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An alumina rotary kiln monitoring system based on infrared ray scanning

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ABSTRACT

In the process of using the sintering technique of rotary kiln to produce alumina, the shape of kiln crust is complex and the temperature measurement is difficult. In order to solve these two problems, an infrared ray scanning and monitoring system of rotary kiln has been developed, which uses infrared temperature measurement and digital filter compensation. From the size and rate of change of the Euclidean distance of the temperature characteristic vector between standard and measured specimen in pattern recognition, the size and rate of change of the kiln surface temperature can be measured and the working condition of alumina rotary kiln can be forecast. The system improves the operation of kiln effectively, enhances the operation rate of facilities and reduces the cost of production.

1. Introduction

The material burning process in the rotary kiln is the most important technology in alumina production by sintering, which directly affects the alumina production and the main technical economic indicators [1]. The quality of kiln crust is the key factor in material production processes with high quality, high yield, low consumption and safety operation. The kiln crust is in balanced between peeling and regeneration, which makes the kiln crust shape change continuously. However, there is difficultly in measuring the kiln crust shape as it is invisible and unable to be directly detected in the operation of rotary kiln [2]. One can use thermal sensors to detect the external temperatures of the stator directly, but the rotary kiln is in motion state and the surface temperature distribution of the rotary kiln is uneven. Therefore, there is not an existing direction measurement method to the temperature of the rotary kiln at present [3–5]. The artificial timing measurement of kiln shell wall temperature is the main method of rotary kiln monitoring in alumina plants now, which can indirectly reflect the thickness of kiln crust and lining. There are many disadvantages to this method, such as intensive labor, poor tracking ability, and adjustments are arbitrary and lagged. In order to solve those problems, according to the characteristics of the shape of kiln crust and lining, an infrared ray instrument measuring temperature was adopted to collect the surface temperature of kiln. By combining this with a digital filter compensating method, a rotary kiln condition monitoring system was developed. The system improves the stability of material sintering, reduces the labor intensity and enhances the efficient of facilities.

2. The production process of alumina rotary kiln

The shape of an alumina rotary kiln is a cylinder with angle of inclination [6]. Pulverized coal is sprayed into the burning zone through the primary air that is 15 m away from the kiln head. They then will combine with secondary air which comes from bottom to cool the high temperature material, burn in high temperature, and release a lot of heat. The raw slurry will then be sprayed into the rotary kiln by slurry pump and move to the kiln head by

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gravity and rotation. The alumina material will generate a series of physical and chemical reactions such as drying, heating and calcining, and then fall on the cooling machine to be cooled [7].

The advantages of non-contact infrared thermometry were discussed in the literature [8,9]. Two problems must be solved if infrared rays are used to measure the temperature during alumina rotary kiln production. First, the length of rotary kiln is 90 m and the length of decomposition zone and sintering zone to be scanned is 45 m. The infrared camera is fixed in the kiln head and the distance between camera and scanning point changes as the scanning angle changes. Because the degree of interference by the air is not the same and the measured standards are not unified, the comparability and accuracy of data are both weak. Second, the water vapor will disturb the infrared temperature measurement. The sprayed water will absorb a lot of heat from the cooling machine that is under the kiln and generate the hot steam which can not be detected by the infrared ray. Under the external influence, the hot steam will variably flow through the kiln, and disturb the temperature measurement by infrared machine.

3. The system temperature compensation

The change in distance between the infrared temperature sensor and the measuring point, the hot steam, dust particles and so on affect the temperature measurement results. In order to improve the accuracy, the compensation and filtering techniques are used for the axial temperature distribution monitoring in the system.

3.1. Dynamic compensation algorithm

There are many researches about dynamic compensation for pressure sensor's response, and the pressure sensor dynamic calibration method is relatively simple [10]. But the research on dynamic error correction for infrared thermometer sensor is very rare, and there is a certain degree of difficulty on the infrared thermometer sensor dynamic response calibration experiment mainly because the detected objects surface temperature changes is often of a gradual process with no mutation [3]. According to scanning distance change, dynamic compensation algorithm must be adopted in the axial temperature distribution profile. The relationship between scanning distance and angle is showed in Fig. 1. When the height of camera is fixed, the scanning distance and compensative temperature can be expressed as follows:

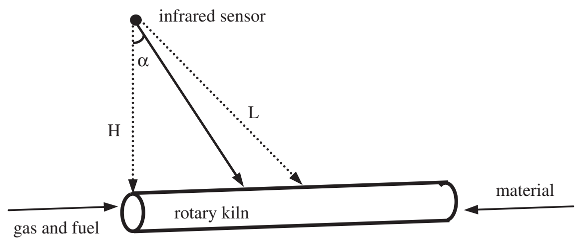

Fig. 1. The dynamic scan diagram of infrared temperature sensor.

$$L = H/\cos\alpha \tag{1}$$

$$\Delta T = T_0(L - H) = T_0(H/\cos\alpha - H) = T_0 H(1 - \cos\alpha)/\cos\alpha \tag{2}$$

$$T_0 = \frac{\Delta T_{max}\cos\alpha_{max}}{H(1 - \cos\alpha_{max})} \tag{3}$$

$$T = T_1 + \Delta T \tag{4}$$

where L is the scanning distance (m), H is the height of camera (m), α is the scan angle (rad), ΔT is the compensative temperature (K), T_0 is the temperature compensation coefficient, T_1 is the measured temperature of infrared sensor (K), T is the axial temperature (K).

3.2. Smoothing filter algorithm

Influenced by dust and steam, the measured temperature will be lower than the actual temperature at a given moment, and the temperature fluctuations will show in the monitor image [11,12]. In order to overcome this phenomenon in the alumina rotary kiln, data pre-processing will be used in temperature signal collection of the system.

At different sampling periods, the monitoring system uses different methods. The first method is to take three samples continuously and get the average value within the same sampling period. The second method is to take seven samples at adjacent temperature point signal and get the weighted average value in different sampling periods. The measured temperature can be expressed as:

$$T_1 = [Q_0 \cdot T(k) + Q_1 \cdot T(k-1) + Q_2 \cdot T(k-2) + Q_3 \cdot T(k-3) + Q_4 \cdot T(k-4) + Q_5 \cdot T(k-5) + Q_6 \cdot T(k-6)]/7 \tag{5}$$

$$Q_0 + Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 = 1 \tag{6}$$

$$Q_0 > Q_1 > Q_2 > Q_3 > Q_4 > Q_5 > Q_6 \tag{7}$$

where Q_0, Q_1, Q_2, Q_3, Q_4, Q_5, and Q_6 are called weight coefficients.

The weight coefficient of past data is small and the weight coefficient of current data is large. So the real-time of temperature collection can be ensured during the filtering process.

4. The feature extraction and condition forecasting of abnormal temperature

The feature extraction and condition forecasting of abnormal temperature is one of the most important purposes of alumina rotary kiln temperature monitoring. The feature selection is the key problem in pattern recognition. The basic task of feature selection and extraction is how to identify the most effective features. Features are generally divided into three categories: physical, structural and mathematical. The identification process includes analyzing the effectiveness of various features and choosing the most representative features. According to the actual tem-