Pyrometer with tracking balancing

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Abstract. Currently, one of the main metrological noncontact temperature measurement challenges is the emissivity uncertainty. This paper describes a pyrometer with emissivity effect diminishing through the use of a measuring scheme with tracking balancing in which the radiation receiver is a null-indicator. In this paper the results of the prototype pyrometer absolute error study in surfaces temperature measurement of aluminum and nickel samples are presented. There is absolute error calculated values comparison considering the emissivity table values with errors on the results of experimental measurements by the proposed method. The practical implementation of the proposed technical solution has allowed two times to reduce the error due to the emissivity uncertainty.

1. Introduction

When using pyrometric devices one of major metrological problems is the control object emissivity uncertainty, due to the fact that this coefficient depends on measured temperature, the test object surface texture and the range of wavelengths in which radiation pyrometric measurement is checked. For example, the integral value of emissivity at the same thermodynamic temperature of the brick lining is 0.8...0.9, and aluminum is 0.05...0.2 [1], and by the steel surface temperature range 730...1080°C at a wavelength of 0.9 µm, it changes more than 50% [2]. Consequently, the thermometer indications without exact emissivity specification in incorrect metering values of this coefficient can vary significantly. Along with this the instrumental error of such a pyrometer does not exceed one percent. The emissivity values, most often, are given in special tables or graphs, with accuracy a few percents. Calculations of the emissivity values specifying errors effect on the magnitude of measured temperature error show that at a deviation of emissivity predetermined value from the true 1%, for example, at the wavelength of 7-14 µm in the range of measured temperatures from 250 to 500 °C can lead to absolute error of temperature from 0.5 % to 2.5 %.

2. Problem statement

There are various ways to reduce the emissivity influence of the control object on the pyrometer readings so in [3] a pyrometer with automatic emissivity correction is proposed, and in [4] a new emissivity measurement device for the infrared spectrum is proposed. In [5] classification ways of the emissivity influence considering, used in pyrometry is proposed. The greatest application have methods that require prior information on emissivity of the control object [6], which is not always convenient technologically. Principle of spectral relations is currently the most widely used instrumental method in pyrometric devices [7]. However, it is not possible to take into account the temperature dependence of the emissivity as a wavelength function. In this article the pyrometer, in which emissivity influence decrease is implemented by the method proposed in [8], is suggested. In this method the process of pre-information on the control object emissivity is actually automated. The device implements the method of measured surface radiation temperature comparison with the sample surface temperature, which is identical to controlled surface. The temperature of controlled surface is measured by the contact thermometer.
3. Theory
Functional diagram of the pyrometer shown in Figure 1.

The thermometer works as follows. Before the measurements beginning a sample of material with the surface identical to the surface of the test object is established into the source of infrared radiation SIR integrated in the device. On the infrared detector IRD via a modulator made in the form of the rotating mirror alternately receives the flows F1 from the object of control and F2 from the internal radiation source. The modulator rotates by the stepper motor SM through a stepper motor controller SMC control signal from the microcontroller. The position of the modulator is controlled by an optical position sensor PS. Flows F1 and F2 measured by the light receiver are compared with the help of the microcontroller and their difference signal is generated by negative feedback control action via the actuator to the heater of the SIR.

In the approximation of the Stefan-Boltzmann flows F1 and F2 can be described by the dependence

$$\Phi = \sigma \cdot \varepsilon \cdot T^4 \cdot A,$$

where: T is the temperature controlled radiating surface, K; \( \sigma \) – Stefan-Boltzmann constant, \((5,6697\pm0,0029)\ \times 10^{-12}\ \text{W/(m}^2\text{K}^4)\); \( \varepsilon \) is the emissivity of heated controlled surface; A is the geometrical parameter visiwave square heated surface, m².

Because the emissivity of the control object \( \varepsilon_{OC} \) and material sample placed in the source of infrared radiation \( \varepsilon_{SIR} \) are the same

$$T_{OC} = \frac{\sqrt{\varepsilon_{SIR}}}{\sqrt{\varepsilon_{OC}}} \cdot T_{SIR} = T_{SIR}.$$

Thus the equality of the control object surface temperature \( T_{OC} \) and the surface temperature of the sample material placed in the source of infrared radiation \( T_{SIR} \) is ensured.
At achieving flows equality $F_1$ and $F_2$ the true temperature of the source of infrared radiation is measured by the contact temperature sensor $DT$ microcontroller and displayed on the temperature indicator $I$ either a personal computer $PC$ as the temperature of the test object.

When measuring the temperature of real objects, a common way of accounting for the control object emissivity value is the use of reference or pre-defined values. The values of the emissivity given in literature and documentation on poromerics the transducers have an uncertainty value $\varepsilon = \Delta \varepsilon$. Calculations of the temperature measurement absolute error from the emission coefficient parametric error $\Delta \varepsilon$ produced by the formula [5]:

$$
[\Delta T] = \frac{1}{n} \left[ 1 - \left( \frac{T_0}{T} \right)^n \right] \frac{\Delta \varepsilon}{\varepsilon} \cdot T
$$

where: $T$ – true surface temperature of OK, K; $T_0 = 27$ K – reflected background temperature; $\Delta \varepsilon$ - parametric error of the task of emissivity; $\varepsilon$ is the integral value of emissivity; $n = 4.83$ – coefficient determined by the spectral interval $\Delta \lambda = 7\text{--}14$ microns.

4. The results of the experiments
In work researches of the pyrometer absolute error in measuring the temperature of aluminum and nickel samples with temperature $T_{OC} = 100^\circ C \pm 0.1^\circ C$ were made. In this connection the absolute error of temperature measurement by the pyrometer, operating on the proposed method amounted to aluminum $3.5^\circ C$. When determining the estimated temperature of the aluminum sample by the formula (3) using the emissivity value equal to 0.2, taken from the reference tabulated data [1], with the introduction coefficient parametric error of the $\Delta \varepsilon = 0.05$ the estimated absolute error in the surface temperature of $100^\circ C$ was $7.5^\circ C$. And at temperatures of $200^\circ C$ and $500^\circ C$ this error was $15^\circ C$ and $124^\circ C$, respectively. Similarly, when determining the nickel sample estimated temperature with the emissivity value 0.07 with the introduction coefficient parametric error $\Delta \varepsilon = 0.02$ the estimated absolute error in the surface temperature of $100^\circ C$ was $12^\circ C$, and at temperatures of $200^\circ C$ and $500^\circ C$ this error was $12^\circ C$ and $97^\circ C$, respectively.

As an infrared detector in the pyrometer thermoelectric receiver MLX90614ACC with built-in ADC was applied. The spectral sensitivity of the receiver in accordance with the passport data of the manufacturer lies in the range $7\text{--}14$ microns. As contact temperature sensor is used the the p-n junction of transistors KT814A, calibrated in a thermostat within $\pm 0.1$ C. Temperature measurement instrumental error of $DT$ is amounted to $0.2^\circ C$.

5. Conclusions
The implementation of the proposed technical solution in the pyrometer has allowed, as shown by the results of the experiment, more than twice to reduce the error due to the blackness coefficient uncertainty. In addition, the infrared detector is a null-indicator in the pyrometer according to the functional diagram with tracking balancing, is shown in Fig. 1. The infrared detector is a measuring tool for balancing two streams: from the test object and from the built-in pyrometer the source of infrared radiation. Therefore, the scheme of such device is not sensitive to temperature and time instability of infrared detector parameters and the enhancer circuit.

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