THE INFLUENCE OF THE EMISSIVITY OF THE MATERIAL OF THE OBSERVATION ON ACCURACY OF THERMAL MEASUREMENT METHOD

A. Levynsky[1], V. Tonkonogy[2], M. Holofieieva[3]
[1] Odessa National Polytechnic University, UKRAINE, E-mail: levinskiy.a.s@gmail.com
[2] Odessa National Polytechnic University, UKRAINE, E-mail: vmt@ukr.net
[3] Odessa National Polytechnic University, UKRAINE, E-mail: mary_sya@ukr.net

Summary: *In the article the problem of analyzing the thermal processes using non-contact method of measuring using infrared technology are investigated. The main issue that arises in the calculation of the temperature on the results of thermal imaging measurement is uncertainty in the setting of the emissivity of the surface of the object, which is characterized surface emission coefficient, whose value for the surface of each individual object is individual and depends on the material and surface treatment condition and the angle of observation. By changing the angle of observation in a wide range, the factor of the emission metals and dielectrics changing several times which significantly affects the accuracy of thermal measurement method. The dependences for the calculation of the impact viewing angle on the emissivity materials are obtained*

Keywords: *Thermal measurement method; factor of the emission of the surface; angle of the observation, uncertainty of the measurement.*

1. INTRODUCTION

Nowadays the problem of energy conservation is extremely urgent. Temperature, as a quantitative measure of internal energy of bodies, is a universal characteristic of objects and processes of the physical world, in which is constantly generation, conversion, transmission, accumulation and use of energy in its various forms is happened.

Industrial activity is accompanied by the irreversible loss of heat, so it is obvious that the analysis of thermal processes (temperature fields, heat loss, and so on.) allows to receive a variety of information on the state of objects and physical processes in nature, energy, construction, industry [1].

The easiest and fastest way to assess the heat loss is to apply the thermal imager, which perceives thermal radiation objects temperature distribution at different points. In addition, temperature characteristics control equipment (among other parameters) allows to control the technical condition of equipment, based on monitoring, defects early diagnosis and prognosis of development, that justifies the relevance of this study.

2. ANALYSIS OF PUBLISHED DATA AND PROBLEM DEFINITION

The problem of heat control is described in a large number of works. Modern School researchers in the field thermal diagnosis represented by such scientists as O. Budadin, A.I. Potapov, V.I. Kalganov, V.V. Klyuev, V.N. Fellini, V.P. Vavilov, A.G. Klimov, T. Trinity-Markov, N. Scherbakov, S.A. Bazhanov, A.B. Kryukov et al. A significant contribution to the practical thermography have made B. Petersson, J. Hart, S. Kimothi, E. Grinzato and many others. They point out the advantages of non-contact measurement method using thermal imaging, among which are the performance and information, and the possibility of contactless trials (in line of sight), mobility equipment, the test speed, independent of the size of the object of control, creating archives termohram, environmental safety, no need to orbital control manual, which provides a significant reduction in costs [2 – 5].

In conducting thermal survey (controls) should pay attention to emerging errors that affect the measurement result. [6] Essential are:

– instrumental error, which is connected with construction measuring device and determined by the properties of the optical system, the inertia detector, and a resolution thermal imaging system in the presence of sharp temperature gradients on the surface of the object;

– methodological error, that occurs directly in most studies and associated with limited precision of physical constants, used in the calculation (emissivity of meteorological conditions, precipitation and so on).

The main issue, that arises in the calculation of the temperature on the results of thermal imaging measurement, is the uncertainty in the task of emissivity of the surface of the objects.

3. THE OBJECT, PURPOSE AND OBJECTIVES OF THE STUDY

Object of study – Thermal control method.

The purpose of the study is the emissivity of material influence on the accuracy of thermal control method. To achieve this goal in the article the following tasks are identified:

1. To analyze the significant factors affecting the accuracy of temperature measurement with infrared survey.
2. Determine the influence of the emissivity of different materials on the final result of temperature measurement.
3. Set the calculation of uncertainty of measurements of the temperature, caused by an error in setting of the emissivity.
4. To analyze the influence of the emissivity of materials on precision of the thermal control method.

Emissivity – is a measure of the amount of energy radiation, emitted by certain surface, compared to the energy, emitted by a completely black body at the same temperature. It is characterized surface radiation coefficient (degree of blackness), whose value to the surface of each individual object is individual and depends on several factors, such as wavelength, angle of radiation, material and so on.

Usually the rate of radiation depends on the material and condition of the surface treatment. Since the object may include more components of dissimilar materials and surfaces, which can be painted, have varying degrees of processing, different emission coefficients, during the infrared control may experience quite large measuring error [7, 8].

To illustrate the impact of the emissivity of the accuracy of temperature measurement experiment was conducted. Fig. 1 shows the thermogram cylindrical galvanized containers filled with water, which is obtained through thermal imager Fluke Ti9.

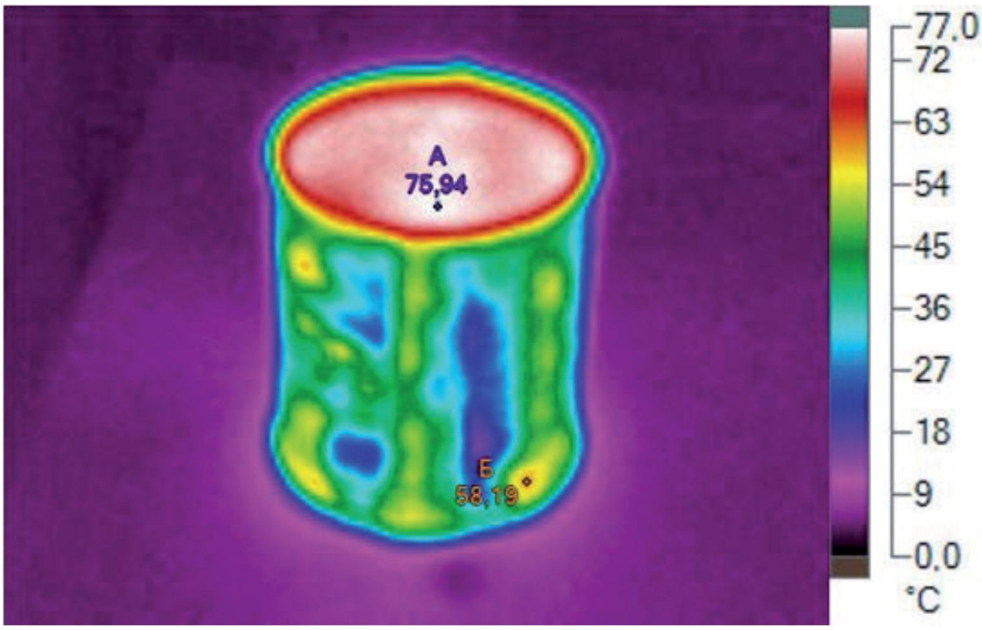


Figure 1: The thermogram galvanized tank, which is filled with water

The capacity of the water it had the same temperature, which was established by measuring the thermocouple. However thermogram shows that the surface temperature is different from the temperature of the water by almost 20 °C. That is a relative measurement error is about 30% and is unacceptable. Various color areas capacitance associated with different states of surface, which also affects the rate of radiative capability [9].

The following thermogram demonstrates how much can really affect the wrong choice emissivity of the material on the measurement result.

In the absence of information on the state of the surface during the measurement radiation coefficient of controlled surface set equal $\varepsilon = 0{,}9$ [7].

The actual temperature of the control object is connected with a coefficient of emissivity capacity of the material ratio [10]:

$$T_{факт} = \frac{T_{рад}}{\sqrt[4]{\varepsilon}}, \qquad (1)$$

where $T_{факт}$ – the actual temperature controlling object;

$T_{рад}$ – the radiation temperature that is perceived by the imager;

ε – the coefficient of emissivity capacity of the material.

The presence of random and systematic component of the error of the measurement result leads to the fact, that the latter may be very close to the meaning the measured value, but do not induce the appropriate level of confidence. Therefore, to assess the quality of the measurement result typically based not on the error, but on its probabilistic characteristics that are based not on actual measured values, but on the observed (estimated) scattering measurement result [11].

Assessment of probability scattering parameters of the measurement result, that characterizes doubts about the reliability of the measurement result, is called measurement uncertainty.

Consider the components of measurement uncertainty with heat control. The rules for evaluating and expressing uncertainty for a wide range of measurements set forth in [12]. This approach includes the evaluation of uncertainty:

– The type A – with the use of mathematical statistics for processing of the measurement results;

– The type B – other methods, including through the use of information regulations.

The total uncertainty u_C can be calculated as [13]:

$$u_C = \sqrt{u_A^2 + u_B^2}, \qquad (2)$$

where u_A – the uncertainty on the type A;

u_B – uncertainty on the type B.

The first group of errors (for evaluation of the uncertainty on the type A) - uncertainty related by such factors as the impact of solar radiation, the angle of observation, wind speed and so on. From the theory of measurement known that the effect of random errors on the result of measurement decreases with increasing number of measurements. In practice, to obtain a satisfactory error value at the lowest cost need only be done 5 (rarely 7) measurements at the point of control [14].

The second group of errors (for evaluation of uncertainty on the type B) is related to factors such as the presence of magnetic fields, errors in the selection coefficient of emissivity, of the resolution, field observations, thermal inertia, weather conditions, the impact of the background and others.

Consider the component of the uncertainty of temperature measurement by using the imager that caused by an error in setting the coefficient of the emissivity.

The component of the uncertainty of measurement instruments temperature by using infrared technology due to an error in setting emissivity refers to the uncertainty of the type B, can be calculated using the formula:

$$u_B = \sqrt{\sum_{i=1}^{m} \left(\frac{\partial f}{\partial x_i} \right)^2 u_B^2(x_i)}, \tag{3}$$

where $\left(\frac{\partial f}{\partial x_i} \right)$ – the partial derivatives of f with respect the arguments x_i.

Given (1) and taking the derivatives, we get:

$$u_{BT} = \sqrt{\frac{1}{\sqrt{\varepsilon}} \cdot u_{BTрад}^2 + \frac{T_{рад}^2}{16\sqrt{\varepsilon^5}} \cdot u_{B\varepsilon}^2}, \tag{4}$$

where $U_{BTрад}$ – measurement uncertainty of the thermal imager;

$U_{B\varepsilon}$ – uncertainty of establishing emissivity coefficient.

The results showed, that the component of the measurement uncertainty, which caused by errors of setting the coefficient of the emissivity may reach 30%, which of course is unacceptable. Therefore, taking into account the deviation of actual value coefficient of the emissivity of the surface of the object of research from the nominal will improve the accuracy of temperature measurement devices using infrared technology.

Often the cause of the deviation of the actual values of the emissivity from the set is incorrectly selected angle observation surface of the object, which significantly affects the rate study. This property is the result of wave reflection at the interface of two different environments and leads to necessity of conducting thermography control surface of the object from different angles and increasing the time required to conduct research. Given that control facilities usually have a complex shape, studies the impact of viewing angle for accuracy non-contact temperature measurement method is quite important.

For the coefficient of the emissivity of metals is unchanged in the range of observation angles 0…40º, for dielectrics – in the range of angles 0…60º. Outside these ranges the coefficient of the emissivity capacity changes significantly at a directed tangential observation [9]. As a result, the effective the coefficient emission unplaned surface is different in different points of the surface [15].

The actual value of the emissivity of coefficient of can be calculated using the formula:

$$\varepsilon_{факт} = \frac{\varepsilon_{вим}}{K_{кут}}, \tag{5}$$

where $\varepsilon_{факт}$ – the actual value of coefficient of the emissivity;

$\varepsilon_{вим}$ – measured value of the coefficient of the emissivity;

$K_{кут}$ – the coefficient of influence of angle of observation.

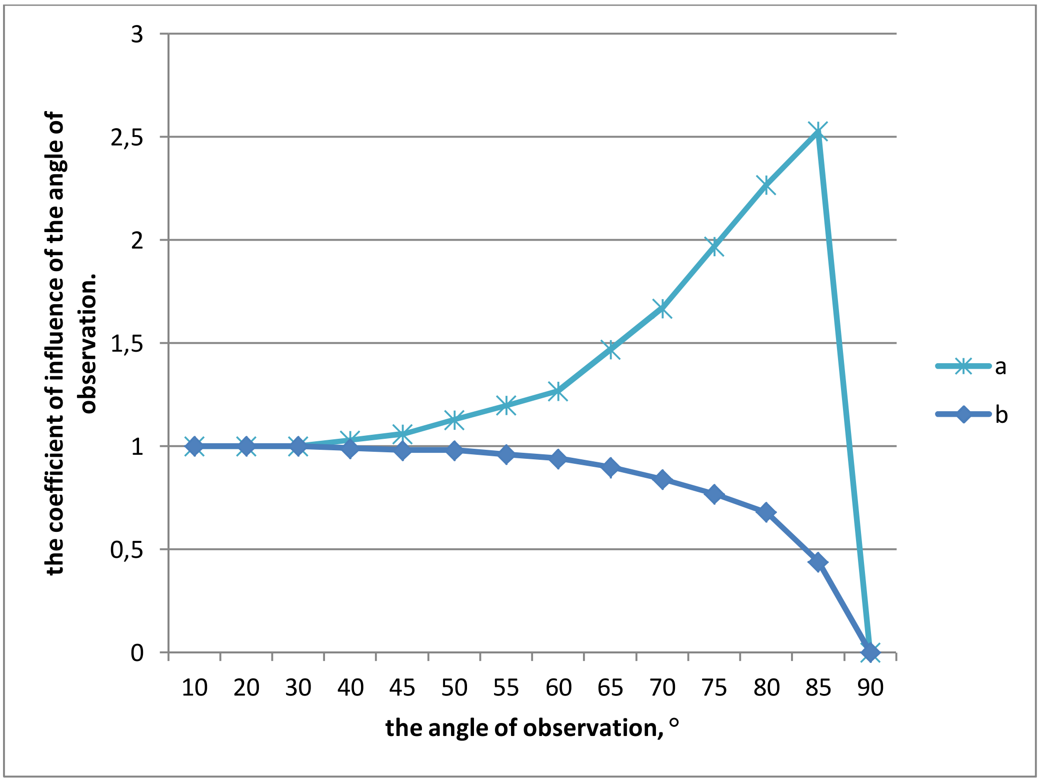
Fig. 2 shows the dependency value of the coefficient $K_{кут}$ on the angle of observation.

The analysis of the results of dependence (Fig. 2) shows, that when changing angle of observation in a wide range, the coefficient of the emissivity capacity metals and dielectrics changing several times, which greatly affects the accuracy of thermal measurement method.

The analysis was obtained $K_{кут}$ dependence of the angle of observation. For metals, this dependence is most accurately described by the formula:

$$K_{кут} = \begin{cases} 0,0164\phi^2 - 0,1067\phi + 1,1464, & 0 \le \phi \le 85 \\ -2,53\phi + 5,06, & 85 \le \phi \le 90 \end{cases}, \tag{6}$$

where φ – the angle of observation.



a - metals; b – dielectric

Figure 2: – The coefficient $K_{кут}$ on the angle of observation

For dielectrics dependence $K_{кут}$ on the angle of observation most accurately described by the formula:

$$K_{кут} = -0{,}0014 \cdot \varphi^3 + 0{,}022 \cdot \varphi^2 - 0{,}1 \cdot \varphi + 1{,}1 . \quad (7)$$

4. CONCLUSIONS

When changing the angle of observation in a wide range, the coefficient of the emissivity capacity as metals and dielectrics, changing several times, which greatly affects the accuracy of thermal measurement method. It is shown that a component of the measurement uncertainty which is caused by errors in the setting of the coefficient of the emissivity of may reach 30%, which of course is unacceptable. To investigate the characteristics of precision measurement method used international approach, including common rules internationally expression of the uncertainty and their summation. The dependence of the angle of observation for metals and dielectrics are obtained. Taking into account the dependence of the emissivity of the angle of observation at a temperature measurement using devices infrared technology will provide an opportunity not only to improve accuracy, but also significantly reduce the time of measurement by reducing the number of required angle shooting object control.

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