

Research on Control Model and Simulation Platform of Cement Rotary Kiln Burning Zone Temperature

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Abstract—The research on the control model and simulation platform of rotary kiln burning zone temperature is the basis of automatic control and process optimization of cement clinker sintering process. Therefore, based on hybrid system theory, thermal regulation, and least squares method, the control model of cement rotary kiln burning zone temperature is given. Then, based on the configuration software, the dynamic simulation platform of the cement rotary kiln burning zone temperature is developed. The data and application prove the validity and practicality of the research.

Keywords—burning zone temperature; model; simulation system; cement rotary kiln

I. INTRODUCTION

Rotary kiln burning zone temperature is the key parameter for cement clinker sintering process. Its control method is gradually changed from the operator-based control method to the hybrid control method combined with accurate model. The research basis is the establishment of the model of the cement rotary kiln burning zone temperature and the development of the simulation platform.

Because that the burning zone temperature is too high and the cement rotary kiln rotates continuously, at present the burning zone temperature cannot be measured directly, but be gotten indirectly through colorimetric pyrometer, image processing and watching fire by operators in most of cement production lines[1]-[3]. But there are some limitations in such methods because of the presence of excessive dust and heavy smoke. The literatures [4]-[6] proposed a variety of burning zone temperature soft measurement methods. But until now there is no widely accepted research on the control model between the coal feeding and the burning zone temperature, which can meet requirements for the research on the simulation platform and control algorithm of the cement clinker sintering process.

Therefore, based on the historical data of a cement factory in Shandong Province, this paper established a number of typical working condition templates. Then based on these working conditions of the burning zone temperature the control model between the coal feeding and burning zone temperature was established. Finally, based on the configuration software, the cement rotary kiln burning zone temperature simulation platform was developed.

II. TYPICAL WORKING CONDITION TEMPLATE OF BURNING ZONE TEMPERATURE

Based on historical data analysis and manual experience of the operators, the working conditions are given as Table I-Table III, which covered 90% of normal running time of the production line.

Then, the soft-measurement model of the burning zone temperature under each working condition can be gotten. Such research is shown in the references [7]-[8] which were previously published by same authors. And now it will not be repeated here again.

TABLE I. WORKING CONDITON 1

Serial number	Related variable	Reference value	Allowable error range
1	Raw material discharge	243.9t/h	±11.1 t/h
2	The current of elevator before kiln	135.81A	±2.32
3	Decomposition furnace outlet temperature	938.225°C	±32.375
4	Kiln speed	3.7r/min	±0.07
5	Smoke chamber temperature	1218 °C	±40 °C
6	Kiln motor current	500A	±60 A
7	Secondary air temperature	1125.69 °C	±80 °C
8	Kiln coal feeding	11.3t/h	±0.1
9	Cooler speed	9.87m/s	±1.18

TABLE II. WORKING CONDITON 2

Serial number	Related variable	Reference value	Allowable error range
1	Raw material discharge	246t/h	±8 t/h
2	The current of elevator before kiln	135A	±5
3	Decomposition furnace outlet temperature	935.8°C	±30
4	Kiln speed	3.725r/min	±0.095
5	Smoke chamber temperature	1173 °C	±233 °C
6	Kiln motor current	454A	±58 A
7	Secondary air temperature	1050.65 °C	±80 °C
8	Kiln coal feeding	11.1t/h	±0.1
9	Cooler speed	9.52m/s	±1.32

TABLE III. WORKING CONDCTION 3

Serial number	Related variable	Reference value	Allowable error range
1	Raw material discharge	229.86t/h	± 13.135 t/h
2	The current of elevator before kiln	135.06A	± 4
3	Decomposition furnace outlet temperature	911.62°C	± 27.65
4	Kiln speed	3.8145r/min	± 0.0945
5	Smoke chamber temperature	1114.5 °C	± 117.315 °C
6	Kiln motor current	473.2A	± 70 A
7	Secondary air temperature	1097.2 °C	± 100 °C
8	Kiln coal feeding	10.9t/h	± 0.1
9	Cooler speed	11.27m/s	± 2.36

III. RESEARCH ON CONTROL MODEL OF BURNING ZONE TEMPERATURE UNDER THE WORKING CONDITIONS

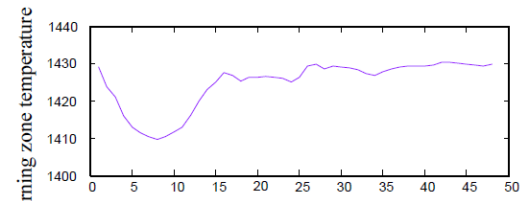
The control models of burning zone temperature under the working condition1-3 are as follows:

$$y(n+1)=363.8507+1.0073y(n)-0.3938y(n-1)+17.163u(n-5)-0.3787u(n-6) \quad (1)$$

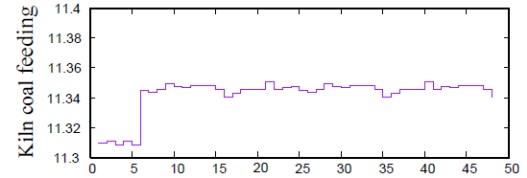
$$y(n+1)=328.7582+1.3948y(n)-0.6885y(n-1)-10.62u(n-5)+18.9849u(n-6) \quad (2)$$

$$y(n+1)=147.1074+0.8356y(n)+0.042y(n-1)-8.9666u(n-5)+11.5667u(n-6) \quad (3)$$

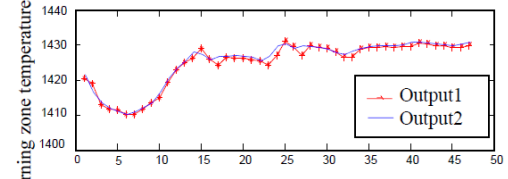
The Figure I (a), Figure I (c), Figure I (e) showed the verification input and output data under the working condition 1-3. The Figure I (b), Figure I (d), Figure I (f) showed the errors between the model outputs and the practical history data under the working condition 1-3. The error values all fluctuated within ± 2 .



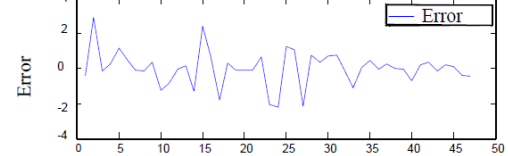
(a) Input and Output Data of Working Condition 1



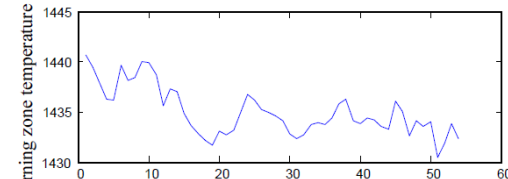
(b) Error Data of Working Condition 1



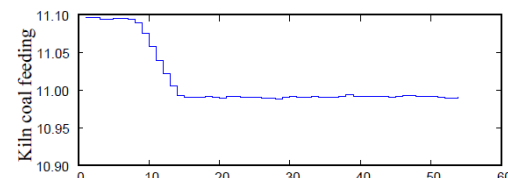
(c) Input and Output Data of Working Condition 2



(d) Error Data of Working Condition 2



(e) Input and Output Data of Working Condition 3



(f) Error Data of Working Condition 3

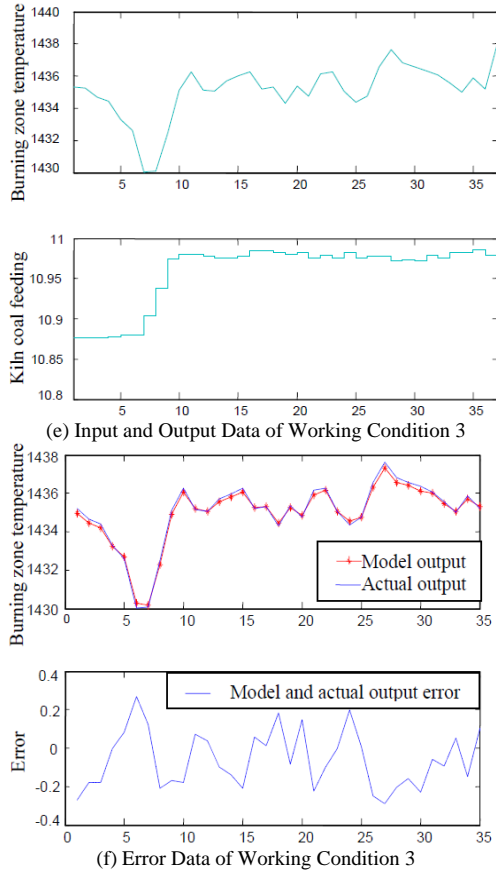


FIGURE I. COMPARISON OF DIFFERENT WORKING CONDITION

IV. REALIZATION OF THE SIMULATION PLATFORM OF BURNING ZONE TEMPERATURE UNDER THE WORKING CONDITIONS

The simulation platform mainly includes the working condition recognizer, the dynamic simulation of the burning zone temperature under the working conditions, and the switching simulation of the burning zone temperature between typical working conditions. Its composition is shown in Figure II.

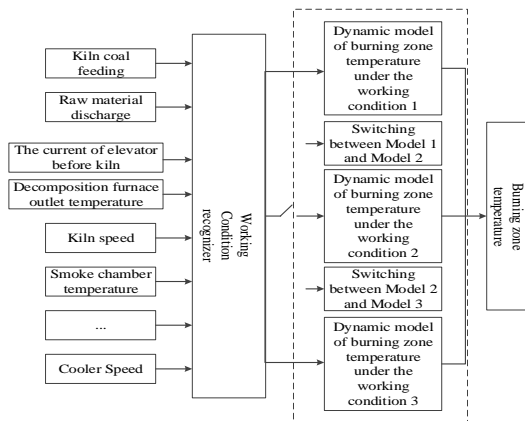


FIGURE II. COMPOSITION OF THE ROTARY KILN DYNAMIC SIMULATION PLATFORM

The simulation platform is mainly used to identify the working conditions through the relevant variables in the DCS configuration software (Freelance2013), and map the identified current operating conditions to the configuration software to select the corresponding dynamic model. The OPC channel is used as the communication method. And database is used as an intermediate data storage link, and the currently determined working condition is stored in the corresponding data table. The relevant variables are assigned via OPC to the DCS configuration software. Through the DIVIS software, the burning temperature trend is displayed on the screen. The software system architecture is shown in Figure III.

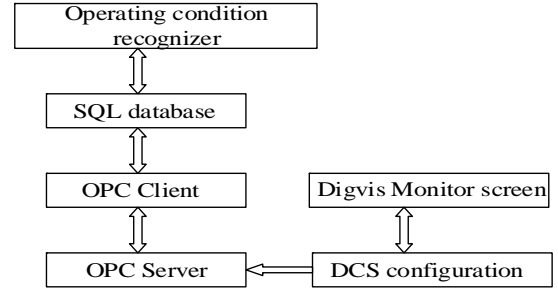


FIGURE III. SOFTWARE ARCHITECTURE OF ROTARY KILN SIMULATION PLATFORM

A. Working Condition Recognizer

The working condition recognizer can determine the current working condition, and then burning zone temperature under the correct working condition can be simulated. The working condition recognizer is established based on judging the value of each variable and the reference value of each working condition. The judging rules are as formula 4-6 to distinguish the working condition 1-3. And the variables of the recognizer rules are the same ones of the work condition templates (Raw material discharge X_1 , The current of elevator before kiln X_2 , Decomposition furnace outlet temperature X_3 , Kiln speed X_4 , Smoke chamber temperature X_5 , Kiln motor current X_6 , Secondary air temperature X_7 , Kiln coal feeding X_8 , Cooler speed X_9).

$$\begin{aligned} &(X_1 \rightarrow 243.9 \pm 11.1) \wedge (X_2 \rightarrow 135.81 \pm 2.32) \wedge \\ &(X_3 \rightarrow 938.225 \pm 32.375) \wedge (X_4 \rightarrow 3.7 \pm 0.07) \wedge \\ &(X_5 \rightarrow 1218 \pm 40) \wedge (X_6 \rightarrow 500 \pm 60) \wedge ((X_7 \rightarrow 1125.69 \pm 80)) \\ &\wedge ((X_8 \rightarrow 11.3 \pm 0.1)) \wedge ((X_9 \rightarrow 9.87 \pm 1.18)) \end{aligned} \quad (4)$$

$$\begin{aligned} &(X_1 \rightarrow 246 \pm 8) \wedge (X_2 \rightarrow 135 \pm 5) \wedge (X_3 \rightarrow 935.8 \pm 3.0) \\ &\wedge (X_4 \rightarrow 3.725 \pm 0.095) \wedge (X_5 \rightarrow 1173 \pm 233) \wedge \\ &(X_6 \rightarrow 454 \pm 58) \wedge ((X_7 \rightarrow 1050.65 \pm 80)) \wedge \\ &((X_8 \rightarrow 11.1 \pm 0.1)) \wedge ((X_9 \rightarrow 9.52 \pm 1.32)) \end{aligned} \quad (5)$$

$$\begin{aligned} &(X_1 \rightarrow 229.86 \pm 13.135) \wedge (X_2 \rightarrow 135.06 \pm 4) \wedge \\ &(X_3 \rightarrow 911.62 \pm 27.65) \wedge (X_4 \rightarrow 3.8145 \pm 0.095) \wedge \\ &(X_5 \rightarrow 1114.5 \pm 117.315) \wedge (X_6 \rightarrow 472.3 \pm 70) \wedge \\ &((X_7 \rightarrow 1097.2 \pm 100)) \wedge ((X_8 \rightarrow 10.9 \pm 0.1)) \wedge \\ &((X_9 \rightarrow 11.27 \pm 2.36)) \end{aligned} \quad (6)$$

B. Dynamic Simulation of Burning Zone Temperature under Typical Working Condition

The control models of the burning zone temperature under different working conditions are established based on Freelance2013 configuration software of ABB, which mainly included hardware configuration, software programming, trend display settings, etc.

C. Switching Simulation between Typical Working Conditions

The switching of dynamic models is mainly happens between two typical working conditions. When the model is switched, the current dynamic model and the weight corresponding to the dynamic model to be switched are calculated. Then, the burning zone temperature simulation value is a summation value. The calculation method of model weights under typical working conditions is determined by some fuzzy rules. The specific implementation is shown in Figure IV.

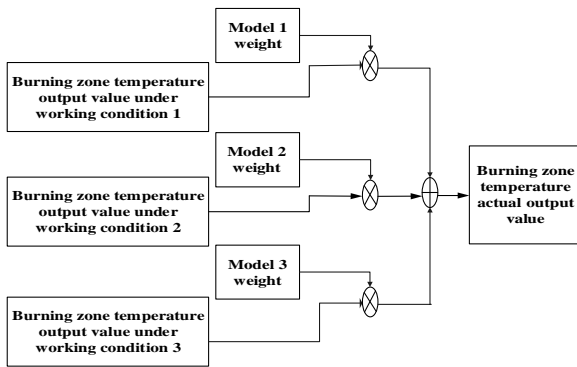


FIGURE IV. DYNAMIC MODEL SWITCHING IMPLEMENTATION

V. CONCLUSION

Figure V shows the trend of the burning zone temperature, the smoke chamber temperature, the secondary air temperature, and the decomposition furnace outlet temperature corresponding to the kiln coal feeding from 10.9t/h to 11.1t/h to 11.3t/h. When the Kiln coal feeding changed, the burning zone temperature also changed correspondingly. The simulation trend fitted the practical trend, which verified the validity and practicality of the research.

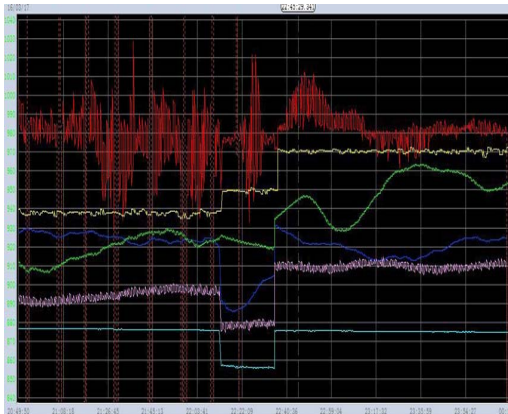


FIGURE V. HISTORY DATA CURVE OF SIMULATION PLATFORM

Note: The red curve represents the burning zone temperature, the yellow curve represents the amount of kiln coal feeding, the blue curve represents the secondary air temperature, the green curve represents the decomposition furnace outlet temperature, the light blue curve represents the smoke chamber temperature, and the pink curve represents the Cooling machine pressure.

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