Measurement of the Molten Steel Temperature Using the Sapphire Fiber

사파이어 광섬유를 이용한 용선 온도측정

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Abstract

Sapphire fiber has been used to provide an optical path for the total radiation pyrometry. In measuring the temperature, we use the two-color detector, which consists of a high-performance Silicon detector mounted in a "sandwich" configuration over a Germanium detector. Sapphire fiber can withstand high temperature in the molten steel for two and a half hours. The maximum value of the error is the ±2.5℃ in the range of 1520℃ ~1600℃. This paper presents the simple scheme for measuring the molten steel temperature in the blast furnace of the iron & steel making process.

1. Introduction

Sapphire single-crystal rod has been used to provide an optical path for total radiation pyrometry. Sapphire single-crystal became available in the 1970s. They can be obtained in lengths of meters. Recently, they have been combined with photoelectric sensors for the high temperature optical fiber thermometry systems with rapid response and superior precision. They have even been proposed to replace thermocouples. The sapphire fiber serves as a wave-guide to transfer the radiation from the high temperature region to the detector. Usually, sapphire fiber can be projected into the high temperature region like a blackbody cavity.

2. Theory and Experiment methods

The intensity for temperature measuring purposes is frequently expressed in terms of wavelength λ. Then Plank's law [1] is

$$I(\lambda) = \frac{C_1 \lambda^{-5}}{\exp(\frac{C_2}{\lambda T} - 1)} . \qquad (1)$$

Here the first radiation constant C_1 has a value $C_1 = 2hc^2/n^2$ which, for n is 1 and c is the velocity of light in a vacuum has a value of $1.19 \times 10^{-16} \cdot m^2/s$. The second radiation constant $C_2 = hc/nk$ which for vacuum properties has the value $0.0143m - K$ As the surface temperature increases, the emittance increases at all frequencies and the frequency of maximum emittance increases proportionally with temperature.

In Experiments, sapphire fiber is a single crystal of sapphire (AL_2O_3) grown in the form of a thin rod ($425 \pm 25 \mu m$ diameter). The length varies according to application, but 1000mm or 2000mm lengths are typical. As figure 1 shows, the sapphire fiber transmits the radiance signal from the blackbody to the optical detector. Sapphire fiber can withstand the high temperature in the molten steel for two and a half hours. It can be connected to the photo diode through an air gap. To measure the temperature, we use the two-color detector, which consists of a high-performance Silicon detector mounted in a "sandwich" configuration over a Germanium detector. The Si photo diode responds to radiation from 400nm to 1000nm. Longer wavelengths pass through the silicon and detected by Ge photo diode. The detectors are ideal for fiber optic power measurements demanding maximum sensitivity at both 800nm and 1300nm. The R-type thermocouple and sapphire fiber are submerged into the molten steel. The processor indicates the temperature of the thermocouple. The sapphire fiber transmits a light energy to a remote two-color detector. At the detector, the light energy is converted into an electrical signal into a temperature reading by use of the Planck Equation.

3. Experiment results

Sapphire fiber can withstand high temperature in the molten steel for two and a half hours. The maximum value of the error is the ± 2.5℃ in the range of 1520℃ ~1600℃. The great advantage of the high temperature measurement using the sapphire fiber is simplicity and good chemical corrosion resistance. There will be a number of applications of this measurement method for the iron & steel making process.

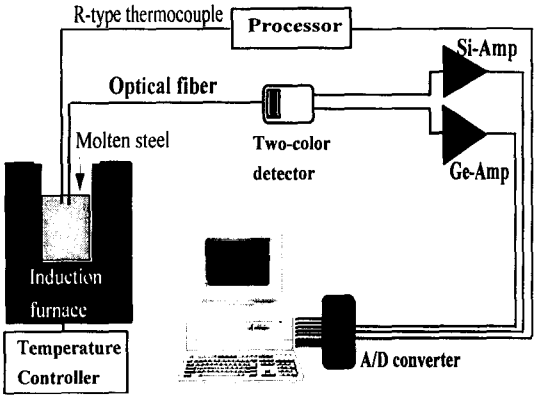

Fig.1 Schematic of the experimental set up for measuring the molten steel temperature.

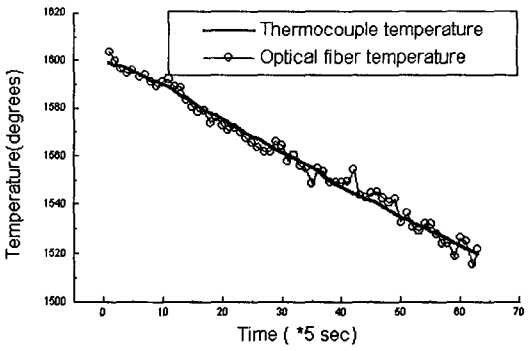

Fig. 2 The results of the molten steel temperature measurement depends on the optical fiber method and thermocouple.

References

1. Thomas D.McGee, Principles and methods of temperature measurement, pp.326, Wiley, New York(1988).