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G. Oborskyi, DSc, Prof.,
B. Morgun, PhD, Assoc. Prof.,
O. Levynskyi,
I. Prokopovych, DSc, Prof.,
J. Morgun,
M. Golofeyeva, PhD
Odessa Polytechnic State University, 1 Shevchenko Ave., Odesa, Ukraine, 65044; e-mail: i.v.prokopovich@op.edu.ua

HIGH-PRECISION REMOTE TEMPERATURE MEASUREMENT METHOD

Г.О. Оборський, Б.О. Моргун, О.С. Левинський, І.В. Прокопович, Ю.Б. Моргун, М.О. Голофєєва. **Високоточний спосіб дистанційного вимірювання температури.** В статі розглянуті питання підвищення точності вимірювання температури за допомогою приладів інфрачервоної техніки. Описано новий спосіб дистанційного вимірювання температури тіл приладами інфрачервоної техніки, розроблений і запатентований авторами, при якому на вимірювальну поверхню накладають еталонний датчик у вигляді тонкої пластинки з високим коефіцієнтом теплопровідності. Спосіб виключає основні проблеми та фактори, які впливають на точність вимірювання, такі як коефіцієнт випромінювання поверхні досліджувального об'єкту, його фізичний стан, наявність забруднення поверхні твердого тіла і тим самим дає можливість оперативно і точно вимірювати температуру поверхні будь-якого тіла. Спосіб дозволяє вимірювати також температуру газового середовища шляхом введення за допомогою державки датчика у вигляді еталонної тонкої пластинки для нагріву в зону контакту з вимірювальним об'єктом, на відміну всіх звісних способів дистанційного вимірювання температури інфрачервоними приладами. Для вимірювання температурного поля газового потоку датчик у вигляді тонкої пластинки за допомогою державки вводять під кутом в зону вимірювань таким чином, щоб інфрачервоне випромінювання було направлено перпендикулярно приймальному елементу пірометра. Приведено результати вимірювань температури поверхні різних тіл в процесі їх нагріву в порівнянні з існуючими способами. Розглянуті можливі похибки, які виникають при проведенні теплового обстеження об'єкту і суттєво впливають на результати вимірювань. Наявність достатньої точності способу дає можливість його застосування в рамках автоматичної системи управління технологічними процесами. Розглянуто використання приладу, основаному на запропонованому способі, в автоматичній системі управління технологічними процесами для вимірювання інтегральних параметрів теплових процесів за рахунок обробки інфрачервоних потоків від поверхні виробів та вбудування його окремою ланкою в загальну систему автоматизованого управління. Показана можливість використання запропонованого способу вимірювання температури в АСУ технологічними процесами.
Ключові слова: тепловізійний метод вимірювання, коефіцієнт випромінювання поверхні, еталонний зразок, точність вимірювання, невизначеність вимірювання

G. Oborskyi, B. Morgun, O. Levynskyi, I. Prokopovych, J. Morgun, M. Golofeyeva. **High-precision remote temperature measurement method**. The article considers the issues of improving the accuracy of temperature measurement with the help of infrared devices. A new method of remote measurement of body temperature by infrared devices, developed and patented by the authors, is described, in which a reference sensor in the form of a thin plate with a high coefficient of thermal conductivity is applied to the measuring surface. The method eliminates the main problems and factors that affect the accuracy of measurement. This is the coefficient of radiation of the surface of the research object, its physical condition, the presence of contamination of the surface of a solid body and, thus, allows you quickly and accurately measure the surface temperature of any body. The method also allows measuring the temperature of the gaseous medium by inserting a sensor into the area of contact with the measuring object in the form of a reference thin plate for heating, unlike all known methods of remote temperature measurement by infrared devices. To measure the temperature field of the gas flow, the sensor is inserted at an angle into the measurement area so that the infrared radiation is directed perpendicular to the receiving element of the pyrometer. The results of measurements of the surface temperature of various bodies in the process of their heating in comparison with existing methods are given. Possible errors that occur during the thermal inspection of the object and significantly affect the measurement results are considered. The presence of sufficient accuracy of the method allows its application within the automatic process control system. The use of the device based on the proposed method in the automatic process control system for measuring the integrated parameters of thermal processes by processing infrared fluxes from the surface of products and its integration into a separate link in the overall automated control system. The possibility of using the proposed method of measuring the temperature in the ACS technological processes is shown.
Keywords: thermal imaging method of measurement, surface radiation coefficient, reference sample, measurement accuracy, measurement uncertainty

Introduction

Temperature affects a large number of processes and reactions that occur in nature. In this regard, the measurement of temperature in all possible cases requires a variety of methods and tools, which,

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depending on the task, there are significantly different requirements for measurement accuracy [1].Prospects for the use of non-contact measurement method are associated with such advantages as high information and productivity, remoteness, mobility of equipment, environmental friendliness, independence from the size of the control object, no need to decommission the control object, and therefore reduce costs [2]. Nevertheless, it is associated with certain difficulties, which often lead to a significant reduction in measurement accuracy.

The biggest problem with the application of thermal control methods outside metrological laboratories is the need to measure body temperature, the emissivity of which is unknown. Due to the variety of radiation properties of real bodies, it is impossible to create a device that could measure the temperature of any body. In practice, there are almost mirror and almost diffuse surfaces, translucent surfaces (melted glass), mixtures of melts with slag, and so on. There is no single method of pyrometry that can take into account all possible situations and objects.

The authors developed and patented a method of remote temperature measurement with infrared devices. It involves the use of a reference sensor in the form of a thin plate with a high coefficient of thermal conductivity placed on the surface of the measuring body. Using a pyrometer determine the temperature of the sensor, the temperature of which is adequate to the temperature of the measuring body.

Analysis of recent research and publications

A large number of works by both domestic and foreign authors are devoted to the study of the analysis of thermal processes. Such scientists represent the modern school of researchers in the field of thermodiagnostics as O. Budadin, A. Potapov, V. Kalganov, V. Klyuyev, V. Felino, V. Vavilov, A. Klimov, T. Troitsky-Markov, M. Shcherbakov, S. Bazhanov, A. Kryukov and others.

Among the foreign authors who have made significant contributions to the practical thermography of recent decades are B. Petersson, J. Hart, S. Kimothi, E. Grinzato and many others. They all note the advantages of the non-contact method of measurement using a thermal imager. These advantages include high productivity and informativeness, contactlessness and remoteness of tests (within line of sight), mobility of equipment, speed of the survey, independence from the size of the control object, creation of thermogram archives, environmental safety, no need to remove the control object from operation, which provides a significant reduction in costs [3 – 7].

In particular, they note the problems and factors that arise in the remote determination of temperature. Mainly insufficient information about the coefficient of radiation of the surface of the object under study [8, 9, 10]. It is shown that the radiation coefficients of heated bodies depend on many factors, such as the geometric shape and orientation of the radiating surface, its chemical composition, physical state, the presence of contaminants on the surface, etc. It is important to know the physical and chemical state of the surface under the conditions of measurement, because the state and properties of the surface change with changing temperature, which is usually accompanied by a change in emissivity. This, in turn, leads to measurement error, which can reach significant values.

When conducting thermal imaging survey there are errors that affect the measurement result [11]. Significant are:

– instrumental error, which is related to the design of the measuring instrument and is determined by the properties of the optical system, the inertia of the radiation receiver, as well as the resolution of the thermal imaging system in the presence of sharp temperature gradients on the surface;

– methodological error that arises directly from the research itself and is associated with limited accuracy of the physical constants used in the calculations (emissivity, meteorological conditions, precipitation, etc.).

The main question that arises when calculating temperatures based on the results of thermal imaging measurements is the uncertainty in the task of the emissivity of the surface of the studied objects.

In [12] to consider the components of measurement uncertainty in thermal imaging control and the method of estimating the total uncertainty of measurements.

The aim of this work is to create a method for determining the temperature of bodies at a distance by estimating their infrared radiation, regardless of their emissivity and surface condition, including oxidation and contamination. As well as determining the temperature of the gaseous medium and sections of the gas flow, assessing the accuracy of the proposed method and the possible scope of its application.

Object of research – the processes of diagnosing the state of objects and the course of physical processes in nature, energy, construction, industry.

The subject of research – non-contact method using infrared devices.

Research results

The authors developed a method of remote temperature measurement with infrared pyrometers, which can be used to measure body temperature, gas environment, or gas flow [13].

There is a method for remote temperature measurement, in which a semiconductor laser diode is installed on the surface of the object as a temperature sensor. After heating, the brightness of the diode radiation is estimated using a pyrometer, compared with the brightness of the initial temperature and the calibration dependence of the temperature of the object from which the laser diode was heated [14].

Disadvantages of this method:

– the need for calculations to obtain information that takes time and reduces the accuracy of measurements;

– the impossibility of using a laser diode at high temperatures;

– he method can be used only to measure the temperature of objects in the form of bodies.

There is also a method of remote measurement of body temperature using an infrared pyrometer. It measures the amount of infrared energy emitted by the object, introduces the coefficient of radiant capacity of the body into the pyrometer and determines the appropriate temperature [15].

Disadvantages of this method:

– the amount of infrared energy emitted by the object depends on its temperature and coefficient of emissivity, which ranges from 0.3 to 0.98 [16], and from many materials known their coefficients are only a few dozen, which dramatically reduces the possibilities use of the method;

– the emissivity of the object depends on the characteristics of its surface, which during operation changes under the influence of the external environment, covered with oxide film, oil and dirt, which reduces the accuracy of temperature measurement;

– the method can be used only to measure the temperature of objects in the form of bodies.

The object of the invention is a high-precision method of remote measurement of infrared energy of objects regardless of their materials and surface characteristics, as well as measuring the temperature of gaseous media and gas flows.

The problem is solved by the fact that when remotely measuring the temperature using an infrared pyrometer enter the tabular coefficient of emissivity of the material. According to the invention, the measurement of the temperature of the object is carried out using a sensor in the form of a reference sample of a thin plate with a known high coefficient of radiant power for heating from contact with the measuring object. When measuring the temperature, the coefficient of radiance of the sensor is introduced into the infrared radiation device and the temperature is determined accordingly, which is adequate to the temperature of the object. At the same time, if it is necessary to measure temperature of a gas stream, it is necessary to establish the sensor at an angle on a holder through an asbestos lining and to enter directly into the measured environment.

The technical effect achieved by the invention is that to determine the temperature of the measured object, the sensor, in the form of a reference sample of a thin plate, pressed against the object in the form of a body or installed in a gaseous medium and gas flow, has a high coefficient thermal conductivity. Therefore, it quickly heats up to the temperature of the object and emits heat flux according to its coefficient of radiance, regardless of the properties of the material and the characteristics of the object. The coefficient of radiance of the sensor is introduced into the pyrometer, and its display shows the actual temperature of the measuring object.

The essence of the method is illustrated by drawings (Fig. 1), which shows:

– in Fig. 1, *a*: *1* – sensor; *2* – measuring object in the form of a body; *3* – infrared pyrometer; *4* – handle; sensor *1* is pressed against the surface of the object *2*;

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– in Fig. 1, *b*: *1* – sensor; *2* – measuring object in the form of a gaseous medium; *3* – infrared pyrometer; *4* – handle; sensor 1 is introduced into the gaseous medium *2*;

– in Fig. 1, *c*: *1* – sensor; *2* – measuring object in the form of gas flow; *3* – infrared pyrometer; *4* – handle; *5* – asbestos gasket; the sensor 1 is inserted at an angle into the gas stream *2*, and the pyrometer 3 is installed perpendicular to the surface of the sensor.

To measure body temperature *2* sensor *1* is pressed to its surface and pyrometer *3*, which introduced the coefficient of emissivity of the sensor material, measures the radiation sensor and sets its temperature, which is adequate to body temperature (Fig. 1, *a*).

To measure the temperature of the gas medium *2* sensor 1 is introduced into it and the pyrometer *3*, which introduced the coefficient of emissivity of the sensor material, measures the radiation of the sensor and sets its temperature, which is adequate to the gas temperature (Fig. 1, *b*).

To measure the temperature field of the gas flow sensor 1 is introduced at an angle to the gas flow. Pyrometer 3, which introduces the coefficient of emissivity of the sensor material and which is perpendicular to its plane, measures the radiation of the sensor and sets its temperature, which is adequate to the temperature of the gas flow in the location of the sensor. Possible outflow of heat flow from the sensor to the handle with a rapid change in the position of the sensor, neutralized by asbestos gasket 5 (Fig. 1, *c*).

The considered method of remote temperature measurement when using it with infrared pyrometers type FLUKE 574, which determine the temperature of bodies with an accuracy of 0.1 ° C and the radiative power of which is known, allows you to quickly, without prior calculations and with high accuracy to measure body temperatures materials and characteristics of their surfaces, measure the temperature field of gaseous media and flows of industrial furnaces, heating and cooling devices.

Consider the possibility of using this method in the ACS technological processes.

Within the ACS, the system of non-contact temperature measurement using infrared devices is designed to measure the integrated parameters of thermal processes in engineering and technology by processing infrared fluxes from the surface of products and is integrated into a separate link in the overall automated control system.

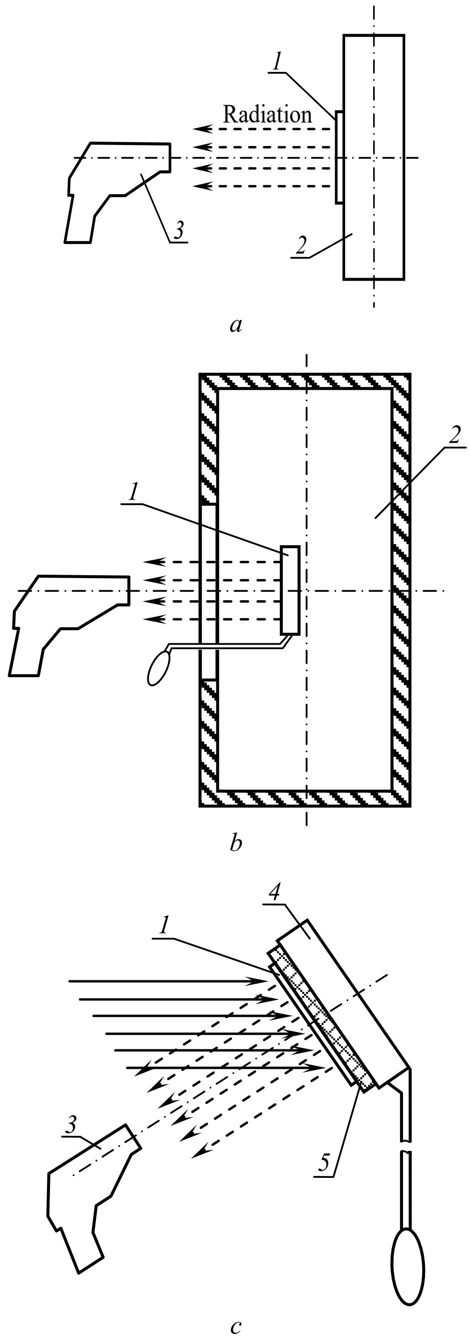

Fig. 1. Method of remote measurement of body temperature (*a*), gaseous medium (*b*) and gas flow (*c*)

By constantly receiving information from the thermal imager from some part of the study object with controlled heating, the measuring system helps the ACS to respond to deviations from the set heating mode, the presence of any anomalies in the temperature field of the object caused by internal defects. By providing negative feedback to the input settings of the control object (for example, with the voltage on the heaters U), the system restores the controlled values. The scheme of “work” of the proposed method within the automated control system is shown in Fig. 2.

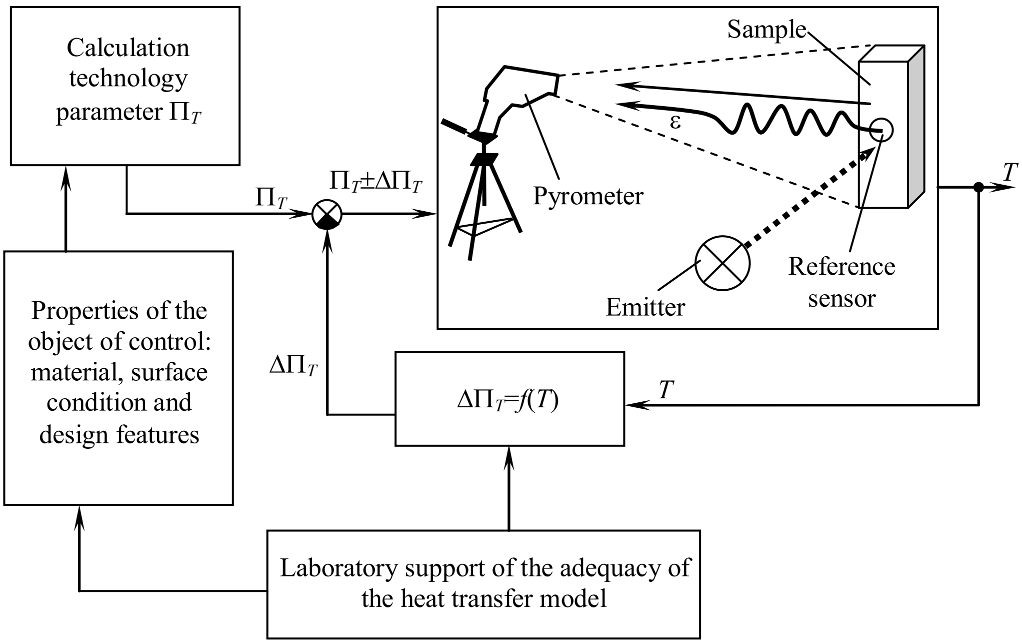

Fig. 2. The scheme of use of the offered method within the limits of the automated control system: T – the actual value of the temperature; Π_T – calculated technological parameter; $\Delta\Pi_T$ – clarification of the calculated technological parameter; ε – emissivity

An experimental study of the accuracy of the proposed method was conducted. Samples of different materials were heated and their temperature was periodically measured with a FLUKE 574 pyrometer without correction and in a new way, where the sensor (see Figures 1, *a*) was pressed against the test sample when measuring the temperature. In parallel, the actual (Fig. 3, abscissa) temperature was measured using a probe for temperature measurement by contact thermocouple [16], which can quickly and accurately measure the surface temperature of conductive bodies [17]. The measurement results are presented in Fig. 3, all samples have the same deviation temperature ±0/1 °C .

Conclusions

Consider improving the accuracy of temperature measurement using infrared devices. A new measurement method has been developed that eliminates the main problems and factors that affect the

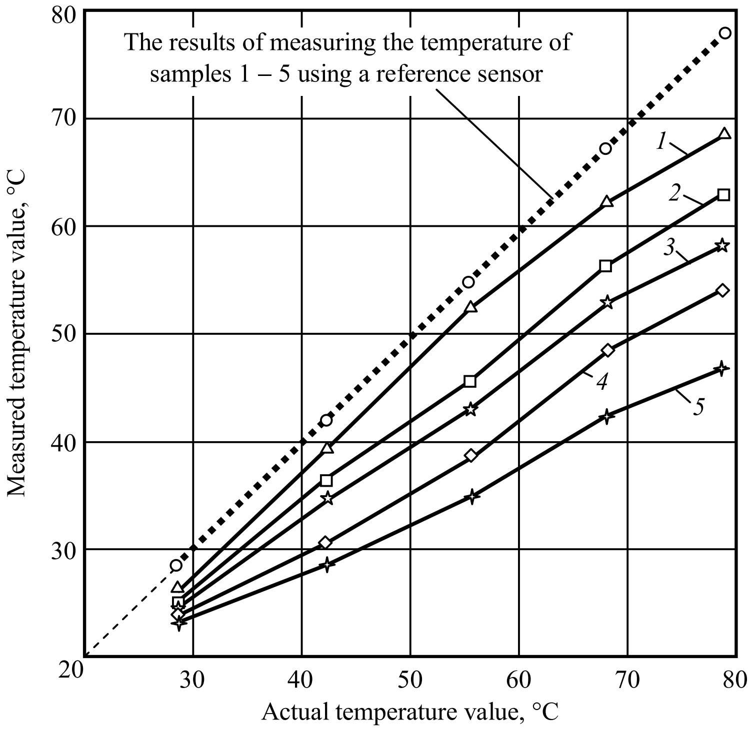

Fig. 3. The results of measuring the temperature of samples with the FLUKE574 pyrometer using (▪▪▪▪▪▪) and without using the reference sensor (———): *1* – copper; *2* – cast iron; *3* – steel; *4* – aluminum; *5* – porcelain

measurement of infrared flux, such as the coefficient of radiation of the surface of the object under study, physical condition and the presence of contamination of the solid surface, etc. The method also allows measuring the temperature of the gaseous medium and the gas flow, which distinguishes it from the known methods of remote temperature measurement. The presence of sufficient accuracy of the method allows its use in the automatic process control system. The researched measurement system helps the ACS to react to deviations from the set heating mode, the presence of any anomalies in the temperature field of the object of study.

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Оборський Геннадій Олександрович; Gennadii Oborskyi, ORCID: https://orcid.org/0000-0002-5682-4768
Моргун Борис Олексійович; Borys Morgun, ORCID: https://orcid.org/0000-0002-5399-9685
Левинський Олександр Сергійович; Oleksandr Levynskyi, ORCID: https://orcid.org/0000-0001-9643-1494
Прокопович Ігор Валентинович; Ihor Prokopvych, ORCID: https://orcid.org/0000-0002-8059-6507
Моргун Юлія Борисівна; Juliya Morgun, ORCID: https://orcid.org/0000-0002-2439-2585
Голофєєва Марина Олександрівна; Maryna Golofeyeva, ORCID: https://orcid.org/0000-0002-7632-9027

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