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New method for contactless temperature measurement of highly reflecting objects in outdoor conditions*

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A method for contactless temperature measurement using multispectral infrared pyrometers was presented by Tank a few years ago. The method was successfully applied to highly reflecting objects of moderate temperatures. Good accuracy was achieved but only for indoor conditions. The method assumes that the environment is a blackbody. The assumption cannot be accepted for some industrial cases, especially for outdoor conditions as the sky radiation does not satisfy the Planck law. A new method acceptable for outdoor conditions has been developed.

1. Introduction

Radiation from any object consists of two components – the radiation emitted by the object and the radiation reflected by the object (Fig. 1). The first component depends on the two parameters of the object – its temperature T_o and emissivity ε_o. The second component is generally the reflected radiation originating in the environment of the object (the radiation of the Sun, sky, the neighbouring objects and atmosphere) and depends on many environment parameters.

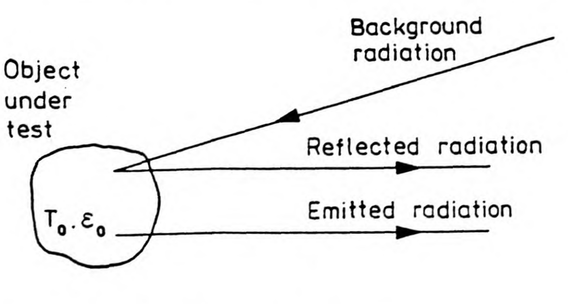

Fig. 1. Structure of a thermal signal

The first component – the emitted radiation – carries useful information about the parameters of the tested object. The second component – the reflected radiation

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– does not give us any useful information; it carries disturbances. But, unfortunately, the reflected radiation cannot be separated from the emitted one and both the components come to the input of the infrared pyrometers or thermographs.

The reflected radiation is negligible when the emissivity of the object is close to unity and its temperature is high. But the reflected radiation is strong and its influence has to be corrected especially for highly reflecting objects of moderate temperatures.

2. Classical method

A new method for contactless temperature measurement using multispectral infrared pyrometers was developed by TANK from Germany a few years ago [1]. The method was advantageously applied to the case of highly reflecting objects of moderate temperatures (emitting no visible radiation), where conventional methods fail.

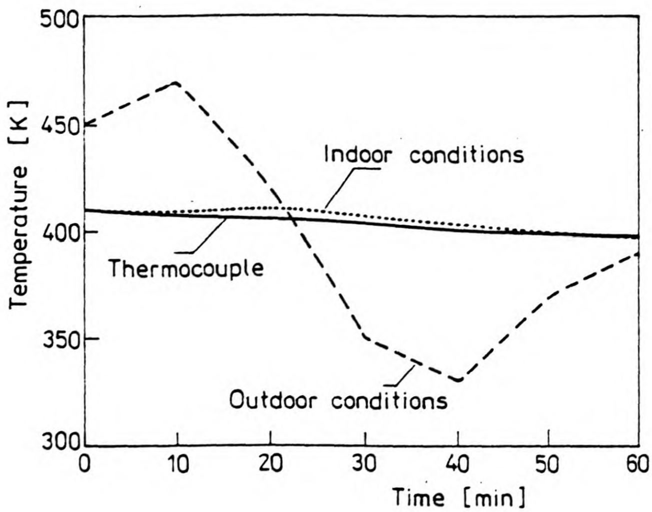

Fig. 2. Temperature of a tested object over time (— thermocouple, ---- multispectral pyrometer)

The method assumes that infrared radiation from the surface of a grey, opaque object is determined by three parameters: its temperature T_o, its emissivity ε_o and the temperature of its environment T_e. Measurement of the emerging radiation at n different wavelengths delivers the functional values for a set of n equations:

$$\left.\begin{array}{l} y_1 = \varepsilon_o L_{\lambda_1}(T_o)+(1-\varepsilon_o)\, L_{\lambda_1}(T_e) \\ y_2 = \varepsilon_o L_{\lambda_2}(T_o)+(1-\varepsilon_o)\, L_{\lambda_2}(T_e) \\ y_3 = \varepsilon_o L_{\lambda_3}(T_o)+(1-\varepsilon_o)\, L_{\lambda_3}(T_e) \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ y_n = \varepsilon_o L_{\lambda_n}(T_o)+(1-\varepsilon_o) L_{\lambda_n}(T_e) \end{array}\right] \qquad (1)$$

The $y_1, y_2, \ldots, y_n$ are the measured values of the emerging radiation at n different wavelengths; object temperature T_o, its emissivity ε_o and the temperature of its environment T_e are unknowns. To determine the three unknowns T_o, ε_o, T_e there have to be given at least three measured values n. Measurement at more than three wavelengths allows the application of balancing calculation to increase the accuracy of the results.

The method presented above was tested experimentally. Very good accuracy has been achieved in laboratory, indoor conditions. The temperature of highly reflected objects of moderate temperatures (300–600 °C) has been determined usually with less than 1–2% deviation from thermocouple measurement. However, the accuracy has been much worse for outdoor conditions. The temperature of the objects has been sometimes determined with 20–40% deviation from thermocouple measurement (Fig. 2).

The method assumes that radiation from both the object and the environment completely fulfil the Planck law. This assumption is satisfied for indoor conditions. However, as it is seen, the environment radiation for outdoor conditions does not fulfil that law (Fig. 3). It causes a decrease of accuracy of Tank's method in outdoor conditions.

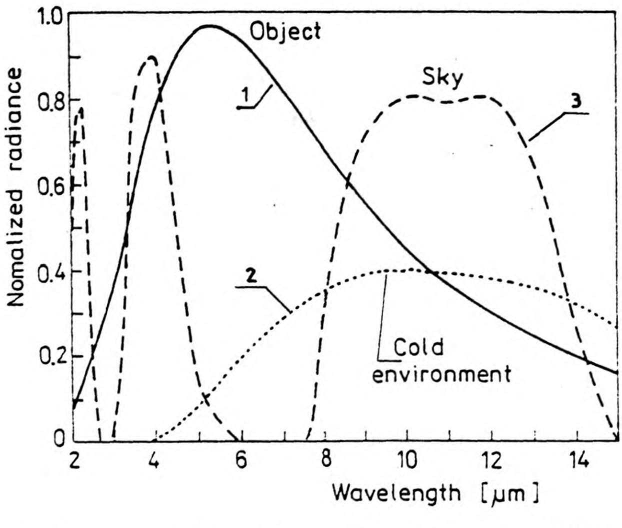

Fig. 3. Spectral radiance of: 1 – a highly reflective object (temperature $T_o = 500$ K, emissivity $\varepsilon_o = 0.1$), 2 – typical indoor environment (temperature $T_e = 290$ K, emissivity $\varepsilon \simeq 1$), 3 – the sky for a typical autumn day

3. New method

Environment radiation for outdoor conditions usually does not fulfil Planck law. This means that the temperature of moderate and highly reflecting object of moderate temperatures for outdoor conditions should not be determined from the set of Eqs. (1). But that set can be transformed to the new form:

$$\left.\begin{array}{l} y_1 = \varepsilon_o L_{\lambda_1}(T_o)+r_1(\varepsilon_o) \\ y_2 = \varepsilon_o L_{\lambda_2}(T_o)+r_2(\varepsilon_o) \\ y_3 = \varepsilon_o L_{\lambda_3}(T_o)+r_3(\varepsilon_o) \\ \cdots\cdots\cdots\cdots \\ y_n = \varepsilon_o L_{\lambda_n}(T_o)+r_n(\varepsilon_o) \end{array}\right] \tag{2}$$

The $y_1, y_2, \ldots, y_n$ are the values of the emerging radiation at n different wavelengths; $\varepsilon_o L_{\lambda_1}(T_o), \ldots, \varepsilon_o L_{\lambda_n}(T_o)$ are the enhancements due to radiation emitted by the tested object and the $r_1(\varepsilon_o), \ldots, r_n(\varepsilon_o)$ are the enhancements due to reflected environment radiation. There are $n+3$ unknowns in the set of Eqs. (2): object temperature T_o, its emissivity ε_o, environment temperature T_e, the enhancement due to reflected environment radiation $r_1(\varepsilon_o), \ldots, r_n(\varepsilon_o)$ and only n measured values of the emerging radiation at n different wavelengths $y_1, y_2, \ldots, y_n$. This means that the set of Eqs. (2) cannot be simply solved.

The components $r_1(\varepsilon_o), \ldots, r_n(\varepsilon_o)$ cannot be simply determined because they depend on the object emissivity ε_o which is also an unknown. But we can create a new set of equations:

$$\left.\begin{array}{l} r_2(\varepsilon_o)/r_1(\varepsilon_o) = k_1 \\ \cdots\cdots\cdots\cdots \\ r_n(\varepsilon_o)/r_1(\varepsilon_o) = k_{n=1} \end{array}\right] \tag{3}$$

The relationships between components $r_1(\varepsilon_o), \ldots, r_n(\varepsilon_o)$ are independent of the emisssivity ε_o and they can be experimentally determined. When, instead of the tested object, we put a cold object of very high reflectivity and approximately identical form as the first one we can assume that only reflected radiation comes to the input of the pyrometer. For such a case, the relationships between components $r_1(\varepsilon_o), \ldots, r_n(\varepsilon_o)$ equal relationships between the measured values of the emerging radiation at n different wavelengths $y_1, y_2, \ldots, y_n$:

$$\left.\begin{array}{l} y_2(\varepsilon=0)/y_1(\varepsilon=0)=k_1 \\ \cdots\cdots\cdots\cdots \\ y_n(\varepsilon=0)/y_1(\varepsilon=0) = k_{n-1} \end{array}\right] \tag{4}$$

Using relationships (3) and (4), the number of unknowns in the set of Eqs. (2) reduces to $u = 3$ and the new set can be solved:

$$\left.\begin{array}{l} y_1 = \varepsilon_o L_{\lambda_1}(T_o)+r_1(\varepsilon_o) \\ y_2 = \varepsilon_o L_{\lambda_2}(T_o)+r_1(\varepsilon_o)k_1 \\ y_3 = \varepsilon_o L_{\lambda_3}(T_o)+r_1(\varepsilon_o)k_2 \\ \cdots\cdots\cdots\cdots \\ y_n = \varepsilon_o L_{\lambda_n}(T_o)+r_1(\varepsilon_o)k_{n-1} \end{array}\right] \tag{5}$$

Measurement at more than three wavelengths allows the application of balancing calculation to increase the accuracy of the results.

The new method has been tested and the results can be seen in Fig. 4.

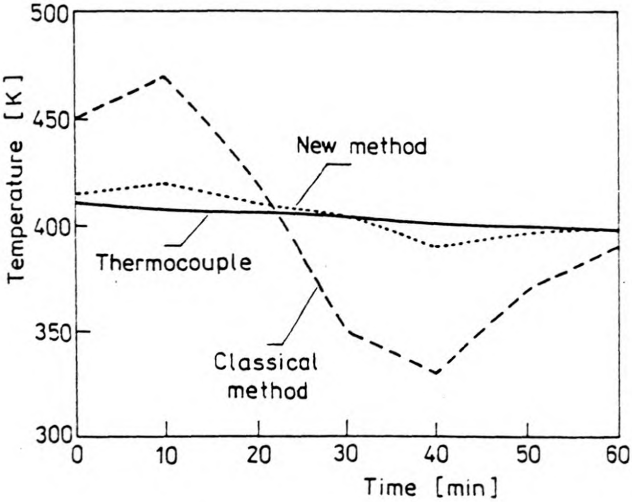

Fig. 4. Temperature of a tested object measured according to the two methods being compared vs. time

As it can be seen, the new method has proved its superiority over the classical method for outdoor conditions, its accuracy being a few times higher under such conditions.

Reference

[1] TANK V., DIETL H., Infrared Phys. **30** (1989), 331.

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