UDC 006.91+536.5

Yu. Dzikovs'ka, N. Gots
National University "Lviv Polytechnic",

Department of Metrology, Standardization and Certification

DEVELOPMENT OF IN-SITU CALIBRATION METHOD'S ALGORITHM FOR THERMAL IMAGER

The effect of impact factors on the output signal of the radiation receiver is analyzed. Necessity to do additional in-situ calibration of thermal imager by using the standard extended area grey emitter is justified. In-situ calibration method's algorithm for thermal imager is developed. It helps to eliminate the effect of impact factors on the measurement results of temperature gradient. The requirements to the standard extended area emitter are formulated.

Keywords - thermal imager, standard extended area grey emitter, calibration's method, impact factors, method's error

Introduction

Thermal imaging research is one of the major and promising areas of development of thermal control [1]. Thermal imaging systems in industry and medicine play an important role as an effective means of obtaining of distance information about the thermal state of research objects. Processing and analysis of the object's thermal image (thermogram) provide the ability to diagnosing the state and the functioning of the object and spatio-temporal distribution of surface temperature informs about its external and internal structure, hidden defects and their location [2]. As a result, all collected data are output information for preventive measures, repair or appointment of the treatment or it is an incentive for the purpose of clarifying these researches.

Clearly, in this case the issue of ensuring the accuracy and reproducibility of the results of thermal imaging measurement of temperature and temperature gradient of objects appears particularly acute. Therefore, as a result of research of Ukrainian normative and technical documents about the measurements of temperature distribution of thermal field of objects in industry and medicine (Table), we defined their outdated, coverage only certain areas, the lack of integrated implementation of measurements, defect of the questions about the reduction of method's errors and a lack of methods of measurement results processing using the concept of uncertainty. Thus, taking this into account, it is important to develop appropriate methods of thermovision measurement and thermal imaging analysis of the results based on justification of significant influence of impact factors in the working conditions and the necessity for additional in-situ calibration.

The ensuring of the measurements accuracy is legally substantiated guaranteed by the technical documentation that came with the imager, where indicated possible deviations between the true and received meaning of the researched value. Thus, the analyzing of the most common in use devices of thermal imaging technology helps us to found that manufacturers indicate such magnitude error: ±(2÷5) % or ±(2÷5) °C, depending on what is more [3]. But we should not forget that it is actually mentioned temperature sensitivity or basic error of temperature measurement, corresponding known as an instrumental error. Thus, the values of subjective and method's errors are leveled that makes the significant adjustments in the value of research results.

In addition, only thermal imaging equipment, that as a result of calibration is fitted, can be used in research. Herewith, the calibration in the calibration laboratories (CL) occurs under the normal conditions that provided by GOST (State Standard) 8.395-80, and also it should be taken into account the requirements of the maintenance document of a particular type of the thermal imager. Thus, the imager calibration function is deliberately programmed with these conditions.

Table **-** *Ukrainian normative maintenance for measuring of the temperature distribution of thermal field of research objects*

No.	Document's title
ГОСТ 8.558-2009	Государственная система обеспечения единства измерений. Государственная поверочная схема для средств измерений температуры
ГОСТ 23483-79	Контроль неразрушающий. Методы теплового вида. Общие требования
ГОСТ 25314-82	Контроль неразрушающий тепловой. Термины и определения (втратив силу в РФ у 01.01.2011 у зв'язку з введенням сучаснішого ГОСТ Р 53698-2009 «Контроль неразрушающий. Методы тепловые. Термины и определения»)
ДСТУ 4017-2001	Метрологія. Шкали температурні (ГОСТ 8.157-2001, IDT)
ДСТУ 3518-97	Термометрія. Терміни та визначення
ДСТУ 3194-2005	Державна повірочна схема для засобів вимірювання температури. Безконтактні вимірювання температури
ДСТУ 2958-94	Приймачі інфрачервоного випромінення. Терміни та визначення
ДСТУ 2820-94	Тепловізійні системи. Терміни та визначення
ДСТУ 3170-95 (ГОСТ 28243-96)	Пирометры. Общие технические требования (питання інструментальної похибки вимірювання тепловізора)
ДСТУ Б EN 13187:2011	Теплові характеристики будівель. Якісне виявлення теплових відмов в огороджувальних конструкціях. Інфрачервоний метод (IEN 13187:1998, IDT; замість ГОСТ 26629-85 «Здания и сооружения. Метод теплового контролю качества теплоизоляции ограждающих конструкций»)
МПУ 219/06-2008	Інструкція. Метрологія. Тепловізори. Методика повірки
МВУ 048/06-2012	Метрологія. Опір теплопередаванню крізь огороджувальні конструкції будівель та споруд різного призначення. Методика виконання вимірювань комбінованим тепловізійно-теплометричним методом
МДУ 026/06-2008	Метрологія. Тепловізори. Типова програма та методика державної метрологічної атестації
Наказ МОЗ від 28 листопада 1997 р. №340	Про удосконалення організації служби променевої діагностики та променевої терапії (а саме, Положення про кабінет клінічної термографії та Рекомендовані розрахункові норми часу на проведення термографічних досліджень)

As a result, the deviation, as the result of the differences between these and working conditions, is appeared, that is why indication of the thermal imager, calibrated using extended area emitter (model of Blackbody Radiation Sources) in normal conditions, when it used to measure the temperature of the object in working conditions, will vary. It determines the error of temperature measurement for radiation under operating conditions [3].

To resolve these discrepancies the algorithm of the additional in-situ calibration of the thermal imager is offered. It allows the determining of amount of the influence of the impact factors for their following usage in thermal imager calibration function. In fact, it is the algorithm of preparation for measurement provided by RMG (Recommendations on Interstate Standardization) 29-99 (according to international recommendations on interstate standardization) as a step of the methods of temperature distribution measurement of the research object. Also, as a result of the theoretical research, the requirements to the standard extended area radiator are formulated (it will ensure the successful implementation of additional calibration algorithm).

Description of algorithm

The values of the metrological characteristics of the thermal imager are installed during calibration. The best should be considered such calibration, in which the basic measurements conditions are simulated, including simulation of the properties of the research object. However, the reproduction of real measurements is rather costly process, moreover, it is not always technically possible. The difficulty of the reproduction of real measurement conditions is caused by the fact that often the emissivity of the research object is unknown.

In developing of the additional calibration methods of thermal imager it is expedient guided by formulas 1 and 2 of output signal of the radiation receiver in normal operating conditions.

$$S_H(\lambda,T)=\int_{\lambda_1}^{\lambda_2} R(\lambda,T)\cdot\tau_{\text{ПСНУ}}(\lambda,T)\left[\varepsilon_{EB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{EB}}}-1\right)^{-1}+(1-\varepsilon_{EB}(\lambda,T))\Phi(\lambda,T_{\text{ФВНУ}})x\right]d\lambda\ ;\quad (1)$$

$$S_P(\lambda,T)=\int_{\lambda_1}^{\lambda_2} R(\lambda,T)\cdot\tau_{\text{ПСРУ}}(\lambda,T)\left[\varepsilon_{OB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{OB}}}-1\right)^{-1}+(1-\varepsilon_{OB}(\lambda,T))\Phi(\lambda,T_{\text{ФВРУ}})\right]d\lambda\ ;\quad (2)$$

where $\tau_{\text{ПСН(Р)У}}(\lambda,T)$ – transmission coefficient of intermediate environment in normal (working) conditions; $\varepsilon_{E(O)B}(\lambda,T)$ – coefficient of emissivity of standard extended area emitter (of research object); $\Phi(\lambda,T_{\text{ФВН(Р)У}})$ – the flow of background radiation of surrounding objects in normal (working) conditions; $\lambda_1 \div \lambda_2$ – working spectral band of optical-reception system of thermal imager; C_1 and C_2 –constants.

Clearly, there are different of basic settings of function that gives deviation. It should be remembered that the flux of background radiation in normal conditions is actually missed out since the emissivity coefficient of extended area emitter is taken like 1.

The first stage of the developed algorithm includes the definition of the parameters that can be found using the extended area emitter, that are the transmittance of intermediate environment and background radiation in working conditions.

As we use a standard extended area radiator, we advance know the values of its emissivity coefficient and temperature. Accordingly, the value of background radiation and the transmittance coefficient of the intermediate environment can be determined by measuring of the radiation flux in measurements at two spectrums, when one of them is inside the other. It means that measurement will be conducted on the basis of the principle called "window in the window" of the specific range that is presented on Fig. 1 for radiation energy *W*. This can be achieved (if this feature is not provided by imager structure) through the use of bandpass filters. It should be remembered that the signal value should fluctuate enough that the search of the individual parameters is occurred at least at the level of a unit of measurement.

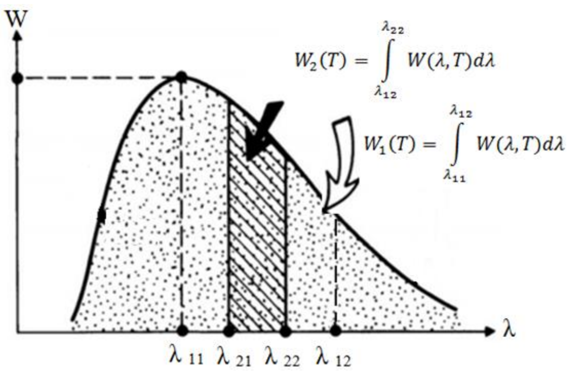

Fig 1. Range division by the principle called "window in the window" on example of Planck law

As the result we get system of two equations with two unknowns. In this case, we consider that environmental conditions remain the same size for fixing the second flux of radiation.

Thus, we need to do the following steps:

1. Standard extended area emitter is heated to a temperature that is as close to the potential temperature of the research object.
2. The imager output signal for the extended area emitter in a wider spectrum is determined λ_{11}:λ_{21}.
3. The imager output signal for the extended area emitter in a narrower spectrum is determined λ_{12}:λ_{22}.
4. The system of equations with two unknowns is made up and solved.

$$\begin{cases} S_1(\lambda,T)=\int_{\lambda_{11}}^{\lambda_{21}} R(\lambda,T)\left[\tau_{\text{ПСРУ}}(\lambda,T)\cdot\varepsilon_{EB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{EB}}}-1\right)^{-1}+(1-\varepsilon_{EB})\Phi(\lambda,T_{\text{ФВРУ}})\right]d\lambda \\ S_2(\lambda,T)=\int_{\lambda_{12}}^{\lambda_{22}} R(\lambda,T)\left[\tau_{\text{ПСРУ}}(\lambda,T)\cdot\varepsilon_{EB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{EB}}}-1\right)^{-1}+(1-\varepsilon_{EB})\Phi(\lambda,T_{\text{ФВРУ}})\right]d\lambda \end{cases}$$

5. $\tau_{\text{ПСРУ}}(\lambda,T)$ and $\Phi(\lambda,T_{\text{ФВРУ}})$ are gotten. These values are typical for given conditions of research and are considered unchanged during the period of further measurements.

So these values of transmittance coefficient of intermediate environment and background radiation can be made as a amendment during the measurement of the object's temperature distribution.

Unknowns in the working conditions still are temperature and radiation coefficient of the research object. In this case, it will be reasonable to carry out the measurement on a similar principle. When we solve this system, we obtain the coefficient of radiation and the temperature of the object in these conditions.

So, we need to do the following steps:

1. The output signal for the research object is determined in the spectrum λ_{11}:λ_{21}.
2. The output signal for the research object is determined in the spectrum λ_{12}:λ_{22}.
3. The system of equations with two unknowns is made up and solved.

$$\begin{cases} S_1(\lambda,T) = \int_{\lambda_{11}}^{\lambda_{21}} R(\lambda,T)\left[\tau_{ПСРУ}(\lambda,T)\cdot\varepsilon_{OB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{OB}}}-1\right)^{-1}+(1-\varepsilon_{OB})\Phi(\lambda,T_{ФВРУ})\right]d\lambda \\ S_2(\lambda,T) = \int_{\lambda_{12}}^{\lambda_{22}} R(\lambda,T)\left[\tau_{ПСРУ}(\lambda,T)\cdot\varepsilon_{OB}(\lambda,T)\cdot C_1\lambda^{-5}\left(e^{\frac{C_2}{\lambda T_{OB}}}-1\right)^{-1}+(1-\varepsilon_{OB})\Phi(\lambda,T_{ФВРУ})\right]d\lambda \end{cases}$$

4. T_{OB} and $\varepsilon_{OB}(\lambda,T)$ are gotten.

General view of the algorithm is represented in Fig. 2.

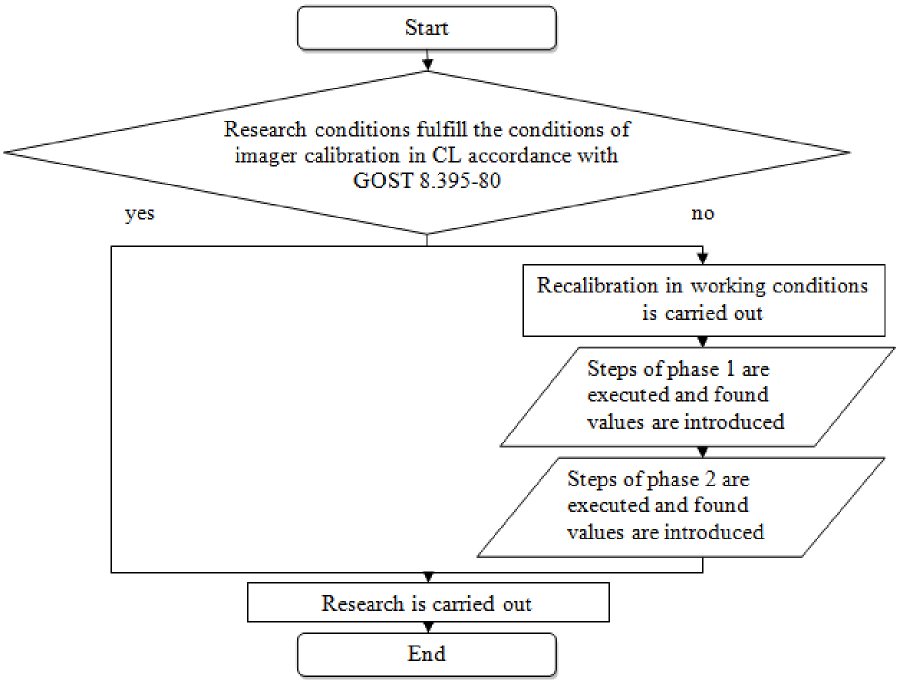

Fig. 2 Method's algorithm of additional in-situ calibration of thermal imager in the research

The use of observations that are made using the principal called "window in window", i.e. simultaneous observation of individual images of the research object in different bands, will give as much information about the object against a background of environment that will reduce ambiguity in its interpretation, and the research of the function of the distribution of radiation coefficient and reflection coefficient in narrow spectrum bands will provide the information about the chemical, physical and biological state of the research object [4]. Thus, it expands the possibilities of thermal imaging researches in general.

Theoretical researches

As for calibration of thermal imagers in calibration laboratories it is used the emitters as a model of extended area blackbody radiation, which coefficient varies between 0,94-0,98, and their price is too large for their successful and available using in operating conditions, we offer to apply extended area emitter with a lower emissivity coefficient [3].

We know that in order to reduce the influence of the temperature difference between the standard and the research object, calibration can be performed by using variable-temperature radiator, but in this case there is an additional error as a result of differences between the emissivity of the object and source of calibration both the absolute value and the spectrum. But if we take in account that the thermal imager has many spectrums and channels, we can estimate the possible measurement error of surface radiation temperature of research object. In this situation we can make calibration by using the constant-temperature emitter. Experimental researches confirm that this error in the range of 2-14 microns and temperature range of 273-800 K does not exceed 3-5% [5]. That is why the focus in the formation of requirements for the model of extended area emitter to determine the values of impact factors in working conditions is done on these two extreme points. In addition, we know that the value of radiation flux can be changed both by changes of temperature, and by the selection of material and characteristics of radiation surface. The choice of material can provide a significant change in the body radiation flux for several stable temperatures. The cheapest material for the manufacture of a standard radiator is steel, the processing techniques of which can be varied (from grinding to minimize emissivity ability to uneven application of the coating to maximize the emissivity of surface).

Results of research

Thus, the following requirements for extended area radiation source is formulated:

1) it is a gray body – a body, for which the absorption coefficient is independent of wavelength: $\alpha = const < 1$;

2) optimal coverage material in terms of ease of processing and cost is steel;

3) the operation temperature range varies between 273-800 K.

Conclusions

Calibration of thermal imager allows the researcher to be confident in the measurement results, such as values of temperature and temperature gradient, that are submitted on thermogram [6].

The article includes the analysis of the use of thermal imagers in working conditions, including the justification of the need for additional in-situ calibration immediately before use. It will help to take into account the impact of working conditions that are different from normal conditions, which are provided in calibration laboratories.

In this paper the calibration method's algorithm of thermal imager in working conditions is developed. Therefore the effect of impact factors on the result of measurement of temperature and temperature gradient of object surface can be considered. These factors include the emissivity of object's surface, transmittance of intermediate environment and the reflection of background radiation of the surrounding objects. The use for the calibration of thermal imager in the working conditions of the standard extended area emitter, which is a gray body, is justified.

The application of this method in real conditions will increase the accuracy of practical measurements, as will provide a significant reduction of method's component of error by taking into account the action effect of object's radiative properties, transmittance of intermediate environment and background radiation on the measurement result.

1. Основы тепловидения / В. В. Коротаев, Г .С. Мельников, С. В. Михеев [и др.]. – СПб: НИУ ИТМО, 2012. – 122 с. 2. Грабко В.В., Грабко В.В. Математическая модель для диагностирования состояния изоляции работающей мощной электрической машины по ее тепловому портрету / В.В. Грабко, В.В. Грабко // Наукові праці ВНТУ. – 2008. – № 1 [Електронний ресурс]. – Режим доступу: http://praci.vntu.edu.ua/article/download/1316/763. – Назва з екрана. 3. Гоц Н.Є., Дзіковська Ю.М. Дослідження особливостей застосування тепловізорів у промислових умовах / Н.Є. Гоц, Ю.М. Дзіковська // Український метрологічний журнал. – 2015. – № 1. – С. 26-31. 4. Боженко В.І. Удосконалення методів та засобів формування зображення тепловізійною системою [Текст]: автореф. дис. на здоб. наук. ступеня канд. техн. наук : спец. 05.12.17 «Радіотехнічні та телевізійні системи» / Боженко В. І. ; Нац. ун-т «Львівська політехніка». – Л., 2011. – 20 с. 5. Сильд Ю. А. Разработка системы метрологического обеспечения измерительных тепловизионных приборов / Ю.А. Сильд, М.А. Иванова, В.А. Никоненко // Измерительная техника. – 2004. – № 4. – С. 48-51. 6. Ochs M. A novel calibration method for an infrared thermography system applied to heat transfer experiments / M. Ochs, T.Horbach, A.Schulz, R.Koch, H-J.Bauer // Measurement Science and Technology. – 2009. – Vol. 20. – P. 1-9.