

DRAFT
RECOMMENDATION

DR 5

13th OIML Conference

Sydney 2008 (Item 4.1.2)

**SUBMITTED
FOR DIRECT
SANCTION**

New Recommendation

Procedure for calibration and verification of the main
characteristics of thermographic instruments

DR 5 - Procedure for calibration and verification of the
main characteristics of thermographic instruments
13th OIML Conference - Sydney 2008



ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

Explanatory Note

This Draft Recommendation is written with the purpose of harmonizing metrological control general-purpose thermographic instruments in the OIML Member States, and can be used as the basis for carrying out verification and calibration of these instruments.

It should be noted that this Recommendation only covers thermographic instruments that represent measuring systems and is not addressed to the so called "finding out infrared systems" ("IR imagers") - optoelectronic instruments intended for visualizing the 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 was no international document related to the verification of these measuring instruments. Thus, this Recommendation was rather urgent. This Recommendation harmonizes 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 consistent by supplementing it with the calibration procedure.

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Foreword

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organization whose primary aim is to harmonize the regulations and metrological controls applied by the national metrological services, or related organizations, of its Member States. The main categories of OIML publications are:

- **International Recommendations (OIML R)**, which are model regulations that establish the metrological characteristics required of certain measuring instruments and which specify methods and equipment for checking their conformity. OIML Member States shall implement these Recommendations to the greatest possible extent;
- **International Documents (OIML D)**, which are informative in nature and which are intended to harmonize and improve work in the field of legal metrology;
- **International Guides (OIML G)**, which are also informative in nature and which are intended to give guidelines for the application of certain requirements to legal metrology; and
- **International Basic Publications (OIML B)**, which define the operating rules of the various OIML structures and systems.

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International Recommendations, Documents, Guides and Basic Publications are published in English (E) and translated into French (F) and are subject to periodic revision.

Additionally, the OIML publishes or participates in the publication of **Vocabularies (OIML V)** and periodically commissions legal metrology experts to write **Expert Reports (OIML E)**. Expert Reports are intended to provide information and advice, and are written solely from the viewpoint of their author, without the involvement of a Technical Committee or Subcommittee, nor that of the CIML. Thus, they do not necessarily represent the views of the OIML.

This publication - reference **OIML R XX**, edition 2008 (E) - was developed by the OIML Technical Subcommittee TC 11/SC 3 *Radiation thermometers*. It was approved for final publication by the International Conference of Legal Metrology in 2008.

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Procedure for calibration and verification of the main characteristics of thermographic instruments

1 SCOPE

This Recommendation applies to general-purpose thermographic instruments and specifies the procedure for their calibration, their initial and subsequent verification.

2 TERMINOLOGY

2.1 Thermographic instrument

Optoelectronic instrument designed for non-contact (remote) observation, measurement and registration of the space/space-time distribution of the radiation temperature of objects in the field of view of the instrument by forming a time sequence of thermograms and by determining the temperature¹ of the object surface on the basis of the known emittance and influencing parameters (ambient temperature, atmospheric transmission, observation distance, etc.).

2.2 Thermogram

Multiple-element, two-dimensional image, each element being attributed a color, or a color gradation, or a screen brightness level, which is determined in correspondence with a conventional radiation scale.

2.3 Standard radiator

Radiator that complies with a black body model (BB).

2.4 Standard large aperture radiator

Standard radiator (i.e. a reference radiator), which angular dimensions are at least ten times larger than the instantaneous field of view of the thermographic instrument².

2.5 Thermal test-object

Device intended to create a plane picture containing a heat-radiating object with the preset spatial frequency or shape, temperature contrast on a uniform radiating background with a known temperature value and a known emittance values of the object and background.

2.6 Number of sensitive elements (detecting elements of thermogram)

Number of photosensitive elements which form the thermographic instrument photodetector.

2.7 Field of view

Solid angle within which the thermogram is formed.

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

² If the thermographic instrument has a large instantaneous field of view angle, an angular dimension of the standard reference radiator should be wide enough for covering the instantaneous field of view of the thermographic instrument.

2.8 Instantaneous field of view (IFOV)

Space angle within which the infrared radiation is detected by one photosensitive element of the photodetector.

2.9 Spatial (angular) resolution

Dimension (angular or in detecting elements) of a slit on a screen installed in front of a large aperture radiator in the field of view of the thermographic instrument, when the ratio between the peak increment of the slit temperature over the screen temperature to the temperature difference of the radiator and the screen reaches the preset value.

2.10 Noise equivalent temperature difference (temperature resolution, ΔT_{NETD})

Temperature increment equal to the root-mean-square value of the noise in a thermogram, when observing a homogeneous background with the specified temperature and with the specified thermogram rate.

2.11 Sensitivity to non-uniformity in the field of a thermographic instrument

Maximum value of the difference of temperature of thermogram fragments of a standard large aperture radiator, with a 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 have to be determined:

- The spatial (angular) resolution;
- The field of view;
- The instantaneous field of view (IFOV);
- The accuracy of radiation temperature measurement;
- The noise equivalent temperature difference;
- The number of damaged sensitive elements;
- The sensitivity to non-uniformity in the field;
- The influence of environmental condition on the performance of the instruments;
- The repeatability of readings.

4 CONDITIONS OF VERIFICATION AND CALIBRATION

The process of verification and calibration should be carried out in a stable indoor environment within the temperature range from 20 °C to 25 °C and with a relative humidity in the range from 40 % to 80 %, unless other conditions are specified in the certificate of the thermographic instrument. The thermographic instrument should not be affected by shocks, vibrations, external electromagnetic fields and external radiation sources affecting the readings of measuring instruments.

5 METHODS FOR VERIFICATION AND CALIBRATION

5.1 Procedures and means of verification

5.1.1 The procedures and measuring instruments, which have to be utilized 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 All measuring instruments and the thermographic instrument to be verified are prepared for operation according to their in-line documentation (ID).

5.1.4 Specialists qualified for performing verification in the field of temperature and radiometric measuring instruments are considered as qualified for verification and calibration.

5.2 External examination

5.2.1 The external examination should demonstrate:

- The correspondence of the complete set and marking of a thermographic instrument to its ID;
- The correspondence of a thermographic instrument to the safety requirements stated in the certificate and/or in the Operating Manual (OM);
- The 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 these requirements can't be considered as verified.

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

Procedure	Item in the Recommendation	Means of verification and their metrological characteristics	Obligation of procedure	
			Initial verification	Periodical verification/calibration
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 noise equivalent temperature difference	5.4	Standard (reference) large aperture radiator for the temperature range over the ambient temperature by 10 °C with an emissivity not less than 0.96. The temperature instability is not more than ± 0.05 °C/min.	Yes	Yes
4. Determination of the number of defective elements	5.5	Standard (reference) large aperture radiator (See 5.4).	Yes	Yes
5. Determination of field of view and instantaneous field of view	5.6	1. Standard (reference) large aperture radiator (See 5.4). 2. Thermal test objects with an emissivity not less than 0.96. See the sketch of the test-objects in Annex A and Annex B. 3. Measuring rule with a length of 500 mm and a scale factor of 1 mm.	Yes	No
6. Determination of spatial (angular) resolution	5.7	1. Standard (reference) large aperture radiator (See 5.4). 2. Thermal test-object (See 5.6).	Yes	Yes
7. Checking the range and estimation of accuracy of radiation temperature measurement	5.8	Standard (reference) radiator.	Yes	Yes
8. Determination of sensitivity to non-uniformity in the field	5.9	Standard radiator (See 5.8).	Yes	Yes
9. Check of the influence of environmental condition on the performance of the instruments	5.10	Standard (reference) radiator (See 5.8). Climatic chamber.	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 and Functional check

5.3.1 Testing (performance check)

The thermographic instrument is switched on and its performances are checked in correspondence with the OM.

The thermographic instrument which has malfunctioned in the testing process can't be considered as verified.

5.3.2 Functional check of a thermographic instrument under various conditions

The thermographic instrument and the radiator (BB model) are set up accordingly to their OM. The thermographic instrument is focused on the emitting surface of the radiation source.

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

If the functions specified in the OM or certificate are not operating under one condition, the thermographic instrument can't be considered as verified.

5.4 Determination of noise equivalent temperature difference

5.4.1 Measurements are taken at a distance that ensures a full covering of the field of view of the thermographic instrument by the radiator aperture.

5.4.2 The temperature of the standard (reference) large aperture radiator is set at 30 °C or at the temperature specified in the OM or certificate for determining the relevant characteristics.

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

5.4.4 The temperature difference Δt_{ij} (in °C) of each detecting element in the areas of the recorded thermograms, which include not less than statistically significant number of detecting elements, is determined using the software provided with the thermographic instrument, or is calculated by the formula:

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

where:

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

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

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

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

where:

Δt_{ij} is the temperature difference of detecting element of the first thermogram with $(i;j)$ coordinates (in °C);

$\overline{\Delta t}$ is the mean temperature difference (in °C);

X is the number of sensitive elements in horizontal direction;

Y is the number of sensitive elements in vertical direction.

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

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

5.5 Determination of the number of defective detecting elements of thermogram

5.5.1 The procedures described in 5.4.1 and 5.4.2 are carried out.

5.5.2 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.

5.5.3 With the help of the software provided with the thermographic instrument the defective sensitive elements are identified. The deviation of the temperatures of each sensitive element δt (in °C) from the mean value of temperature of thermogram (in °C) shall not exceed the value of temperature resolution, determined in 5.4, more than 6 times. The sensitive element for which the deviation of temperature does not meet this requirement is declared defective.

5.5.4 The number of defective sensitive elements shall not exceed 0.3 % of the total number of sensitive elements specified in the OM or shall not exceed the value specified in the OM, or certificate, of the thermographic instrument.

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

5.6.1 Selection of the working distance.

5.6.1.1 The temperature of the standard (reference) 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.

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

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

5.6.1.4 The working distance R (in 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.

5.6.2 Determination of the field of view and the instantaneous field of view

5.6.2.1 The temperature of the standard (reference) large aperture radiator is set 10 °C 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.

5.6.2.2 The operating mode of a thermographic instrument shall be able to attain its maximum sensitivity. The image of the thermal test object shall match with the central area of the thermogram. Measurements are carried out at the working distance R specified in 5.6.1.

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

5.6.2.4 Instantaneous field of view (IFOV) γ (in rad) is calculated by the formula:

$$\gamma = \frac{2}{a} \operatorname{arctg} \frac{A}{2R} \quad (3)$$

where:

a is the distance between the marginal marks of the test object (in element);

A is the distance between the marginal marks of the test object (in mm);

R is working distance determined in 5.4.1 (in mm).

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

$$\varphi_x = \gamma \cdot X \cdot \frac{180}{\pi} \quad (4)$$

$$\varphi_y = \gamma \cdot Y \cdot \frac{180}{\pi} \quad (5)$$

where:

γ is instantaneous field of view (IFOV) (in rad);

X is the number of sensitive elements in horizontal direction;

Y is the number of sensitive elements in vertical direction.

5.6.2.6 The instantaneous field of view γ and the fields of view φ_x and φ_y should correspond to those indicated in the OM or in the certificate of the thermographic instrument.

5.7 Determination of the spatial (angular) resolution

5.7.1 Determination of the scale parameter

5.7.1.1 The sequence of operations is carried out in accordance with items 5.6.2.2, 5.6.2.3.

5.7.1.2 The distances between the holes of the thermal test object are measured in detecting elements, using the obtained 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 (in element) and those on the thermal test object (in mm).

5.7.2 Determination of the 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 orientated vertically – along the height of the thermogram).

5.7.2.2 The sequence of operations is carried out in accordance with item 5.6.2.2.

5.7.2.3 The maximum width of the slit is set and then measured. The maximum temperature of the slit t'_{max} (in °C) 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:

$$K_s = \frac{t'_{max} - t'_0}{t_s - t'_0} \quad (6)$$

where:

t'_{max} is the maximum temperature value of the slit with width A determined by the thermogram (in °C);

t'_0 is the mean temperature value of the shutters determined by the thermogram (in °C);

t_s is the maximum temperature value of the slit at the maximum width determined by the thermogram (in °C).

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:

$$a = A \cdot k \quad (7)$$

where:

a is the slit size (in element);

A is the slit width (in mm);

k is the scale parameter determined by 5.7.1 (in elements/mm).

5.7.2.5 The slit width A (in 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 obtained measurement results, the dependence of slit contrast on thermograms K_s upon slit width a (in element) – 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 in 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 detecting elements, to the slit size, should correspond to the value specified in the OM or in the certificate of the thermographic instrument, for 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 similar way to the one described in 5.7.2. The thermal test object with variable slit is set flat (the slit axis being orientate 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 detecting elements of the thermogram Y are used.

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

5.8 Checking 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 that ensures coverage by the aperture of the radiator greater than 20 % of the field of view of the thermographic instrument. The emitting surface of the standard radiator is matched with the central area of the thermogram.

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

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

5.8.6.3 The accuracy Δt (in °C) for each temperature of a thermographic instrument is calculated by the formula:

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

where:

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

t_{90} is the temperature of the standard radiator (in °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 to non-uniformity in the field

5.9.1 The procedures from 5.8.1 are carried out.

5.9.2 The sensitivity to non-uniformity in the 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, a minimum of five measurements is taken at each temperature.

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

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

5.9.5 The sensitivity to non-uniformity in the field of a thermographic instrument δt (in °C) is calculated by the formula:

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

where:

\bar{t}_{\max} is the maximum temperature value among the mean obtained temperatures;

\bar{t}_{\min} is the minimum temperature value in the area 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 for three points of the working temperature range (the lower, the upper and one point within the range) for each operation mode (temperature range). When the steady-state conditions of a radiator are set, a minimum of five measurements using the thermographic instrument is taken for each temperature. The average (mean) value of the standard radiator radiation temperature is determined using the thermogram t_{mean}^t (in °C) taking into account its emissivity and the background radiation temperature.

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

$$\Delta t_{EC} = t_{90} - t_{mean}^t \quad (11)$$

where:

t_{mean}^t 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 (in °C);

t_{90} is the value of the standard radiator (in °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 does comply 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 °C higher than the ambient temperature.

5.11.2 The image of the center of the standard extended radiator matches 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 OM.

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 reports, 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. If the verification or calibration results are unfavorable, a notice of non-serviceability of the thermographic instrument is issued, the reasons being identified.

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

- The spatial (angular) resolution;
- The field of view;
- The instantaneous field of view (IFOV);
- The accuracy of radiation temperature measurement;
- The noise equivalent temperature difference (temperature resolution, ΔT_{NETD});
- The number of defective sensitive elements;
- The sensitivity to non-uniformity in the field;
- The influence of environmental condition on the performance of the instruments;
- The repeatability.

ANNEX A (*informative*)

Sketch of the thermal test-object with a variable slit

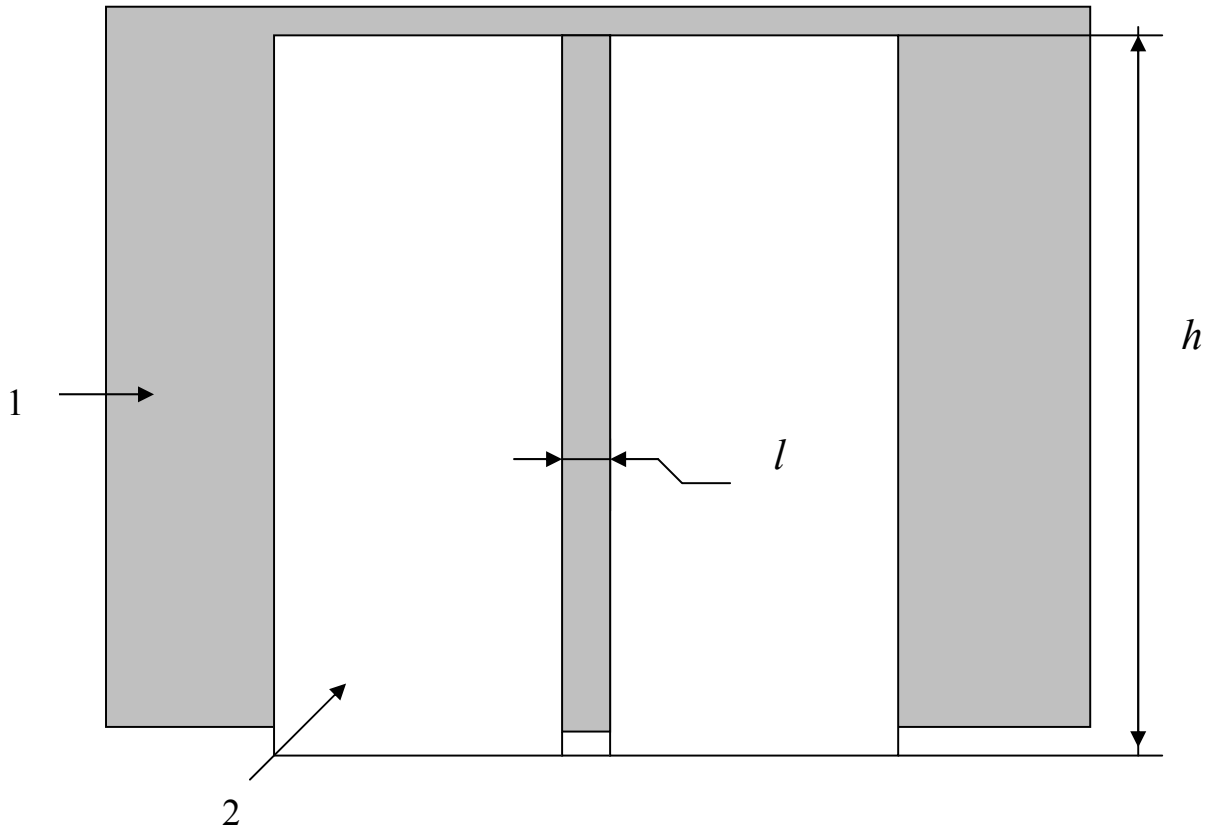


Figure A1

The shutters of the thermal test object are made of 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 $h=\text{const}$, distance between the shutters l changes from 0 to 50 mm, the pitch being 1 mm, the uncertainty of setting the slit width is $\pm 0,1$ mm.).

ANNEX B (*informative*)

Sketch of the thermal test-object with marks

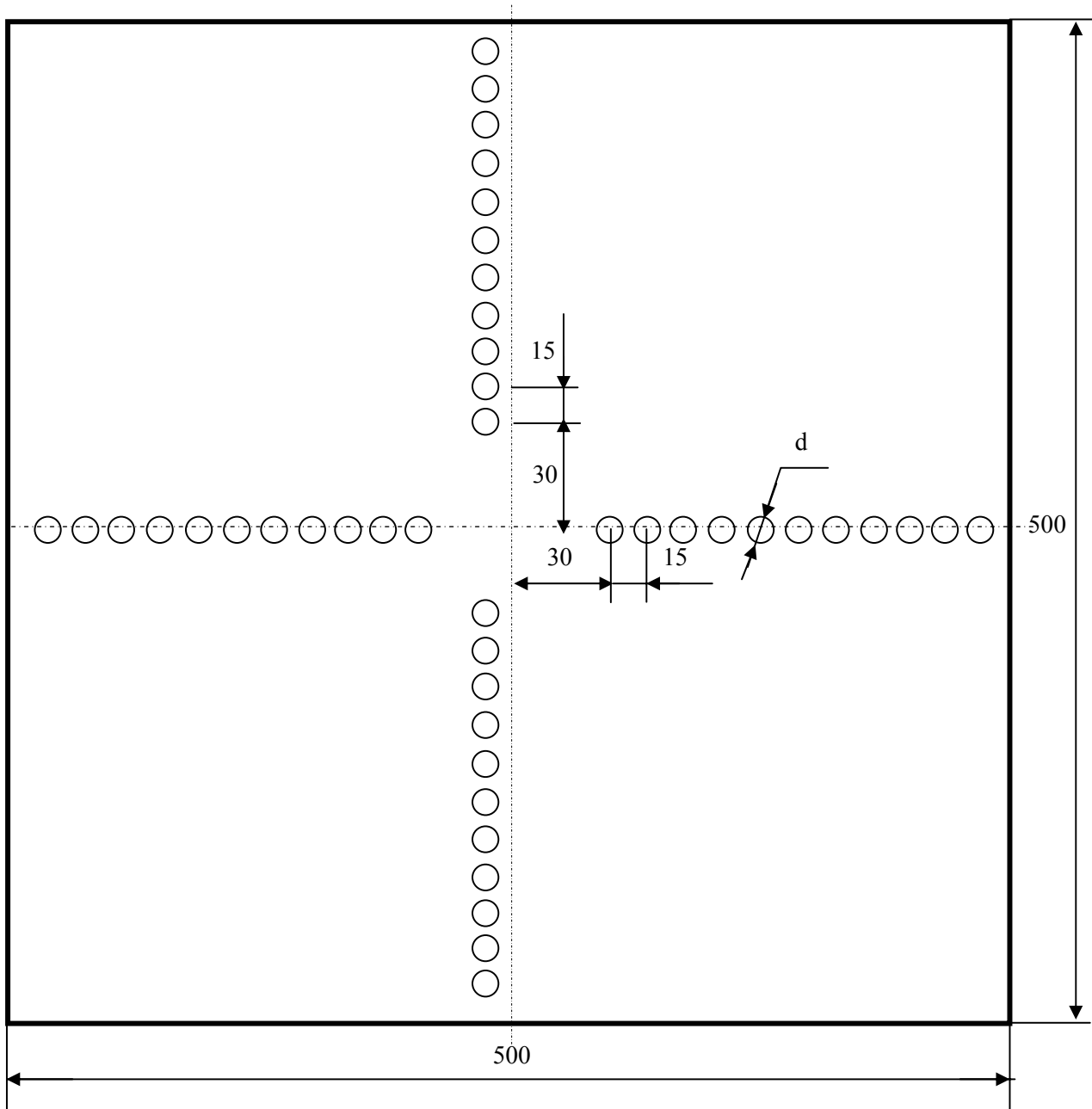


Figure B1

Material – copper, 1 mm thick.

Outer side is blackened.

d – diameter of the hole (10 mm).

ANNEX C (*informative*)

Calculation of the spatial resolution in the horizontal direction.

With the Gaussian approximation of line spread function, the function of the slit response is determined by the ratio transformed to the table function $erf(x)$:

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

where:

a is the slit width (in element);

σ is a parameter determining the width of spread function line (in element).

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

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

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:

$$F_x = \sigma_x \cdot 3.64 \quad (C3)$$

where:

σ_x is the value of the parameter σ (in element) in the detecting elements, chosen as a result of the approximation.

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

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

where:

X is the number of detecting elements in a row of the thermogram;

φ_x is the angle of field of view of the thermographic instrument along a row (in grad).

ANNEX D (*informative*)

Thermographic instrument verification report

D1 Verification conditions

D1.1 Humidity

D1.2 Ambient temperature

D2 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 the 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 detecting elements	In millirad	In detecting elements	In millirad

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

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

D6 Results of determining the sensitivity to non-uniformity in the field.

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} (in °C)						
Mean measured temperature, t_{mean}^t (in °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} (in °C)						
Minimum value of the mean temperatures obtained, \bar{t}_{min} (in °C)						
Sensitivity to non-uniformity over the field, δt (in °C)						
Measurement uncertainty (in °C)						

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

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

D8 Results of checking repeatability of thermographic instrument readings

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