K_d$ to the output characteristics for different $e$ and $ec$. Consequently, we can obtain one control rules:

1 If ($E$ is NB) and ($EC$ is NB) then ($U$ is PB)  \hfill (4)
2 If ($E$ is NB) and ($EC$ is NM) then ($U$ is PB)  \hfill (5)

Fuzzy decision making adopts the following definition, such as AND is expressed as the min, OR is expressed as the max, Implication is expressed as the min and Aggregation is expressed as the max. In addition, defuzzification is expressed as som. Relationship curve of input and output of fuzzy controller according to such design method is observed through their own View Editor Window, relationship curve of input and output of fuzzy controller for $K_d$ is shown in Fig.5. We can keep its expectation near the center of the output conclusion space of fuzzy control in the control surface [20–24]. Otherwise we should re-adjust the rules, membership function or fuzzy operator when it surpasses 20% to implement the optimization to fuzzy controller finally.

Fig.5 Fuzzy control inference output

Tables constituted of the 49 fuzzy conditional statements...
respectively, as shown in table I. Inputting the rules separately in their respective the rule editor window, for example see in fuzzy table.

### B. Parameter control algorithm of self-adjusting PID

**fuzzy control of drum water level**

Here, we can easily calculate output control $u$ using self-adjusting PID parameters $k_p$, $k_i$, $k_d$ on line, according to discrete differential formula of PID control algorithm. The adopted frequently incremental algorithm in practical application can be expressed as:

$$U(K) = K_pE(K) + K_i \sum E(K) + K_d EC(K)$$  \hspace{1cm} (6)

Where $\sum E(K)$ is deviation sum, $E(K)$ is error, and $EC(K)$ is change of error, $k_p$, $k_i$ and $k_d$ are determined separately as:

$$K_p = K_{p1} + \{E_i, \Delta E\}_p$$ \hspace{1cm} (7)

$$K_i = K_{i1} + \{E_i, \Delta E\}_I$$ \hspace{1cm} (8)

$$K_d = K_{d1} + \{E_i, \Delta E\}_d$$ \hspace{1cm} (9)

where $\{E_i, \Delta E\}_p$, $\{E_i, \Delta E\}_I$ and $\{E_i, \Delta E\}_d$ are fuzzy inference results, i.e. parameters calibration $\Delta K_p$, $\Delta K_i$, $\Delta K_d$ and $k_{p1}$, $k_{i1}$ and $k_{d1}$ are initial values for parameters. We introduce a conventional PID control for the choosing $k_{p1}$, $k_{i1}$ and $k_{d1}$ as long as guaranteeing the system stability, even that performance indicator of the system at this time can not meet the requirements incompletely\[25-29\. For resolving the problem, we should regarding this groof PID parameters as the initial values of self-adjusting PID fuzzy controller then make fine-tuning parameters by calibration concluded through fuzzy inference to ensure system performance indicator meet the requirement.

![](Fig6_Output_curve_of_the_two_control_method.png)

It is obvious from simulation result that self-tuning fuzzy PID control quantity of drum water level is superior to the conventional PID control, expressing in its overshoot reduces and the time of transition process short significantly.

### B. Simulation comparison of two ways of control of the drum water level under the disturbance of steam flow

Here, we can add external disturbance of steam flow signal to the system at $t=300s$ under the premise of each parameter is invariant, where the drum level water dynamic response curve of the self-adjusting PID fuzzy control system and the conventional PID control system under the disturbance of steam flow is shown in Fig.7.

### IV. SIMULATION

#### A. Simulation comparing self-adjusting PID fuzzy control of drum water level with the conventional PID control

From fig 3, parameters are defined as follow:
Transfer coefficient of Steam flow, water-supply flow and measurement transmitter of drum water level \( r_D \), \( r_G \) and \( r_H \) are respectively 0.083, 0.083 and 0.033. The partial pressures coefficient of steam flow, water flow \( n_D \), \( n_G \) are 0.21. The characteristics coefficient of actuator, valve \( K_z \) and \( K_f \) are 10 and 2 (regarding approximately as proportional element) separately, and vice regulator \( G_c(s) \) can be seen P adjuster when \( K_P \) is 0.4648.

![Fig.7 Curve of the two control methods of drum water level under the disturbance of steam flow](image)

![Fig.8 Curve of drum water level under the disturbance of water supply](image)

In the simulation research, regulator as the PID, among them \( K_P=3 \), \( K_I=0.02 \) and \( K_D=3.5 \). Similarly initial value of PID parameters of self-adjusting PID fuzzy control are chosen as \( K_P=3 \), \( K_I=0.02 \) and \( K_D=3.5 \). The quantify coefficient are chosen as \( k_e=2.5 \) and \( k_{ec}=50 \), proportional coefficient is chosen as \( k_u=0.05 \). The input signal is step input. Setting steam flow disturbance signal and water-supply disturbance signal all equal 0. The dynamic response curve of the self-adjusting PID fuzzy control system of drum water level and conventional the PID control system is shown in Fig.6.
**E. Simulation comparison of two ways of control of the drum water level when time constant is changed**

Here, we change time constant of object model, from 30 to 45 under the premise of each parameter is invariant, where the dynamic response curve of the self-adjusting PID fuzzy control system and the conventional PID control system from above simulation results, Fig.9 and Fig.10, we can conclude that overshoot of the conventional PID and transition process time increase significantly when parameters of control object model are changed, while the self-adjusting PID Fuzzy.

**C. Simulation comparison of two ways of control of the drum water level under the disturbance of water supply**

Here, we can add internal disturbance of water supply signal to the system at t=300s under the premise of each parameter is invariant, where the drum level water dynamic response curve of self-adjusting PID fuzzy control system and conventional PID control system under the disturbance of water supply is shown in Fig.8.

It is obvious from simulation result Fig.7 and Fig.8 that the self-adjusting PID fuzzy control bas anti-disturbance.
Fig 5.3: Membership function for error(e(t))

Fig 5.5: Membership function for current
5.6 SIMULATION AND RESULTS

![Simulink model of PI Controller](image)

**Fig 5.6: Simulink model of PI Controller**

5.4.2 Rule base table

Fuzzy logic uses linguistic representation of engineering knowledge to implement a control strategy. The rules used by an operator or expert to manoeuvre a process are described by IF-THEN rules in fuzzy logic.

### Table 5.1: Linguistic variables used for the fuzzy

<table>
<thead>
<tr>
<th>SI.NO</th>
<th>FEED WATER FLOW (Litres/s)</th>
<th>VALVE CURRENT OPENING (%)</th>
<th>CURRENT (in mA)</th>
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<td>1</td>
<td>13.89</td>
<td>10%</td>
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<td>6</td>
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<td>20</td>
</tr>
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</table>

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