ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE

OIML

International Recommendation

PROCEDURE FOR CALIBRATION AND VERIFICATION OF THE MAIN CHARACTERISTICS OF THERMOGRAPHIC INSTRUMENTS

2006

Contents

Explanatory Note

This Draft Recommendation is written with the purpose of metrological control of production and operation of general-purpose thermographic instruments in the OIML member-states, and can be used as the basis for carrying out verification and calibration of these products.

It should be noted that this recommendation covers only those thermographic instruments that represent measuring systems, unlike so called "finding out infrared systems" ("IR imagers") - optoelectronic instruments intended for visualization of thermal fields of objects on the basis of their thermal radiation in the infrared spectrum with the possibility to display the motion of the objects owing to the change of images close to each other as to their contents.

The production and scope of thermographic instruments have significantly grown lately. However, there have been no international documents on verification of these measuring instruments, yet. So, this Recommendation is rather urgent. The Recommendation allows for unification of the methods and means for verification and calibration of thermographic instruments in the OIML member-states.

The Secretariat has made the title of the Recommendation more exact by supplementing it with the calibration procedure.

1 Scope

The Recommendation applies to general-purpose thermographic instruments and establishes a procedure for their primary and periodical verification and calibration.

2 Terminology

2.1 Thermographic instrument: An optoelectronic instrument designed for noncontact (remote) observation, measurement and registration of the space/space-time distribution of the radiation temperature of objects in the field of view of an instrument by forming a time sequence of thermograms and determining the temperature[1] of the object surface on the basis of the known emittances and shooting parameters (ambient temperature, atmospheric transmission, observation distance, etc.).

2.2 Thermogram: A multiple-element, two-dimensional image, each element being attributed a color, or color gradation, or brightness range of screen, which are determined in correspondence with a conventional temperature scale.

2.3 Standard radiator: A radiator in the form of an absolute black body (ABB) model.

2.4 Standard large aperture radiator: A standard (reference) radiator, which angular dimensions are ten and more times bigger than the instantaneous field of view of a thermographic instrument.

2.5 Thermal test-object: A device intended for creation of a picture plane containing a heat-radiating object with the preset spatial frequency or shape, temperature contrast on a

[1] According to the International Temperature Scale (ITS-90)

uniformly radiating background with the known temperature value and the emittance values of the object and background.

2.6 Number of sensitive elements (dissection elements of thermogram): The number of photosensitive elements in the photodetector of the thermographic instrument.

2.7 Field of view: A solid angle, within which a thermogram is formed.

2.8 Instantaneous field of view (IFOV): Space angle within which the infrared radiation is sensed by one photosensitive element of the photodetector.

2.9 Spatial (angular) resolution: A size (angular or in dissection elements) of a slit in a screen installed in front of a large aperture radiator in the field of view of a thermographic instrument, when the ratio between the peak increment of slit temperature over screen temperature on a thermogram to the temperature difference of radiator and screen reaches the preset value.

2.10 Noise equivalent temperature difference (temperature resolution, ΔT_{NETD}): A temperature increment equal to the root-mean-square value of noise in a thermogram, when observing a homogeneous background with the specified temperature, at a specified thermogram rate.

2.11 Sensitivity non-uniformity on a field of a thermographic instrument: A maximum value of the temperature difference of thermogram fragments of a standard radiator with uniform radiation over the surface.

3 Characteristics of thermographic instruments to be verified

In the process of verification the following metrological characteristics of a thermographic instrument are to be determined:

- Spatial (angular) resolution;
- Field of view;
- Instantaneous field of view (IFOV);
- Accuracy of radiation temperature measurement;
- Noise equivalent temperature difference;
- Number of damaged sensitive elements;
- Sensitivity non-uniformity over the field;
- The influence of environmental condition on the performance of the instruments;
- Repeatability of readings.

4 Conditions of verification and calibration

4.1 In the process of verification and calibration the conditions of an environment should correspond to ISO/IEC 17025:2005, unless the other conditions are specified in the certificate of a thermographic instrument.

5 Methods for verification and calibration

5.1 Procedures and means of verification.

5.1.1 The procedures and measuring instruments, which are to be applied in the process of verification and calibration, are listed in Table 1.

5.1.2 All measuring instruments indicated in Table 1, must have the relevant verification or certification documents.

5.1.3 Measuring instruments the thermographic instrument to be verified are prepared for operation in correspondence with their in-line documentation (ID).

5.1.4 Specialists qualified for performance of verification in the field of temperature and radiometric measurements, are admitted to verification and calibration.

5.2 External examination

5.2.1 The external examination should find out the following:

- correspondence of the complete set and marking of a thermographic instrument to its ID;
- correspondence of a thermographic instrument to the safety requirements stated in the certificate and/or in the Operating Manual (OM);
- absence of external damage of the thermographic instrument set to be verified, which can impact its metrological characteristics.

A thermographic instrument, which does not meet the requirements, is not entitled to be verified.

Table 1: Procedures and Means of Verification and Calibration of Thermographic Instruments

Procedure	Item in the Recommen-dation	Means of verification and their metrological characteristics	Obligation of procedure	
			Primary verification	Periodical verification
1. External examination	5.2		Yes	Yes
2. Testing. Functional check of thermographic instruments under various conditions	5.3	Radiator in the form of an BB model	Yes	Yes
3. Determination of field of view and instantaneous field of view	5.4	1. Standard (reference) large aperture radiator for the temperature range over the ambient temperature by 10 ^{o}C with the emittance not less than 0.96. Expanded uncertainty of the radiator is 1.1 ^{o}C (with *k*=2). The temperature instability is not more than ±0.05 ^{o}C/min. 2. Thermal test objects with the emittance not less than 0.96. See the sketch of the test-objects in Annex A and Annex B. 3. Measuring rule with the length of 500 mm and the scale factor of 1 mm.	Yes	No
4. Determination of noise equivalent temperature difference	5.5	Standard (reference) large aperture radiator (See 5.4).	Yes	Yes
5. Determination of the number of defective elements	5.6	Standard (reference) large aperture radiator (See 5.4).	Yes	Yes
6. Determination of spatial (angular) resolution	5.7	1. Standard (reference) large aperture radiator (See 5.4). 2. Thermal test-object (See 5.4).	Yes	Yes
7. Checking of the range and estimation of accuracy of radiation temperature measurement	5.8	Standard (reference) radiator. Expanded uncertainty of the radiator is 0.6 °C (with *k*=2) for the temperature range from -50 ^{o}C to 80 ^{o}C. Expanded uncertainty of the radiator is from 0.5 ^{o}C to 7.5 ^{o}C (with *k*=2) for the temperature range from 0 ^{o}C to 2500 ^{o}C.	Yes	Yes
8. Determination of sensitivity non-uniformity on a field	5.9	Standard (reference) radiator (See 5.8).	Yes	Yes

Procedure	Item in the Recommen-dation	Means of verification and their metrological characteristics	Obligation of procedure	
			Primary verification	Periodical verification
9. Check of the influence of environmental condition on the performance of the instruments	5.10	Standard (reference) radiator (See 5.8). Climatic chamber. Error in reproducing the temperature of 2 °C in the range from -15 to 60 °C. Error in reproducing the humidity of 3% in the range from 0 to 95 %.	Yes	No
10. Determination of repeatability of thermographic instrument readings	5.11	Standard (reference) large aperture radiator (See 5.4).	Yes	No

5.3 Testing. Functional check of thermographic instruments under various conditions

5.3.1 Testing (performance check).

A thermographic instrument is turned on and its performance is checked in correspondence with the OM.

A thermographic instrument, which has shown a malfunction in the process of testing, is not entitled to be verified.

5.3.2 Functional check of a thermographic instrument under various conditions.

A thermographic instrument and a radiator in the form of an ABB model are made ready for work according to the OM's of these instruments. The thermographic instrument is focused on to the emitting surface of the radiation source.

The operation of a thermographic instrument is checked under all conditions specified in the OM.

If the functions specified in the OM or certificate, are not hold even under one condition, a thermographic instrument is not entitled to be verified.

5.4 Determination of the field of view and instantaneous field of view.

5.4.1 Selection of working distance.

5.4.1.1 The temperature of the standard (reference) large aperture radiator is set 10 ^{o}C higher than the ambient temperature. A thermal test-object with a variable slit is placed in front of the radiator at the distance of 1-3 cm.

5.4.1.2 Operating mode of a thermographic instrument should be able to attain its maximum sensitivity. The image of the thermal test object shall be matched the central area of the thermogram.

5.4.1.3 The maximum width of the slit is set, and the maximum temperature of the slit in the thermogram is measured.

5.4.1.4 The working distance *R*, mm, is chosen as the maximum distance between the thermographic instrument objective and the thermal test-object with a variable slit, which provides for the maximum temperature value of the slit in the thermogram, the slit being opened completely.

5.4.2 Determination of the field of view and instantaneous field of view

5.4.2.1 The temperature of the standard (reference) large aperture radiator is set 10 ºC higher than the ambient temperature. A thermal test-object with marks is placed in front of the radiator at the distance of 1-3 cm.

5.4.2.2 Operating mode of a thermographic instrument shall be able to attain its maximum sensitivity. The image of the thermal test object shall be matched with the central area of the thermogram. Measurements are effected at the working distance *R* specified in 5.4.1.

5.4.2.3 The marginal marks recorded horizontally or vertically, are noted on the thermogram received. The distance between the marginal marks of the test object is measured in millimeters and in dissection elements.

5.4.2.4 Instantaneous field of view (IFOV) γ, rad, is calculated by the formula:

$$\gamma = \frac{2}{a} arctg \frac{A}{2R}, \tag{1}$$

where a is the distance between the marginal marks of the test object, elements;
A is the distance between the marginal marks of the test object, mm;
R is working distance determined in 5.4.1, mm;

5.4.2.4 The field of view in horizontal φ_x and vertical φ_y directions, degrees, is determined, respectively, by the formulas:

$$\varphi_x = \gamma \cdot X \cdot \frac{180}{\pi}, \tag{2}$$

$$\varphi_y = \gamma \cdot Y \cdot \frac{180}{\pi}, \tag{3}$$

where γ is instantaneous field of view (IFOV), rad;
X is the number of sensitive elements in horizontal direction;
Y is the number of sensitive elements in vertical direction;

5.4.2.5 Instantaneous field of view γ and the fields of view φ_x and φ_y should correspond to those indicated in the Operation Manual or in the Passport of the thermographic instrument.

5.5 Determination of noise equivalent temperature difference

5.5.1 Measurements are taken at the distance, which ensures full covering of the field of view of the thermographic instrument by the aperture of the large aperture radiator.

5.5.2 The temperature of the standard (reference) large aperture radiator is set 30 ^oC or otherwise, which corresponds to the OM or certificate for determination of the given characteristic.

5.5.3 The thermographic instrument is focused to the central region of the radiator aperture and is fixed in the chosen position. Two thermograms are recorded into memory of the thermographic instrument in a short interval of time.

5.5.4 The temperature difference Δt_{ij}, °C for each dissection element in areas of the recorded thermograms which include not less than statistically significant number of dissection elements is determined using the software that comes with thermographic instruments, or it is calculated by the formula:

$$\Delta t_{ij} = t_{ij}^{(1)} - t_{ij}^{(2)} \quad , \tag{4}$$

where $t_{ij}^{(1)}$ – is the temperature of dissection element of the first thermogram with (*i;j*) coordinates, °C;

$t_{ij}^{(2)}$ – is the temperature of dissection element of the second thermogram with (*i;j*) coordinates, °C;

5.5.5 The temperature resolution Δt_{NETD}, °C is calculated by the formula:

$$\Delta t_{NETD} = \frac{\sqrt{2}}{2}\sqrt{\sum_{i=1}^{X}\sum_{j=1}^{Y}\frac{\left(\Delta t_{ij} - \overline{\Delta t}\right)^2}{X \cdot Y}}, \tag{5}$$

where Δt_{ij} is the temperature difference of dissection element of the first thermogram with (*i;j*) coordinates, °C;

$\overline{\Delta t}$ is the mean temperature difference, ^oC;

X is the number of sensitive elements in horizontal direction;

Y is the number of sensitive elements in vertical direction.

5.5.6 If a thermographic instrument has several thermal working ranges, the noise equivalent temperature difference shall be defined for each mode.

5.5.7 The received value of Δt_{NETD} should not exceed the one specified in the OM or certificate of the thermographic instrument.

5.6 Determination of the number of defective dissection elements of thermogram

5.6.1 The procedures from 5.5.1 and 5.5.2 are carried out.

5.6.2 The thermographic instrument is pointed at the central region of the radiator aperture and is fixed in a chosen position. The thermogram is recorded in the storage device of the thermographic instrument.

5.6.3 With the help of the software that comes with the thermographic instrument the defective sensitive elements are revealed. The deviation of the temperatures of each sensitive element δt_i, ºC from the mean value of temperature of thermogram, °C shall not exceed the value of temperature resolution, determined in 5.5, more than 6 times. The sensitive element for which the deviation of temperature does not meet this requirement is recognized defective.

5.6.4 The number of defective sensitive elements shall not exceed 0.3 % of the total number of sensitive elements specified in the Operation Manual or value which is specified in the OM or certificate of the thermographic instrument.

5.7 Determination of spatial (angular) resolution

5.7.1 Determination of scale parameter.

5.7.1.1 The sequence of operations is carried out in accordance with items 5.4.2.2, 5.4.2.3.

5.7.1.2 The distances between the holes of the thermal test object are measured in dissection elements using the received thermogram of the thermal test-object with marks.

5.7.1.3 The scale parameter *k* is determined as a ratio of the distance between the corresponding holes on the thermogram, elements, and those on the thermal test object, mm.

5.7.2 Determination of resolution in the horizontal direction

5.7.2.1 The temperature of the large aperture radiator is set 10 °C higher than the ambient temperature. A thermal test-object with a variable slit is placed in front of the radiator at the distance of 1-3 cm in the vertical direction (the slit axis is directed vertically – along the height of the thermogram).

5.7.2.2 The sequence of operations is carried out in accordance with item 5.4.2.3.

5.7.2.3 The maximum width of the slit is set and then measured. The maximum temperature of the slit t^t_{max}, ºC, is determined on the basis of the thermogram. On the basis of the temperature measurement results the contrast of the slit K_S on the thermograms is calculated by the formula:

$$K_s = \frac{t^t_{\max} - t^t_0}{t_s - t^t_0}, \qquad (6)$$

where t^t_{max} is the maximum temperature value of the slit with width *A* determined by the thermogram, ºC;

t^t_0 is the mean temperature value of the shutters determined by the thermogram, ºC;

t_s is the maximum temperature value of the slit at the maximum width determined by the thermogram, ºC.

5.7.2.4 On the basis of the recorded values of the slit width *A*, mm, the slit width a put in the image (thermogram) plane is calculated by the formula:

$$a = A \cdot k\ , \qquad (7)$$

where *a* is the slit size, elements;

A is the slit width, mm;

k is the scale parameter determined by 5.7.1, elements/mm;

5.7.2.5 The slit width *A*, mm, is reduced and measurements are taken according to 5.7.2.3, 5.7.2.4.

5.7.2.6 The procedures from 5.7.2.5 are performed at least five times.

5.7.2.7 On the basis of the received measurement results, the dependence of slit contrast on thermograms K_s upon slit width *a*, elements, – the function of reaction for the slit (*FRS*) is set:

$$FRS = K_s(a) \quad (8)$$

5.7.2.8 An example for calculating the spatial resolution in the horizontal direction F_X is given is Annex C.

5.7.2.9 The resolution in the horizontal direction F_X, equal to the resolution in the angular direction or, in terms of dissection elements, to the slit size, should correspond to the value specified in the Operation Manual or in the Passport of the thermographic instrument, at a specified value of the slit contrast.

5.7.3 Determination of resolution in the vertical direction

5.7.3.1 The vertical resolution is determined in a way similar to the one described in 5.7.2. The thermal test object with variable slit is set aflat (the slit axis being directed along the thermogram row). To calculate the angle dimension of the slit, the angle of field of view of the thermographic instrument φ_y, determined in 5.7 and the number of the vertical dissection elements of the thermogram *Y* are used.

5.7.3.1 The resolution in the vertical direction F_Y equal to the angular one or to the slit size in dissection elements should correspond to the value specified in the OM or certificate of a thermographic instrument, the slit contrast value being fixed, too.

5.8 Checking of the range and estimation of the accuracy of radiation temperature measurement

5.8.1 Measurements are taken at a distance from the reference radiator and the thermographic instrument, which ensures covering by the aperture of the radiator at least 20% of the field of view of the thermographic instrument. The emitting surface of the standard radiator is matched with the central region of the thermogram.

5.8.2 The accuracy of a thermographic instrument is determined at least five points of the working temperature range (the lower, the upper and three points within the range). When the steady-state conditions of a radiator are set, minimum five measurements are taken by the thermographic instrument at each temperature.

The mean value of the radiation temperature of the standard radiator is determined using the thermogram t^t_{mean}, °C taking into account its radiation capacity and the temperature of the background radiation.

5.8.6.3 The accuracy Δ*t*, °C for each temperature of a thermographic instrument is calculated by the formula:

$$\Delta t = t_{90} - t^t_{mean}, \quad (9)$$

where t^t_{mean} is the mean temperature value in the region confining the image of the radiator aperture on the thermogram, which is determined by the thermographic instrument, °C;

t_{90} is the temperature of the standard radiator, °C.

5.8.4 The results of verification or calibration are considered to be favorable if the accuracy calculated by Eq.(9), does not exceed the values specified in the OM for all points.

5.9 Determination of sensitivity non-uniformity on a field

5.9.1 The procedures from 5.8.1 are carried out.

5.9.2 The sensitivity non-uniformity on a field of a thermographic instrument is determined at five points of the working temperature range (the lower, the upper and three points within the range). When the steady-state conditions of a radiator are set, minimum five measurements are taken at each temperature.

5.9.3 The emitting surface of the standard radiator is matched successively with at least five different regions of the thermogram (e.g. with the center and four corners of the thermogram).

5.9.4 The mean temperature of the radiation source, in the various positions on the thermogram corresponding to the source aperture is measured.

5.9.5 The sensitivity non-uniformity on a field of a thermographic instrument δt, ºC, is calculated by the formula:

$$\delta t = \bar{t}_{\max} - \bar{t}_{\min}, \qquad (10)$$

where $\bar{t}_{\max}$ is the maximum temperature value among the mean temperatures obtained;
$\bar{t}_{\min}$ is the minimum temperature value in the region of the thermogram.

5.9.6 The received value of δt should not exceed the one specified in the OM or certificate of the thermographic instrument.

5.10 Check of the influence of environmental condition on the performance of the instruments

5.10.1 The check of the influence of environmental condition on the performance of the instruments shall be carried out in the climatic chamber at upper and lower limits of operating temperature and humidity values.

5.10.2 Measurements are taken according to 5.8.1.

5.10.3 The check of the influence of environmental condition on the performance of the thermographic instrument is determined at three points of the working temperature range (the lower, the upper and one point within the range). When the steady-state conditions of a radiator are set, minimum five measurements using the thermographic instrument are taken at each temperature. The average (mean) value of the standard radiator radiation temperature is determined using the thermogram t^{t}_{mean}, °C taking into account its radiant capacity and the background radiation temperature.

5.10.4 The accuracy of the thermographic instrument Δt_{EC}, °C for each its temperature is calculated by the formula:

$$\Delta t_{EC} = t_{90} - t^{t}_{mean}, \tag{11}$$

where t^{t}_{mean} is the mean temperature value in the region confining the image of the radiator aperture on the thermogram, which is determined by the thermographic instrument, ^{o}C;
t_{90} is the value of the standard radiator, ^{o}C.

5.10.4 The accuracy of thermographic instrument (5.8) must be valid over the complete operating ambient temperature and air humidity range specified in the Operation Manual for the instrument, if not otherwise stated. If the accuracy is not compliant with the complete operating ambient conditions range, the manufacturer must state a temperature and humidity coefficients which gives the additional measurement uncertainty when the instrument temperature deviates from a given reference temperature.

5.11 Determination of repeatability of thermographic instrument readings

5.11.1 The temperature of the standard (reference) large aperture radiator is set 10 ^{o}C higher than the ambient temperature.

5.11.2 The image of the center of the standard extended radiator is matched with the central region of the thermogram; measurements are taken every 10-15 seconds during 15 minutes, if no other minimum time interval is specified in the Maintenance Documentation.

5.11.3 The mean temperature values are determined on the basis of the measurement results during three time intervals, five minutes each. The difference between maximum and minimum values of the mean temperature values should not exceed the temperature repeatability specified in the OM or certificate of the thermographic instrument.

5.12 Drawing up verification and calibration results

5.12.1 Verification and calibration results are recorded in protocols, which forms are given in Annex D.

5.12.2 A verification or calibration certificate is issued if the verification or calibration results are favorable.

5.12.3 The verification or calibration certificate contains the following data and parameters:

• Spatial (angular) resolution
• Field of view
• Instantaneous field of view (IFOV)
• Accuracy of radiation temperature measurement
• Noise equivalent temperature difference (temperature resolution, ΔT_{NETD})
• Number of defective sensitive elements
• Sensitivity non-uniformity on a field
• The influence of environmental condition on the performance of the instruments
• Repeatability.

5.11.4 If the verification or calibration results are unfavorable, a notice on unserviceability of a thermographic instrument is issued, the reasons being identified.

Annex A (recommended)

Sketch of the thermal test-object with a variable slit

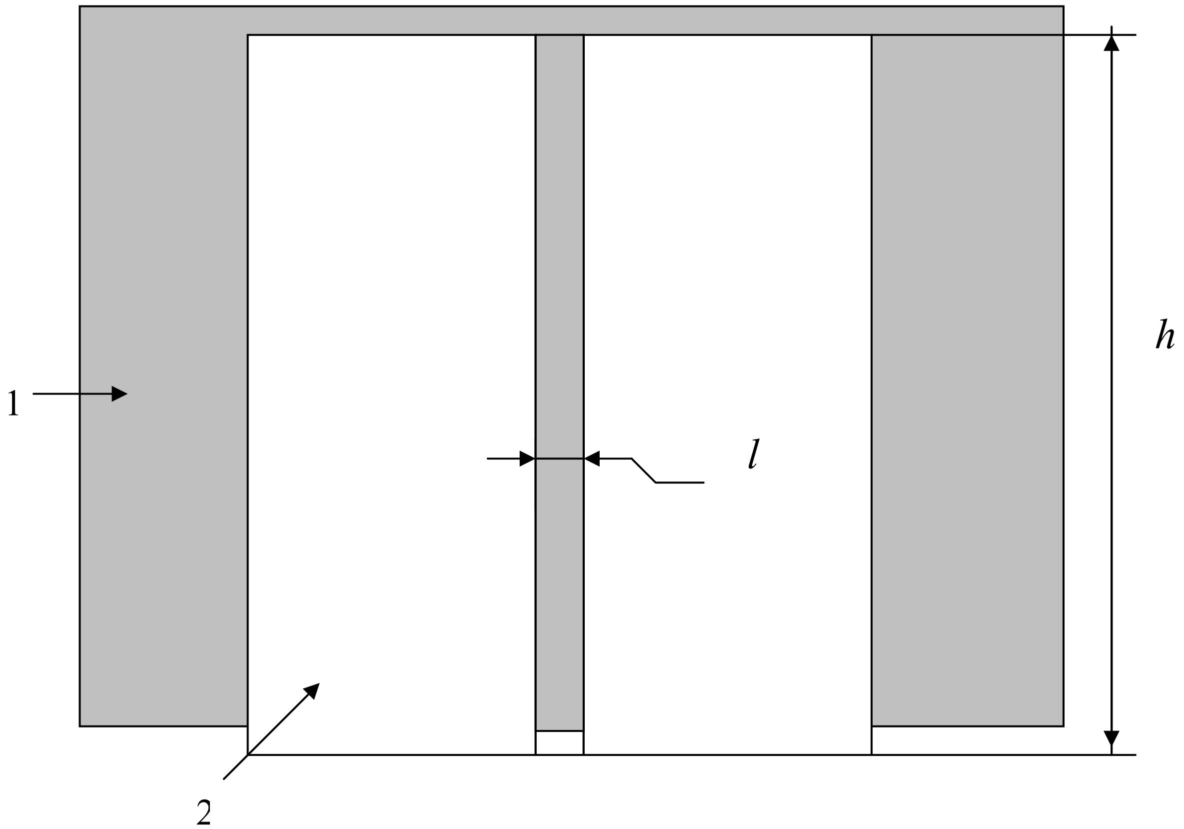

Figure A1

The material, which the shutters of the thermal test object are made of, is copper, 1 mm thick. The shutters are blackened from the outer side.

1 – standard large aperture radiator;

2 – thermal test-object with a variable slit (shutters height *h*=const, distance between the shutters *l* changes from 0 to 50 mm, the pitch being 1 mm, the uncertainty of setting the slit width is ±0,1 mm.)

Annex B (recommended)

Sketch of the thermal test-object with marks

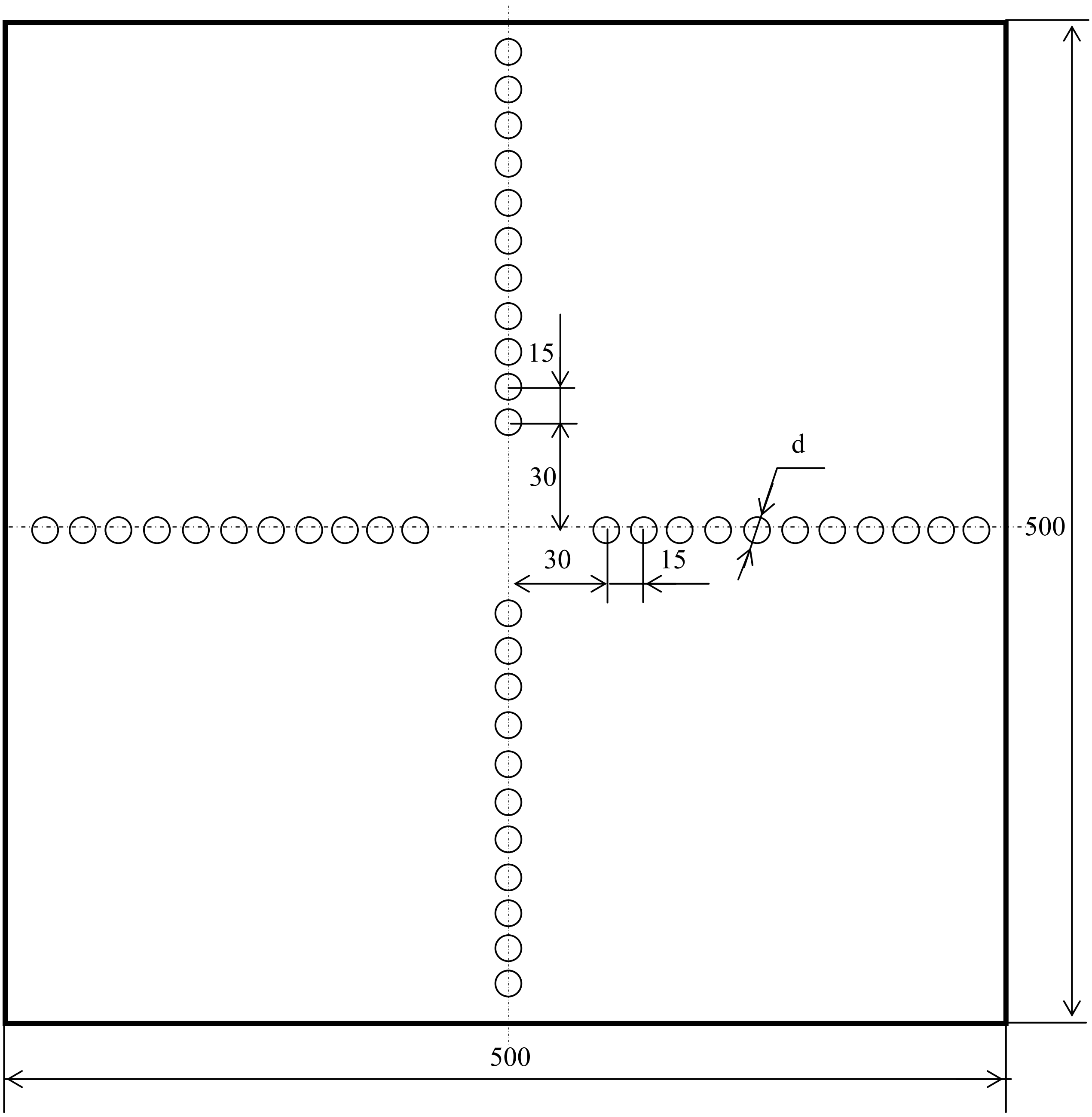

Figure B1

Material – copper, 1 mm thick.

Outer side is blackened.

d – diameter of the hole (10 mm).

Annex C (recommended)

Calculation of the spatial resolution in the horizontal direction.

With the Gaussian approximation, the function of the slit response is determined by the ration transformed to the table function *erf(x)*:

$$FRS(a) = erf\left(\frac{a}{2\sigma}\right) \tag{C1}$$

where a is the slit width, elements.

σ is a parameter determining the width of spread function line, elements.

The approximation of the experimental data array (K_{si},$_{ai}$) using the equation C1 is made through choosing the value of the parameter σ , that will ensure the minimum value of the standard deviation (SD) of the experimental data from the specified function:

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(K_{Si} - erf(\frac{a_i}{2\sigma}))^2} \tag{C2}$$

where N is the number of measurement results.

The spatial resolution in the horizontal direction is determined as the slit width at which the contrast on the thermogram is equal to 99 % of the maximum value:

$$F_x = \sigma_x \cdot 3{,}64 \tag{C3}$$

where σ_x is the value of the parameter σ, elements, in the dissection elements, chosen as a result of the approximation.

The angular dimension of the space resolution in the horizontal direction is determined in rad:

$$\Sigma_x = 2arctg\left(\frac{F_x}{X} tg\frac{\varphi_x}{2}\right) \tag{C4}$$

where X is the number of dissection elements in a row of the thermogram;

φ_x is the angle of field of view of the thermographic instrument along a row, grad.

Annex D (recommended)

Thermographic instrument verification protocol

D1. Verification conditions.

D1.1. Humidity.

D1.2. Ambient temperature.

D 2. Results obtained in determining the instantaneous field of view and the angle of field of view in horizontal and vertical directions.

D2.1. The angle of field of view of the thermographic instrument was measured against a thermal test object with marks.

Temperature of the standard large aperture radiator, t_{90}, ___°C.

Working distance from the radiator, R, ____ mm.

Instantaneous field of view, γ ___ rad.

The thermographic instrument angle of field of view is equal to, in the horizontal direction, φ_x, __ degrees, in the vertical direction, φ_y, ____ degrees.

Measurement uncertainty is __________.

D3. Results of determining noise equivalent temperature difference.

Temperature of the standard large aperture radiator, t_{90}: ___°C.

Noise equivalent temperature difference, Δt_{NETD}: ___° C.

Number of defective sensitive elements, ____elements

D4. Determining the spatial (angular) resolution of thermographic instrument having the horizontal field of view of _____ degrees, and vertical field of view ______ degrees.

The spatial resolution of a thermographic instrument is determined by the slit response function *(FRS)* in the horizontal and vertical directions, and is measured against a thermal test object having a variable slit.

Temperature of the standard (reference) large aperture radiator, t_{90}, ___°C.

D4.1. Results obtained in determining the spatial resolution of the thermographic instrument:

Spatial resolution in horizontal direction F_x		Spatial resolution in vertical direction F_y	
In dissection elements	In millirad	In dissection elements	In millirad

D5. Results of checking the temperature range and determining the accuracy.

Temperature of standard radiator, t_{mean},°C	Reading of thermographic instrument, t^t_{mean}, °C	accuracy, Δt, °C	Permissible error of thermographic instrument, °C	Measurement uncertainty, °C

D6. Results of determining the sensitivity non-uniformity over the field.

Table D6.1. Mean measured temperature of the standard radiator at different positions of the standard radiator in the field of thermogram.

Temperature of standard radiator, t_{90},°C						
Mean measured temperature, t^t_{mean}, °C	In the upper left region of the thermogram					
	In the upper right region of the thermogram					
	In the central region of the thermogram					
	In the lower left region of the thermogram					
	In the lower right region of the thermogram					
Maximum value of the mean temperatures obtained, $\bar{t}_{\max}$, °C						
Minimum value of the mean temperatures obtained, $\bar{t}_{\min}$, °C						
Sensitivity non-uniformity over the field, δt, °C						
Measurement uncertainty, °C						

D7. Results of checking of the influence of environmental condition on the performance of the instruments.

Condition in the climatic chamber: temperature, °C, humidity, %	Temperature of standard radiator, t_{90},°C	Reading of thermographic instrument, t^t_{mean}, °C	Error in readings, Δt, °C	Permissible error of thermographic instrument, °C	Measurement uncertainty, °C

D8. Results of checking of repeatability of thermographic instrument readings

Temperature of standard radiator, t_{90},°C	Mean measured temperature for the 1st time interval, t^t_{mean1}, °C	Mean measured temperature for the 2nd time interval, t^t_{mean2}, °C	Mean measured temperature for the 3rd time interval, t^t_{mean3}, °C	The difference between maximum and minimum values of the mean temperature values, Δt^t_{mean}, °C	The temperature repeatability of thermographic instrument, °C	Measurement uncertainty, °C