Infrared Physics & Technology 79 (2016) 160–164

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Research on application of polynomial fitting technique in rotary kiln infrared temperature measurement system

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HIGHLIGHTS

- A precise nonlinear method for rotary kiln temperature measurement is proposed.
- The cubic polynomial fitting is used to compensate temperature.
- The proposed method effectively improves temperature measurement accuracy.

ARTICLE INFO

Article history:
Received 6 October 2016
Revised 20 October 2016
Accepted 24 October 2016
Available online 26 October 2016

Keywords:
Rotary kiln
Temperature compensation
Polynomial fitting
Measurement accuracy

ABSTRACT

Aiming at the linear temperature compensation algorithm's disadvantage of temperature measurement error in rotary kiln infrared scanning temperature measurement process, this paper proposes a precise nonlinear cubic polynomial fitting temperature compensation algorithm. The proposed algorithm compensates the temperature values of scanning points on rotary kiln surface by following steps: Calculating temperature difference between the real temperature value of rotary kiln and temperature value measured by infrared scanning temperature measurement system; Fitting the temperature difference data with cubic polynomial; Using the obtained function to compensate temperature. Experimental result shows that compared with the usual linear temperature compensation algorithm, the accuracy of proposed algorithm has raised about 2.25 times when cubic polynomial is used.

1. Introduction

Rotary kiln is a thermal equipment for dying and baking materials, it is widely used in the technological process of cement, nonferrous metallurgy, iron and steel metallurgy and building materials and occupies an important role in the production line of these fields, its running status directly affects production quantity, quality and energy consumption, too high temperature or too large thermal swing may cause kiln lining's damage, even results in "red kiln" accident, so it is necessary to monitor calcination circumstances real time [1]. There are a wide range of temperature monitoring devices of rotary kiln, and among these devices, infrared scanning temperature measurement system (ISTMS) has a wide application in rotary kiln temperature measurement process because of its advantages such as non-contact temperature measurement, high stability and simple installation [2]. However, the scanning distance between rotary kiln and ISTMS affects the temperature measurement accuracy seriously, therefore, it is significant to study the influence of scanning distance on the accuracy of infrared temperature measurement. In the past decades, many experts and scholars at home and board have done a lot of research to reduce the impact of measuring distance on infrared temperature measurement. Chrzanowski [3,4] studied the influence of changes of object-system distance on the temperature measurement accuracy of infrared systems and developed a theory which has shown that the difference between the real measuring distance and calibration distance causes significant temperature measurement errors for high temperature objects. Kargel [5] drawn a conclusion that infrared temperature measurement system could not measure objects' temperature preciously when measuring distance between system and object were not determined. Sun [6] analyzed the influence of measuring distance on the temperature measurement accuracy of infrared thermal imager and proposed a method of fitting experimental data to improve temperature measurement accuracy under short-distance condition. Guo [7] analyzed the influence of field angle and measuring distance on the measurement accuracy of infrared systems and introduced an

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http://dx.doi.org/10.1016/j.infrared.2016.10.012
1350-4495/

error compensation method. Zhang [8] proposed a method to reduce the influence of measuring distance on measurement accuracy, the effect principle of the contrast between objects' temperature and environmental temperature, the atmospheric transmittance and field angle of infrared system under close range are analyzed. But for ISTMS of rotary kiln, the scanning distance is generally several tens meters and changes constantly during the measurement process, the method for reducing the influence of measuring distance on temperature measurement accuracy should be easy to realize to ensure the real time of data process. The commonly used linear temperature compensation algorithm [9] compensates the temperature value by measuring the maximum distance between rotary kiln and ISTMS and the maximum temperature difference between the real temperature value measured by hand-hold infrared thermometer and the temperature value measured by infrared detector, calculating temperature compensation coefficient and then getting temperature compensation equation, but this linear compensation algorithm is not accordance with infrared radiation attenuation characteristics of ISTMS, so it has large temperature measurement error. This paper proposes a non-linear polynomial fitting temperature compensation algorithm, experiments show that the proposed algorithm can effectively improve the temperature measurement accuracy.

2. Infrared scanning temperature measurement principle of rotary kiln

ISTMS is an optical, mechanical and electronic integration equipment, which combines infrared radiation temperature measurement technology with optical scanning technology [10], it mainly consists of four parts: optical system, motor and driver, infrared detector, signal processor and transmission module, the optical scanning lens driven by motor rotates to collect the infrared radiation on rotary kiln surface and then reflect the radiation to infrared detector, at the same time, rotary kiln rotates on its own axis to complete the overall scanning of rotary kiln surface, as shown in Fig. 1, then the infrared radiation energy is converted into electrical signal by digital signal processor and then the processor converts the electrical signal into digital temperature signal [11].

3. Linear temperature compensation algorithm

Linear temperature compensation algorithm [12,13] is widely used in rotary kiln infrared scanning temperature measurement process, the algorithm compensates the temperature value of measuring points on rotary kiln surface by determining linear compensation coefficient and compensating temperature value according to the scanning distance between ISTMS and rotary kiln. The specific implementation process is described as follow:

As shown in Fig. 2, where cylindrical object represents rotary kiln, it is supposed that rotary kiln and ISTMS are at the same height, where O represents vertical point between rotary kiln and ISTMS, L represents the length of rotary kiln, h represents the vertical distance between ISTMS and rotary kiln, the distance between kiln head and ISTMS is l, the scanning angle is α, and s represents the scanning distance, it can be calculated by the following equation:

$$s = h/\cos\alpha \tag{1}$$

In order to determine the linear compensation coefficient, the algorithm firstly calibrates the parameters of ISTMS such as the emissivity of rotary kiln and air humidity to ensure that the temperature value of vertical point O measured by ISTMS is in accordance with the real temperature measured by hand-held infrared thermometer in near distance. It is worth mentioning that the temperature values of measuring points on rotary kiln surface measured by hand-held infrared thermometer in near distance can avoid the influences of atmospheric attention and the scanning distance, so it can be regarded as the real temperature value of scanning points on rotary kiln surface. As the coefficient is a fixed value, it can be concluded that when the scanning distance reaches the maximum value, the temperature difference reaches the maximum value.

The calculation method of the maximum scanning distance and the maximum temperature difference can be divided into the following two ways:

1. When the vertical point is on the left side of midpoint of rotary kiln axis:

$$\Delta T_{\max} = T_{rt} - T_{it} \tag{2}$$

where $\Delta T_{\max}$ represents maximum temperature difference, T_{rt} represents the real temperature value on rotary kiln tail measured by hand-held infrared thermometer in near distance, T_{it} represents the temperature value on rotary kiln tail measured by ISTMS without compensation.

At the same time, the maximum scanning distance difference can be expressed as below:

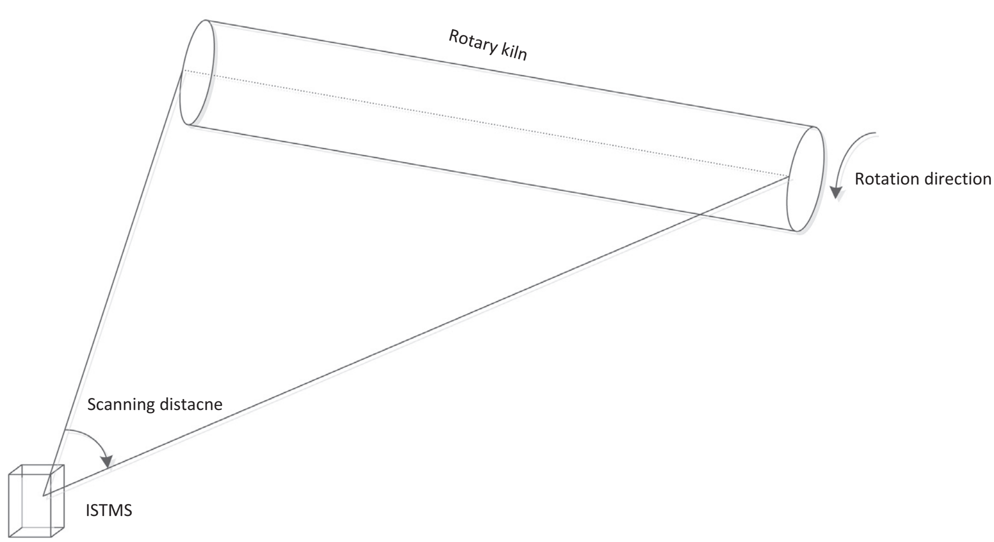

Fig. 1. Scanning temperature measurement principle of ISTMS.