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Study on infrared colorimetric temperature measurement in vacuum furnace

XiantaoYang[1], Jie Yang[2], YueGu[3]
1.Jilin EngineeringNormal University, Changchun 130052, China
2. China Machinery Test Equipment Co., LTD., Changchun 130000, China
3.Changchun Datang No. 3 Thermal Power Plant, Changchun 130000, China

Abstract: In view of the situation that on-line continuous temperature measurement can not be realized and the cost of thermocouple temperature measurement is high, the infrared dual-light colorimetric temperature measurement method is proposed in this paper. Based on Wien's formula, a temperature model is established. Through theoretical analysis and experiment to select the appropriate double light wavelength, through laboratory calibration and field calibration proved the feasibility of the infrared double light colorimetric temperature measurement system adopted in this paper, not only can realize online continuous temperature measurement, can realize smelting in strict accordance with the smelting process curve, to ensure the time of steel and the content of each element, it is of great significance to China's metallurgical industry.

Key words: vacuum furnace, double light colorimetry, temperature measurement, smelting

I. Introduction

In this paper, the temperature detection of vacuum furnace in the smelting of stainless steel is analyzed and studied. The temperature of molten steel is an important parameter in the smelting process. The temperature of molten steel is too high or too low in the smelting process will affect the normal production, and the high temperature of molten steel will seriously corrode the furnace lining. When the temperature of molten steel is too low, the quality of the alloy will also be affected. The result of steel temperature control not only affects the yield of alloying elements, the quality index of finished products, but also has an important impact on the energy consumption in the smelting process and the service life of the furnace lining. Therefore, temperature measurement is very important for the composition and pouring quality of ferroalloy.

At present, the temperature measurement of vacuum furnace mainly depends on the contact temperature measurement, and the thermocouple is often used in smelting. Thermocouple temperature measurement is a waste of resources, and can not achieve on-line continuous temperature measurement, the end point hit rate is low.

II.The principle of temperature measurement and hardware structure

Double wavelength temperature measurement method is also known as double light colorimetric temperature measurement method, is to obtain two different wavelengths of radiation energy, and then calculate the temperature according to the ratio of radiation energy, at the same time need to perform blackbody calibration of the instrument, at this time the measured temperature is called color temperature.

Assume that the selected central wavelength is λ_1 and λ_2, and the radiant energy near them is E_{λ_1} and E_{λ_2}, according to Wien,The basic formula can be obtained:

$$E_{\lambda_1} = K_1 \cdot \varepsilon_{\lambda_1} \cdot C_1 \cdot \lambda_1^{-5} \cdot e^{-\frac{C_2}{\lambda_1 T_C}} \Delta\lambda_1 \quad (1)$$

$$E_{\lambda_2} = K_2 \cdot \varepsilon_{\lambda_2} \cdot C_1 \cdot \lambda_2^{-5} \cdot e^{-\frac{C_2}{\lambda_2 T_C}} \Delta\lambda_2 \quad (2)$$

Amongthem, K_1, K_2 are the instrument constants of the two channels, ε_{λ_1}, ε_{λ_2} are the emissivity of the two wavelengths, $\Delta\lambda_1$, $\Delta\lambda_2$ are the bandwidth of the two wavelengths, ε_{λ_1} and ε_{λ_2} are different because the emissivity is related to the radiation wavelength.

The ratio of E_{λ_1} and E_{λ_2} is K ,denoted as follows: $K = \frac{E_{\lambda_1}}{E_{\lambda_2}} = \frac{K_1 \cdot \varepsilon_{\lambda_1}}{K_2 \cdot \varepsilon_{\lambda_2}} \cdot \left(\frac{\lambda_1}{\lambda_2}\right)^{-5} \cdot e^{-\frac{C_2}{T_C}\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)} \left(\frac{\Delta\lambda_1}{\Delta\lambda_2}\right)$ (3)

The bandwidth of the two fi lters is the sameand are equal,and the object is assumed to be a pure blackbody, andare both 1, so (3) can be written:

$$T_C = \frac{C_2\left(\lambda_2^{-1} - \lambda_1^{-1}\right) \cdot T_S}{C_2\left(\lambda_2^{-1} - \lambda_1^{-1}\right) - T_S \cdot \ln\left(\varepsilon_{\lambda_1} / \varepsilon_{\lambda_2}\right)} \quad (4)$$

According to the above formula, if the reflectance of the measured object is fixed and not affected by wavelength changes, then the real temperature of the measured object is the same as its color temperature, and the measurement accuracy is not affected by the measured target. When selecting the wavelength, its influence on the emissivity should be considered. If the distance between the two wavelengths is large, that is K , the ratio of radiant energy is large, the resolution of the thermometer is high; However, the greater the spacing, the greater the emissivity difference between the two wavelengths, which will increase the measurement error. In this system, when two wavelengths are considered to be close to each other, their corresponding emissivity is considered to be approximately equal. Therefore, the two wavelengths selected should be as close as possible, and then it is considered that the color temperature of the measured object is equal to the real temperature.

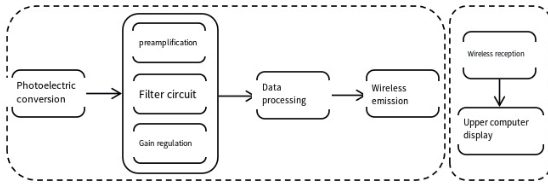
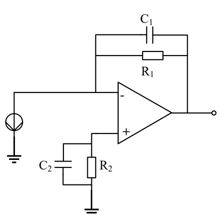
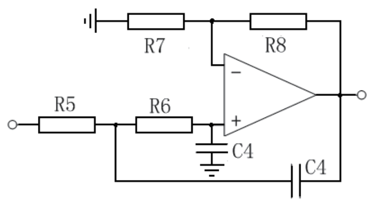


Figure 1 Block diagram of the system function

The functional block diagram of the system is shown in Figure 1. The photoelectric conversion link changes the optical signal into electrical signal through the photoelectric sensor; The electrical signal transformed by the received optical signal is very weak, so the pre-amplification link is designed; The noise signal is amplified by the filter circuit; The radiation intensity of the instrument will change for a long time, which is adjusted by the gain regulating circuit. Finally, the analog signal is converted into a digital signal, and the data is processed and calculated by the CPU. Finally, the data information is sent to the upper computer through the wireless transmitter module, and then the upper computer carries out comprehensive processing and calculation compensation for the data.

The signal collected by the photodetector is relatively weak, and the received weak signal is amplified through the operational amplifier. The pre-amplification circuit of the system is shown in the following figure.





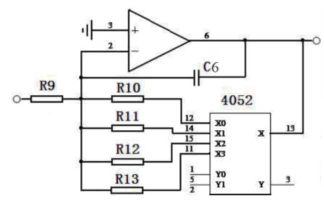


Figure 2 Pre-amplification circuit Figure 3 Second-order volt-controlled low-pass filter circuit Figure 4 gain regulation circuit

The output voltage of the preamplifier circuit is as follows: $U_o=-\frac{R_1}{1+j\frac{f}{f_h}}I$ (5)

Where, f is the frequency of the photocell output signal; $f_h=\frac{1}{2\pi R_1C_1}$; If the signal frequency in the circuit is satisfied, it can be obtained. $f<<f_h$, $U_o=-R_1I$.

According to the working frequency of the temperature measurement system, this design uses a low-pass filter circuit, low-pass cutoff frequency is, its transfer function is as follows: f_H $H(S)=\frac{K}{S^2+aS+b}$ (6)

The formula, $K=\frac{A_3}{R_5R_6C_4^2}$; $A_3=1+\frac{R_8}{R_7}$; $a=\frac{1-A_3}{R_6C_5}+\frac{1}{R_5C_4}+\frac{1}{R_6C_4}$; $b=\frac{1}{R_5R_6C_4^2}$. If taken $R_5=R_6$, its cutoff frequency is:

$f_0=\frac{1}{2\pi R_6C_4}$ (7)

Voltage magnification is: $A_u=\frac{R_7+R_8}{R_7}$ (8)

Gain regulation circuit magnification is: $A_u=-\frac{R_X}{R_9}$ (9)

The system detects the incident and processing of two wavelengths of the circuit in a symmetrical form, which can ignore the influence of electrical parameters on temperature measurement. The transmittance of the filter can not reach 100%, but also affected by the electrical parameters, if all the above factors are assumed to be monotone influence K_T, so the K_T complete expression can be obtained, that is, formula (10) is shown:

$$K_T=\frac{\partial K}{\partial T}=\frac{\varepsilon_{\lambda1}}{\varepsilon_{\lambda2}}\cdot\cdot\frac{I_{\lambda1}}{I_{\lambda2}}\cdot\frac{\delta_{\lambda1}}{\delta_{\lambda2}}\cdot\left(\frac{\lambda_1}{\lambda_2}\right)^{-5}\cdot\frac{c_2}{T^2}\cdot\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)\cdot e^{-\frac{C_2}{T}\left(\frac{1}{\lambda1}-\frac{1}{\lambda2}\right)} \quad (10)$$

Through the experiment, the filter selected by the system is the infrared narrow-band pass filter, the central wavelength is λ_1=800nm and λ_2=1000nm, the bandwidth δ_λ is 22nm, and the peak transmittance is 90%.

III.Calibration

The thermometer after two levels of calibration, respectively laboratory calibration, and smelting site calibration.

Laboratory calibration, mainly determine the ratio of the instrument constant of the two channels μ, that is K_1/K_2, in addition, the laboratory calibration also determines the emissivity at the wavelength of the filter selected by the two channels ε_1 and ε_2 the error brought by the difference. In the selection of filter experiment, the corresponding data of 800nm and 1000nm wavelength are used as reference for laboratory calibration data.

First, the ratio of the two channels K_1/K_2 of instrument constants was determined, and the experimental value was 0.5462, μ which compensated for the error caused by the different sensitivity of the photodetector at the two wavelengths and the different electrical parameters. In order to ensure the consistency of temperature characteristics and conversion efficiency characteristics, the same kind of silicon photocell is selected for the two detectors, and there is no choice of different types of silicon photocells for different spectral sensitivity, but the sensitivity of the same kind of silicon photocell at 800nm and 1000nm is obviously different.

Since this paper is aimed at the measurement of the temperature of molten steel after melting in vacuum furnace, the temperature correction range is 1400℃-1900℃ to ensure the measurement accuracy of this system. The modified fitting curve of this paper is shown in the following formula.

$$T_X = -6.571\times10^{-4}T^2 - 1.392T + 2094 \quad (11)$$

The above formula T_X is the corrected temperature, which can be considered to be the actual temperature of the isothermal blackbody.

Due to the calibration of the blackbody furnace used in the laboratory, it is very different from the actual smelting process, and the calibration result only determines the basic parameters of the instrument. The field calibration can improve the measuring accuracy of the instrument, and is more suitable for the application environment. It is the correction of the temperature compensation model.

The 0.5 ton vacuum furnace of a factory is selected for on-site calibration, and thermocouple is still used as the temperature measurement standard. The temperature is measured in the smelting process stage of the vacuum furnace selected in the calibration, and the average value is measured three times in each stage. The results are compared with those measured by the compensation model of the thermometer. When measuring the temperature with the thermocouple, the workers are required to put the vacuum furnace in a constant state, that is, to give the vacuum furnace a constant temperature power, so as to ensure the accuracy of the data.

Table 1 Comparison of temperature measurement values of on-site calibration vacuum furnace (unit °C)

Thermocouple		1520.3	1537.4	1558.8
Thermometer	The first time	1517.6	1534.6	1559.7
	The Second time	1517.2	1535.8	1560.2
	The Thirdtime	1516.8	1535.0	1561.3
	The fourth time	1517.5	1536.1	1560.6
	Averagevalue	1517.3	1535.4	1560.5

It can be seen from the data in the above table that with the change of smelting process, the environmental adaptability of temperature compensation model is very good, the measurement accuracy is more accurate, and it can meet the needs of the site. However, the compensation model does not calculate the standard deviation and relative standard deviation, so there are still systematic errors in this system. The measurement accuracy of the temperature compensation model can meet the requirements of the field process after the positive value is added to the experimental steel. But the smelting of different alloys should have different corrections, so a database should be established, and the corresponding data can be queried and retrieved when the temperature is measured.

IV. Error analysis

The infrared double light colorimetric temperature measurement system is designed based on the ideal environment, so the error is inevitable, and the error is also an important sign to consider the performance of a measuring equipment. According to the structural characteristics of the system, the reasons for the error are analyzed as follows:

1. Error caused by emissivity. This system is based on the blackbody theory to establish a model, and the actual working environment can not be blackbody, in the processing of object emissivity, the emissivity of the two channels according to equal treatment, and different objects, different wavelengths of emissivity will not be exactly the same, can only say that the emissivity of similar wavelengths is also relatively close.

2. Error caused by temperature compensation model. When the temperature compensation model is established, the entire temperature field is not modeled, and the sampling point is relatively fixed, so there is bound to be model errors.

3. Measurement error caused by optical system. Although the system uses a symmetrical optical path, and the distance between the two sampling points is very close, there are still errors caused by the position deviation of the imaging points of the two optical paths.

V.Conclusion

Through the field experiment, it is found that the double light colorimetric temperature measurement method can be better applied to the metallurgical industry, and can achieve online continuous temperature measurement, and the economic benefits are obvious. The next step will be the establishment of temperature field models for vacuum furnaces of different tonnage, so as to achieve higher measurement accuracy and better application in production practice.

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