Research on Modelling of Grate Cooler Based on Typical Operating Conditions

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Abstract: In the long-term operation of grate coolers, the application of a single model to grate cooler control has great limitations. Based on the statistical analysis of production site data and the expert experience of cement plant operators, this paper identifies the typical working reference points for the grate coolers for cement clinker production lines and typical operating conditions. After that, a dynamic model of the continuous characteristics of each typical operating condition was established. Simulation results prove the validity and practicality of the above model.

1 INTRODUCTION

The grate cooler is the main equipment for clinker cooling and heat recovery in the sintering process of cement clinker, and maintaining the grate cooler pressure stability is the basis for ensuring efficient heat exchange between the clinker of high temperature and the air of normal temperature. The grate cooler pressure is affected by the multi-variables such as the grate speed, raw material quantity, and the temperature of the material exiting the kiln. Therefore, based on expert knowledge and historical data analysis, this paper has determined the typical working condition template of grate cooler. Afterwards, a modeling study was performed on each typical working condition with continuous dynamic characteristics, which provided a good basis for subsequent grate cooler pressure control[1-3].

2 GRATE COOLER TECHNOLOGY INTRODUCTION AND WORKING REFERENCE POINT DETERMINATION

2.1 Grate Cooler Technology

The main function of the grate cooler is to cool the high temperature clinker, the high temperature clinker calcined in the rotary kiln falls from the kiln hood into the grate cooler, with the reciprocating motion of the grate plate, the high temperature clinker is distributed on the full grate bed, to form a layer of material with a certain thickness. The high pressure cold air blown into the plenum below the grate cooler is quickly blown into the material layer to cool the clinker. While cooling the clinker, the cooling wind exchanges heat with the high-temperature clinker and turns into hot air, This is the secondary air and the tertiary air in cement production. They are fed into the rotary kiln system through a secondary air duct and a tertiary air duct respectively. After cooling, the small pieces of clinker can fall through the grid screen into the conveyor, and the large pieces of clinker must be broken into the conveyor. In the grate cooler cooling process, the speed of cooling and the degree of sufficient cooling are of critical importance to ensure the quality and thermal efficiency of the clinker. In addition, there is an important goal is to stabilize the secondary air temperature, and the thickness of the material layer is the key to stabilize the secondary air temperature. If the material layer is too thick, the cooling air cannot blow through the clinker, the clinker cooling is uneven, and the effect is not good, and due to too much high-temperature clinker damage to the sampan; If the material layer is too thin, the cooling wind will quickly blow through the clinker, without sufficient heat exchange, resulting in a decrease in the temperature of the second and third air, and also affect the heat recovery for waste heat power generation. However, in actual production, the thickness of the material layer is difficult to measure directly, so the pressure of the material cooler is usually used to reflect the thickness of the material layer, the greater the thickness, the greater the pressure. Therefore, based on the idea of hybrid systems, this paper establishes a grate cooler control model based on grate cooler pressure output.[4-5]

2.2 The Dominant Factors Affecting the Pressure of Grate Cooler

2.2.1 Grate Speed and Grate Cooler Pressure

The most directly controlled grate cooler pressure is the grate speed (abbreviation: grate speed). Adjust the speed of the propelled material by adjusting the speed of the raft, that is, by adjusting the speed of the grate speed to change the pressure of the cooler. Change the pressure and stabilize it at the optimal layer thickness. Under the condition that the cooling material flow rate of the grate cooler remained unchanged under the same material, the greater the thickness of the clinker material layer, the greater the grate cooler pressure and the need to increase the grate speed; If the thickness of the material layer is smaller, the pressure of the grate cooler is smaller and the idle speed needs to be reduced. This is the current main control technology for the grate cooler: adjust the grate cooler pressure by idling to stabilize the layer thickness. Therefore, the grate speed and pressure of the grate cooler are important variables in grate cooler modeling.

2.2.2 Balance Fan Current and Grate Cooler Pressure

According to the introduction of the cement plant's on-site sintering system control operator, the balance fan, that is, the cooling fan of the grate cooler, is very important for the control of the grate cooler, with good real-time performance and high reference value. For the "off the kiln skin" and other abnormal conditions can be real-time and accurate response and to some extent, the pressure of grate coolers is reflected. The performance is that when the balance fan current increases, the wind pressure increases and the grate cooler pressure decreases. When an abnormal operating condition occurs, the parameter can also change significantly, and the current drop is greater. It represents a larger kiln skin off,it need to ensure a balanced fan speed constant. Therefore, balancing the fan current is also very important, which helps the operator to perform timely operations and stabilize production.

2.2.3 Kiln Current and Grate Cooler Pressure

The Kiln current t is also a key parameter in the grate cooler control, which has important guiding significance for the change of the material quantity in the rotary kiln. At the same time, it can also intuitively reflect the abnormal phenomena such as “off the kiln skin” and “burning flow” in the rotary kiln. When the kiln skin falls, the force of the kiln body will increase instantly, so that the current of the kiln main body will increase instantly. In addition, when the burning flow occurs in the rotary kiln, the current of the kiln main machine will instantly drop, and the clinker after the burning flow will fall into the grate cooler, and will form a large block under the effect of cooling, so that the grate cooler pressure will increase. Therefore, considering the relationship between the kiln host current and the grate cooler pressure also has certain reference value.

2.2.4 Raw Material Quantity and Grate Cooler Pressure

The quantity of raw material to be discharged determines how much clinker is produced. That is, it is determined how many clinker coolers need to be cooled, and it is also common for the production site to have abrupt changes in the amount of raw meal. Therefore, it is necessary to consider the impact of the raw material discharge amount in the grate cooler control. When the quantity of raw material is increased, after a certain time delay, the pressure will increase, and vice versa. In the cement production process, the operation of stopping the material will often occur. Therefore, it is necessary to take into account the sudden decrease in the quantity of material to be discharged in order to ensure a stable grate cooler pressure.

2.2.5 Secondary Air Temperature and Grate Cooler Pressure

After the cooling wind blows through the clinker, it exchanges heat with the high-temperature clinker to form secondary and tertiary air. It is used in the grate cooler and the rotary kiln for combustion, which is crucial to ensure high heat recovery efficiency. At the same time, the chiller clinker temperature is a key indicator for the quality of clinker. The secondary air temperature can effectively reflect the temperature of the grate cooler clinker, which directly affects the thermal efficiency. The higher the secondary air temperature, the more heat is recovered and the higher the thermal efficiency. Therefore, there is a certain relationship between the secondary air temperature and the grate cooler pressure.

2.3 Grate Cooler Typical Working Reference Point Determination

Relying on the historical data of a cement production line in Shandong Province for statistical analysis, combined with the expert experience of operators, a typical working point for a grate cooler with a daily output of 5,000 tons of cement clinker production line can be established. As shown in Table 1.

Table 1: Reference points for key process parameters in grate cooler systems.

No	parameter name	Reference value	Adjustment range
1	Grate cooler for a period of idle speed	9.5 r/m	±0.2 r/m
2	Grate cooler section of grate cooler pressure	5800 Pa	±300 Pa
3	Unloading amount	240 t/h	±10 t/h
4	Kiln main motor current	480 A	±50 A
5	Raw material into kiln hoist current	135 A	±5 A
6	Balancing fan current	45 A	±25 A
7	Balance fan speed	1330 rpm	±15 rpm
8	Secondary air temperature	1040 ℃	±50 ℃
9	Third air temperature	920 ℃	±30 ℃
10	Kiln head negative pressure	-70 Pa	±60 Pa
11	Cooling machine current	45 A	±5 A
12	Kiln smoke chamber temperature	1100 ℃	±100 ℃
13	Kiln tail gas temperature	135 ℃	±15 ℃

3 RESEARCH ON MODELLING OF GRATE COOLER BASED ON TYPICAL OPERATING CONDITIONS

Grate speedand grate cooler pressure model:

$$G(s)=\frac{656.64}{(1+0.001s)(1+111.74s)(1+111.68s)} \quad (1)$$

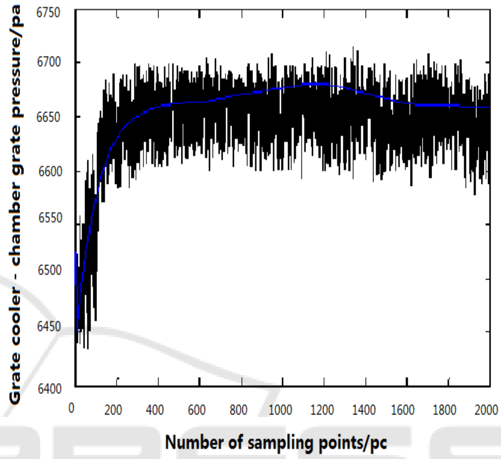

Figure 1: grate speed and grate cooler pressure model test.

Balance fan current and grate cooler pressure model:

$$G(s)=\frac{1.97*10^{-5}(1-1.3*10^{6}s)}{s(1+254.48s)} \quad (2)$$

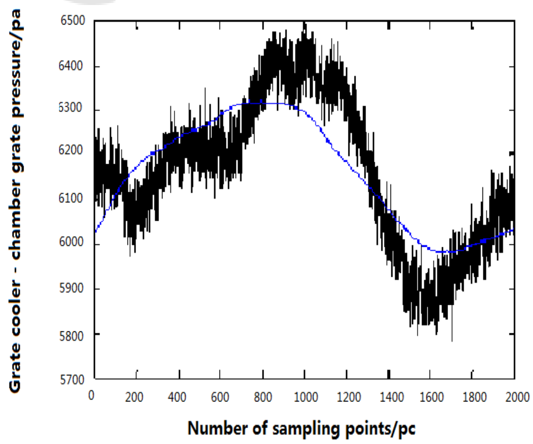

Figure 2: Balanced fan current and grate coolerpressure model verification.

Kiln current and grate cooler pressure model:

$$G(s)=\frac{13.66(1+5183.2s)}{(1+5353.8s)(1+355.69s)(1+950.39s)} \quad (3)$$

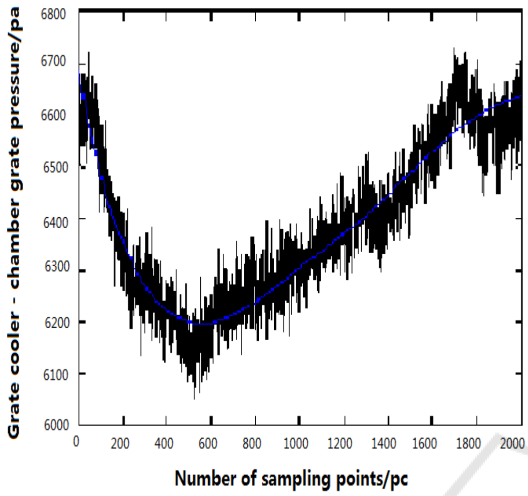

Figure 3: Kiln current and grate cooler pressure model validation.

Input raw material quantity and grate cooler pressure data collected into the system identification toolbox, can get birth raw material quantity and grate cooler pressure model（formula：4）：

$$G(s)=\frac{3.9*10^{-5}(1-1.6*10^{6}s)}{s(1+111.45s)(1+109.24s)}e^{-27.03s} \quad (4)$$

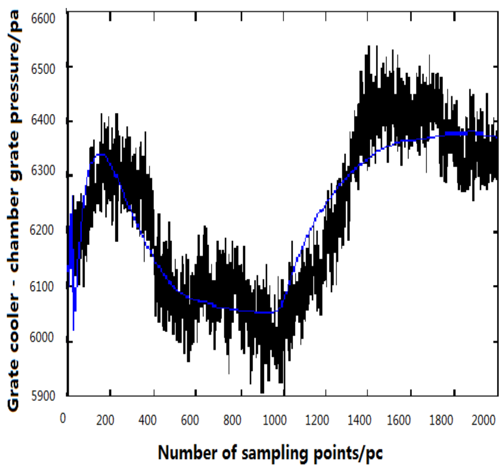

Figure 4: Raw material quantity and grate cooler pressure model verification.

Secondary air temperature and grate cooler pressure model（formula：5）：

$$G(s)=\frac{0.46(1+36074s)}{(1+39518s)(1+0.17s)(1+62.87s)} \quad (5)$$

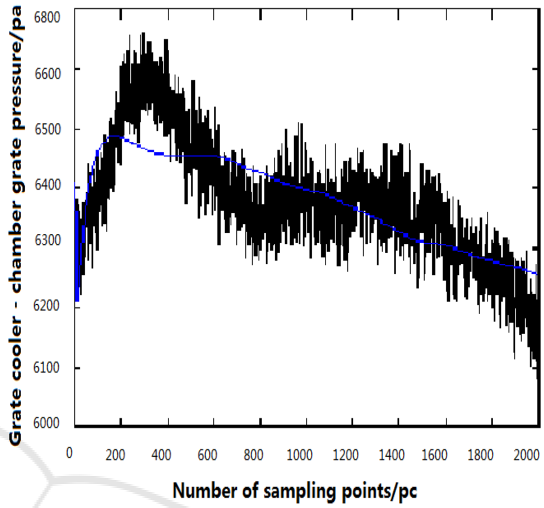

Figure 5: Secondary air temperature and grate cooler pressure model verification.

The above six single input and single output models for grate coolers obtained from the MATLAB system identification toolbox. Entering the verification data in the system identification toolbox proves that the model has certain rationality.

After that, the least squares algorithm was applied to obtain the grate speed, secondary air temperature, and grate cooler pressure models（formula：6）：

$$y(n+2)=-2229+1.13y(n+1)-0.14y(n)+3464u(n+2)-4680u(n+1)+1388u(n)-1.02z(n+2)-0.24z(n+1)+1.32z(n) \quad (6)$$

Similarly, the quantity of raw material, secondary air temperature and grate cooler pressure model（formula：7）：

$$y(n+2)=-188.00+0.93y(n+1)-0.04y(n)-1.43u(n+2)-0.70u(n+1)+1.25u(n)+1.14z(n+2)+0.84z(n+1)-0.86z(n) \quad (7)$$

Similarly, kiln host current, secondary air temperature and grate cooler pressure model（formula：8）：

$$y(n+2)=25378+0.85y(n+1)+0.10y(n)-0.08u(n+2)+0.14u(n+1)+0.03u(n)-0.19z(n+2)+0.27z(n+1)-0.07z(n) \quad (8)$$

Similarly, Balancing fan current, secondary air temperature, and grate cooler pressure model（formula：9）：

$$y(n+2)=91.07+0.80y(n+1)+0.17y(n)+0.03u(n+2)+0.35u(n+1)-0.11u(n)+1.74z(n+2)-0.15z(n+1)-1.54z(n) \quad (9)$$

The above-mentioned four dynamic models of the two-input single-output of the grate cooler obtained by the least-squares method.

Grate speed, secondary air temperature and grate cooler pressure model fitting curve shown in Figure (6)

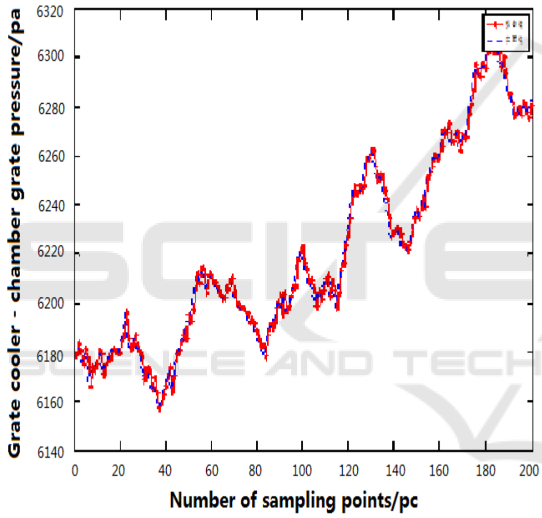

Figure 6: Grate cooler idling, secondary air temperature and grate cooler pressure model fitting curve.

Raw material quantity, secondary air temperature and grate cooler pressure model fitting curve shown in Figure(7)

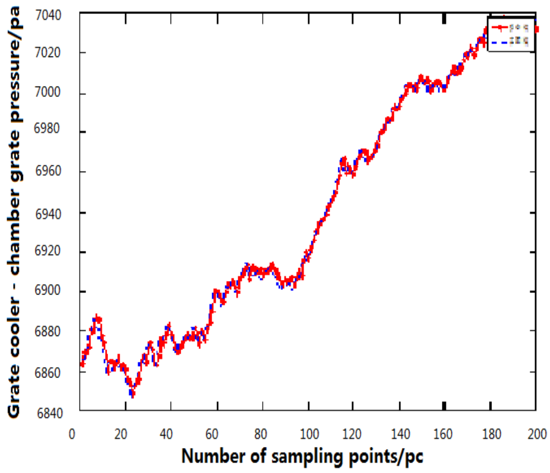

Figure 7: Raw material quantity, secondary air temperature and grate cooler pressure model fitting curve.

Kiln master current, secondary air temperature and grate cooler pressure for the grate cooler shown in Figure(8)

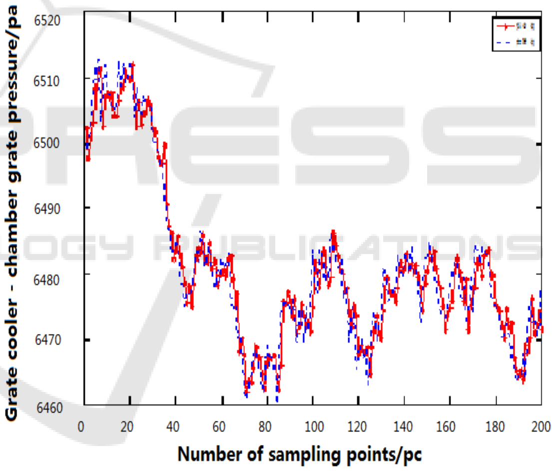

Figure8: Kiln current, secondary air temperature and grate cooler pressure for the grate cooler.

Grate cooler balance fan current, secondary air temperature and grate cooler pressure model fitting curve shown in Figure(9)

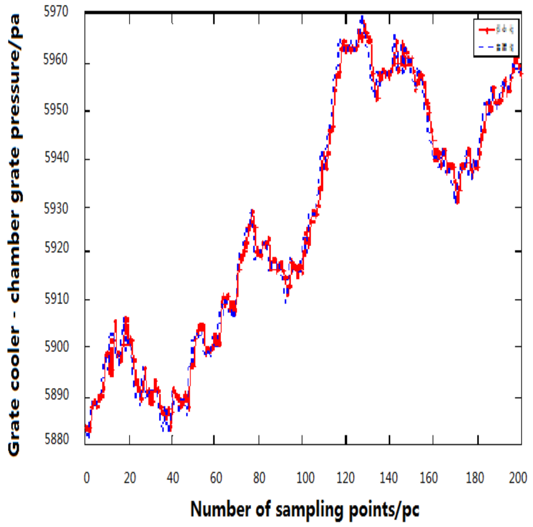

Figure9: Grate cooler balance fan current, secondary air temperature and grate cooler pressure model fitting curve.

4 CONCLUSIONS

In the long-term operation of the grate cooler, the application of a single model to grate cooler model control will have significant limitations. Based on statistical analysis of production site data and expert experience of cement plant operators, this paper identifies the typical operating reference points for the clinker cooler for a 5000 t/d cement clinker production line and typical operating conditions. Through simulation data verification, it proves the practicability and effectiveness of the established model and condition identifier, and lays a good foundation for the subsequent grate cooler model control.

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