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# Research on the surface temperature compensation model of rotary kiln based on polynomial fitting and piecewise correction function

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ABSTRACT

Infrared scanning temperature measurement is applied more and more widely in rotary kiln, however, the less and less radiation energy can be received by the infrared scanner with the change in scanning angle (kiln head or kiln tail) of the monitoring system, which is one of the main factors that lead to temperature measurement error. The most common method is compensating based on cosine theorem, however, with the distance from the vertical point increasing, the error of temperature compensation is bigger. It's easy to appear the phenomenon of excessive compensation. According to the principle of temperature monitoring, this paper analyzes the reason for inadequate and excessive compensation, the real temperature of target is between the data after inadequate and excessive compensation by experimenting with different compensation methods. By observing the data distribution of the target temperature, it can be found a boundary point in the trend of temperature change (without any compensation), that means the temperature is approximately same when the angle change is very small. Therefore, this paper proposes piece-wise correction model which includes two parts, the first is constant which represents the part where the temperature is unchanged, the second is to apply temperature compensation factor formula acquired by polynomial fitting to original data. Experimental results show that the correction model proposed in this paper can not only describe the relationship between angle and measure error accurately, but also reduce the relative error of temperature measurement to 0.275% successfully.

## 1. Introduction

The temperature measurement system based on infrared scanning is widely used in manufacturing because of the superiority of non-contact, safety and real time. However, in complex environment, the accuracy of temperature measurement has been affected by various factors such as radiation distance, scanning angle and ambient temperature. Rodriguez [1] discussed the effects of distances on temperature measurement and evaluated their contribution to the measurement uncertainty. Zeng Qiang [2] mentioned the effects of measuring angle in his paper and Chang Songtao [3] proposed a method which can remove the effect of ambient temperature on radiometric calibration. In order to improve the temperature measurement accuracy of rotary kiln, it is necessary to carry out specific analyses on each influencing factor. Thus, this paper mainly analyzes and compensates the influence of the measurement angle on the temperature measurement precision of the rotary kiln.

For the special cylindrical structure of rotary kiln, the radiation reception of scanning system at both ends has a certain angle, which leads to the measurement error. The surface temperature monitoring system of rotary kiln based on infrared scanning developed by our team was used for experiments, taking the 300 °C blackbody as radiation source and changing the placement of blackbody to observe the temperature shown in this system, the result shows as Fig. 1.

And then compensating the temperature of both ends by the law of cosines. The result shows as Fig. 2.

Comparing Figs. 1 and 2, we can find the temperature of both ends is lower than center in the condition without any compensation and the temperature of both ends is higher than center in the condition with cosine compensation. The former can be described as inadequate compensation, while the later can be described as excessive compensation. It is extremely significant for researchers to propose an effective compensation method which can avoid these two kinds of

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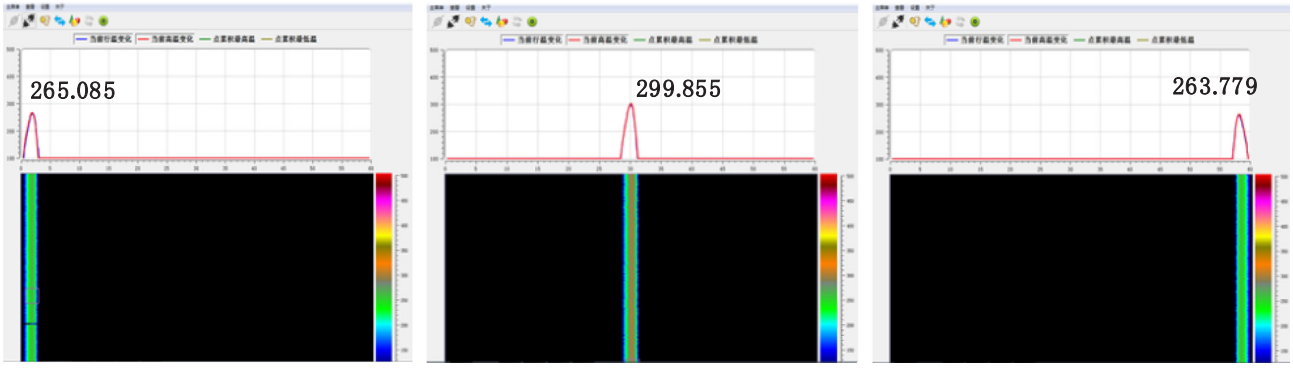


**Fig. 1.** The measured temperature without any compensation of blackbody at different positions.

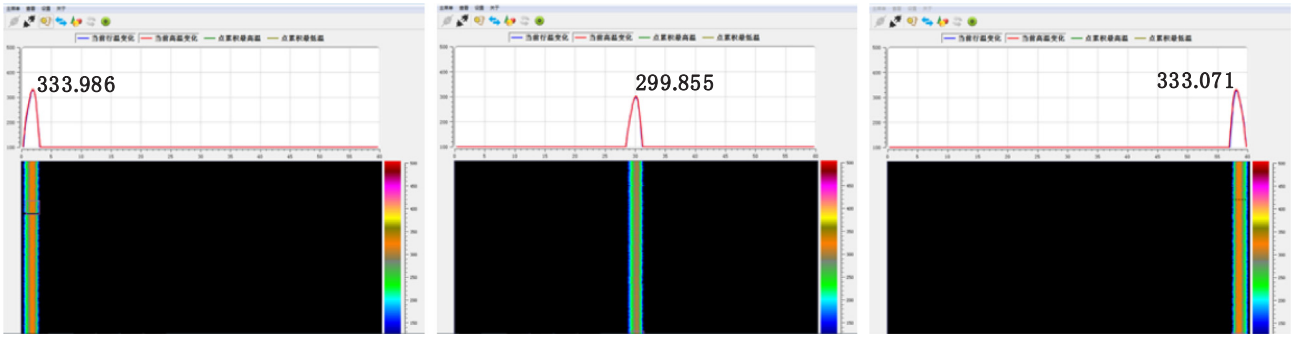


**Fig. 2.** The measured temperature with cosine compensation of blackbody at different positions.

compensation phenomenon and improve the accuracy of temperature measurement. Through improving the traditional method, Wang Linling proposed the linear compensation method in [4] and Guo Zhongyuan proposed the nonlinear compensation method in [5], the common shortcoming of them is conduct compensation as long as the angle is changed. There is a phenomenon that the error caused by angle is close to zero when the angle is small sufficiently during the course of the experiment. At present, the number of sample points of widely-used temperature scanning system is between 700 and 1400 [6]. With the number of scanning points increasing, the difference of adjacent points is smaller. Thus the improving methods also cannot solve the problem of inadequate and excessive compensation.

Aiming to these problems, this paper firstly analyzes the reason for inadequate and excessive compensation. And then conducts experiments to find out the boundary angle that causes the obvious error. Finally, the correction function is be defined based on piece-wise fitting. Through experimental validation, this method can effectively improve the accuracy of temperature detection.

## 2. The reason for inadequate and excessive compensation

### 2.1. Inadequate compensation

According to Lambert cosine law [7], the radiation intensity of the ideal diffuse body (reflector) in any direction is proportional to the cosine of the angle from the vertical. That is

$$I_\theta = I_O \cos\ \theta \tag{1}$$

In this formula, $I_\theta$ is the radiation intensity in the direction of θ from the normal to the observation. $I_O$ is the radiation intensity in the normal

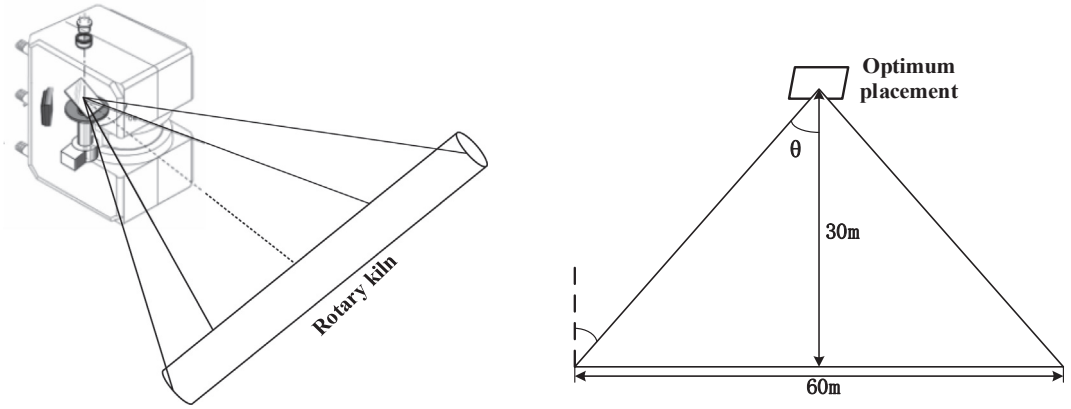


**Fig. 3.** The temperature measurement principle of the rotary kiln surface.

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