IEC TS 63144-1

Edition 1.0 2020-04

TECHNICAL SPECIFICATION

Industrial process control devices – Thermographic cameras –
Part 1: Metrological characterization

IEC TS 63144-1:2020-04(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

IEC TS 63144-1

Edition 1.0 2020-04

TECHNICAL SPECIFICATION

Industrial process control devices – Thermographic cameras – Part 1: Metrological characterization

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.200, 25.040.40

ISBN 978-2-8322-7969-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

INDUSTRIAL PROCESS CONTROL DEVICES – THERMOGRAPHIC CAMERAS –

Part 1: Metrological characterization

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a Technical Specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 63144-1, which is a Technical Specification, has been prepared by subcommittee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement, control and automation.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
65B/1129/DTS	65B/1159/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63144 series, published under the general title *Industrial process control devices – Thermographic cameras*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Thermographic cameras (also called "thermographic imagers" or "infrared cameras") are being increasingly used for spatially and temporally resolved, non-contact radiation temperature measurement. Tracing the temperature values indicated by these instruments to the International Temperature Scale (ITS-90) is gaining in importance for the comparability of measurements. The precondition for their calibration and metrological application with low uncertainties is to accurately describe and determine the essential metrological data of thermographic cameras. Whereas there are international regulations to determine the technical specifications for radiation thermometers – namely IEC TS 62492-1 and IEC TS 62492-2 – there is a lack of such regulations for thermographic cameras in such a detailed form.

This document is Part 1 of a series of technical specifications for thermographic cameras. It is intended to improve comparability and testability of the essential metrological technical data of thermographic cameras. To this end, unambiguous procedures are laid down for the indication and the determination of this technical data. Future IEC TS 63144-2 is intended to specifically address the absolute calibration procedures and the corresponding uncertainties for thermographic cameras in more depth and detail.

INDUSTRIAL PROCESS CONTROL DEVICES – THERMOGRAPHIC CAMERAS –

Part 1: Metrological characterization

1 Scope

This part of IEC 63144 applies, in the field of metrology, to the statement and testing of technical data in datasheets and instruction manuals for thermographic cameras that are used to measure the temperature of surfaces. This includes, unless otherwise stated, both two-dimensional and one-dimensional (line cameras or line scanners) temperature measuring instruments, independently of the scanning principle (fixed multi-element detector or scanning camera system).

This document describes standard test methods to determine relevant metrological data of thermographic cameras. Manufacturers and sellers can choose relevant data and can state that the data shall be compliant with this Technical Specification.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

NOTE The term “uncertainty” used in this document is precisely derived from the above databases and more specifically from ISO/IEC Guide 98-3:2008 [3].

3.1
blackbody radiator
radiator that emits radiation in a very good approximation of Planck's radiation law

Note 1 to entry: A blackbody radiator is a source of thermal radiation with an effective emissivity close to 1.

3.2
coverage factor
numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

Note 1 to entry: Coverage factor, k, is a number larger than one and, typically, in the range from 2 to 3.

3.3
detector format used
number of detector elements (detector pixels) that have actually been used to record the image

Note 1 to entry: The term "pixel", which is frequently used, will not be used in this document since it can refer both to the detector (detector element) and to the image (image element).

3.4
exposure time
minimum period of time during which the input quantity (measurement temperature or measurement radiation) is applied in the event of abrupt changes in order for the output signal of the thermographic camera to reach a pre-defined value

3.5
emissivity setting range
range within which the emissivity of the target can be set at the thermographic camera

3.6
field of view
FOV
horizontal and vertical angle of the maximum realizable image section of the thermographic camera, with specified optics

Note 1 to entry: The field of view is the angular extent of the observable world that is seen at any given moment.

3.7
influence of air humidity
parameter which gives the additional uncertainty of the measured temperature value of a target depending on the deviation of the actual humidity from the humidity at calibration referring to a defined measuring range

[SOURCE: IEC TS 62492-1:2008, 3.1.11, modified – "depending on the relative air humidity at a defined ambient temperature" replaced with "of a target depending...measuring range".]

3.8
influence of the internal instrument temperature
parameter which gives the additional uncertainty of the measured temperature value of a target depending on the deviation of the actual internal temperature of the thermographic camera from the internal temperature at calibration referring to a defined measuring range

[SOURCE: IEC TS 62492-1:2008, 3.1.10, modified – "depending on the deviation of the temperature...ambient conditions" replaced with "of a target depending...measuring range".]

3.9
inhomogeneity equivalent temperature difference
IETD
smallest resolvable temperature difference that corresponds to the noise distributed over the surface of the image elements in an image

Note 1 to entry: "Noise distributed over the surface" means the position-dependent deviation of the indicated value of an image element from the mean value of all elements without the influence of time-dependent noise at a homogeneous radiance of the source.

3.10
instantaneous field of view
IFOV
horizontal and vertical angle resulting from the computation of the section of the field of view detected by a single detector element of the thermographic camera with aberration-free optics with a specified focal length

3.11
integration time
time span in which a quantum detector converts the incident radiation into an output signal

Note 1 to entry: The measurement signal is also integrated when using thermal detectors, but in this case, the integration time is not representative for the description of the time-dependent behaviour.

3.12
integration time setting range
range in which the time span for the conversion of the radiation signal into an output signal can be set (for thermographic cameras with a quantum detector)

3.13
interchangeability
half the maximum deviation between the measurement results of two thermographic cameras of the same type that are operated under identical conditions

[SOURCE: IEC TS 62492-1:2008, 3.1.15, modified – Definition revised.]

3.14
internal instrument temperature
internal temperature which is determined by the manufacturer at one or several representative points and is provided to the user in order to monitor the admissible operating temperatures and to indicate additional components in the measurement uncertainty

3.15
long-term stability
reproducibility of measurements repeated over a period of at least three months

[SOURCE: IEC TS 62492-1:2008, 3.1.12, modified – "over a long time" replaced with "a period of at least three months".]

3.16
measurement accuracy
closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept "measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

3.17
measurement uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

EXAMPLE The half-width of an interval having a stated coverage probability.

Note 1 to entry: "Measurement uncertainty" and "measurement accuracy" are not synonyms.

[SOURCE: ISO/IEC Guide 98-3:2008, 2.2.3, modified – Notes replaced with the example and note to entry.]

3.18
measuring distance
distance or distance range between the thermographic camera and the target for which the thermographic camera is designed and in which a focussed imaging of the target is possible

[SOURCE: IEC TS 62492-1:2008, 3.1.4, modified – "radiation thermometer" replaced with "thermographic camera" and "and in which a focussed imaging of the target is possible" added.]

3.19
measuring temperature range
temperature range, with respect to the blackbody, for measurements in which the thermographic camera is designed

Note 1 to entry: For this temperature range, the measurement uncertainty remains within defined limits.

[SOURCE: IEC TS 62492-1:2008, 3.1.1, modified – "radiation thermometer" replaced with "thermographic camera", "with respect to the blackbody, for measurements in which" and note added.]

3.20
minimum field of view for temperature measurement
$MFOV_T$
field of view of the circular target with the smallest possible diameter, which, when measured proportionally to the radiance, does not result in a decrease compared to the reference value larger than that specified

3.21
noise equivalent temperature difference
NETD
contribution to the measurement uncertainty, indicated in K or in °C, which occurs due to time-dependent instrument noise

[SOURCE: IEC TS 62492-1:2008, 3.1.3, modified – Definition revised.]

3.22
non-uniformity
inhomogeneity of detector responsivity
maximum difference between the indicated temperature values in an image when viewing an image-filling, homogeneous radiance of the measurement object and neglecting the time-dependent intrinsic noise of the instrument

3.23
number of image elements
number of single values of which the image provided by the thermographic camera consists, horizontally and vertically

3.24
operating humidity range
admissible humidity range within which the thermographic camera may be operated

[SOURCE: IEC TS 62492-1:2008, 3.1.19, modified – "permissible" replaced with "admissible" and "radiation thermometer" replaced with "thermographic camera".]

3.25
operating temperature range
admissible temperature range within which the thermographic camera may be operated

[SOURCE: IEC TS 62492-1: 2008, 3.1.19, modified – "permissible" replaced with "admissible" and "radiation thermometer" replaced with "thermographic camera".]

3.26
image element
image pixel
smallest independent thermographic detector cell of a thermographic camera

Note 1 to entry: The term "pixel", which is frequently used, will not be used in this document since it can refer both to the detector (detector element) and to the image (image element).

3.27
Planck's radiator
idealized thermal radiation source, which emits radiation with a characteristic spectrum that only depends on the temperature and is fully described by Planck's law

3.28
reference radiator
radiating source for the metrological characterization of a thermographic camera whose radiating surface has a sufficient size, temperature homogeneity and spectral emissivity that is sufficiently stable and sufficiently well-known for its application

Note 1 to entry: The requirements on the reference radiator result from the technical specifications of the thermographic camera to be characterized and the intended uncertainty of its characterization.

3.29
refresh rate
number of output images in the specified resolution (number of image elements) per second

3.30
repeatability
twice the standard deviation of measurements repeated under the same conditions within a time span of at least three minutes

[SOURCE: IEC TS 62492-1:2008, 3.1.14, modified – "very short time span (several minutes)" replaced with "a time span of at least three minutes".]

3.31
response time
time interval between the instant of an abrupt change in the value of the input parameter (measurement temperature or measurement radiation) between two constant values and the instant from which the measured value of the thermographic camera remains within specified limits of its final value

[SOURCE: IEC TS 62492-1:2008, 3.1.16, modified – "object" replaced with "measurement", "between two constant values" added and "radiation thermometer" replaced with "thermographic camera".]

3.32
short-term stability
reproducibility of measurements repeated over a period of at least three hours

[SOURCE: IEC TS 62492-1:2008, 3.1.13, modified – "a short time period (several hours)" replaced with "a period of at least three hours".]

3.33
size-of-source effect
SSE
change in the radiation value or temperature value indicated by the thermographic camera when viewing the centre of a radiating surface with a homogeneous temperature when the area of the radiation surface is enlarged

3.34
slit response function
SRF
relative change in the value measured at the centre of the slit, in radiance-proportional quantity while reducing the width of a slit-shaped aperture oriented horizontally and/or vertically with respect to the detector and positioned in front of a homogeneously temperature-stabilized radiator

3.35
spectral range
parameter that gives the lower and upper limits of the wavelength range over which the thermographic camera detects radiation from the target

[SOURCE: IEC TS 62492-1:2008, 3.1.9, modified – "radiation thermometer operates" replaced with "the thermographic camera detects radiation from the target".]

3.36
warm-up time
maximum time period needed by the thermographic camera after switching on to operate according to its specification

[SOURCE: IEC TS 62492-1:2008, 3.1.18, modified – "maximum" added and "radiation thermometer" replaced with "thermographic camera".]

4 Symbols

For the purposes of this document, the symbols listed in Table 1 below are used:

Table 1 – Symbols

Symbol	Description	Unit
U	Expanded measurement uncertainty	
M	Measurement result	
k	Coverage factor	1
FOV_{h}	Horizontal field of view	°
FOV_{v}	Vertical field of view	°
$IFOV_{\mathrm{h}}$	Horizontal instantaneous field of view	mrad
$IFOV_{\mathrm{v}}$	Vertical instantaneous field of view	mrad
$MFOV_{\mathrm{T}}$	Minimum field of view for temperature measurement	mrad
n_{h}	Horizontal image element number	1
n_{v}	Vertical image element number	1
χ_{Ideal}	Idealized measurement field	mm
d	Measuring distance	m
f_{Optic}	Optical factor	1
λ	Wavelength	µm
$\overline{\Delta T}$	Mean temperature difference	K
t	Time	s
t_{W}	Warm-up time	s
f_{B}	Refresh rate	Hz
t_{M}	Integration time	s
$NETD$	Noise equivalent temperature difference	°C

5 Abbreviated terms

For the purposes of this document, the abbreviated terms listed below are used:

IETD inhomogeneity equivalent temperature difference
SRF slit response function
FWHM full width at half maximum

NUC non-uniformity correction

6 Determination of technical data

6.1 General

A typical setup for the determination of characteristics of thermographic camera is shown in Figure 1. The following test conditions apply for all measurements, if not stated otherwise:

1) ambient temperature range in the laboratory: 18 °C to 28 °C;
2) thermographic camera to be connected to a power supply in accordance with the manufacturer's instructions;
3) positioning system which allows linear and angular alignment of the thermographic camera in respect of the optical axis of the reference radiator;
4) compliance with the warm-up time specified by the manufacturer;
5) use of a reference radiator;
6) presupposition that, if the measuring distance is indicated in accordance with the measurement provisions, the objective of the thermographic camera is focussed on this distance.

NOTE The reference radiator is, if possible, a cavity blackbody radiator that is a good approximation of Planck's radiator, or a large-area surface radiator with a good temperature homogeneity and a coating characterized by a homogeneous and high emissivity (> 0,95 if $T \leq 150$ °C and > 0,90 if $T > 150$ °C).

If detector elements are faulty, which the manufacturer most of the time replaces by special algorithms, this shall not influence the measurements; if needed, the manufacturer shall be asked to provide these algorithms or the measurements shall be repeated at different positions.

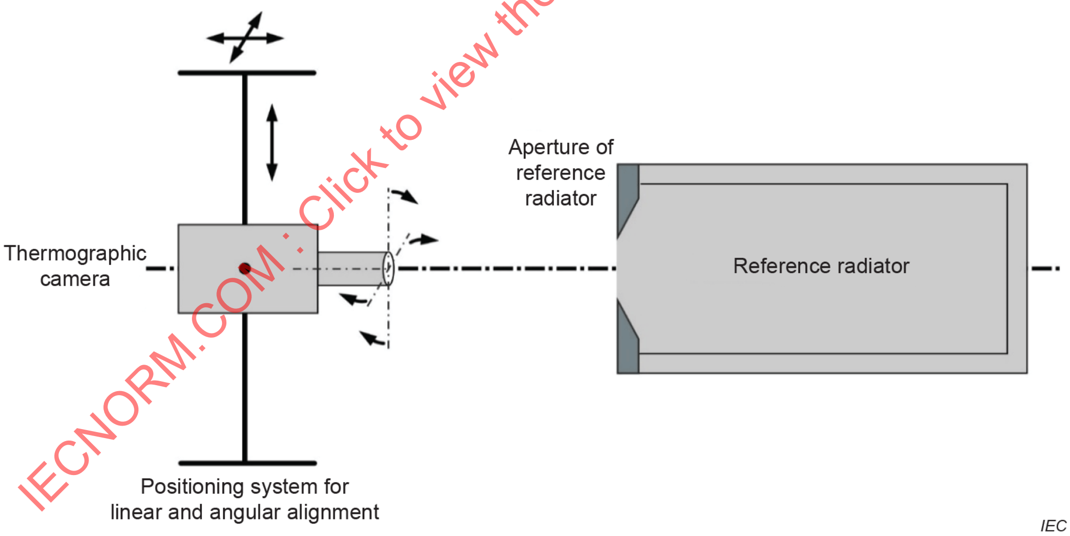


Figure 1 – Schematic measuring setup

6.2 Measuring temperature range

6.2.1 General

The temperature range for which the thermographic camera is designed and in which the measurement uncertainty lies, within the given specification, always refers to the blackbody.

Besides the specified measuring temperature range, a temperature indication range may be given. Within the limits of this range, the thermographic camera indicates measured values without necessarily complying with the specified measurement uncertainty.

6.2.2 Required parameters

In the case of interchangeable objectives, spectral filters or diaphragms, the arrangement used shall be indicated. If wider measuring temperature ranges are divided into several manually or automatically adjustable individual ranges, this division shall also be indicated.

6.2.3 Examples of indications

a) Measuring temperature range: −20 °C to 300 °C

b) Measuring temperature ranges: (1) −20 °C to 120 °C and (2) 0 °C to 600 °C

6.2.4 Test condition, method and procedure for measuring temperature range

The measuring temperature range is closely linked to the measurement uncertainty (3.17) and can therefore be fully determined in connection with the latter only.

To determine the temperature indication range, the thermographic camera is placed centrally in front of a reference radiator of known temperature and emissivity. The temperature of the reference radiator is progressively brought closer to the specified minimum and maximum temperatures of the respective temperature indication range. Taking the specified measurement uncertainty of the thermographic camera and the uncertainty of the reference radiator used into account, the indication of the lowest and of the highest temperature in the thermographic image is recorded and compared with the manufacturer's declarations.

6.3 Noise equivalent temperature difference (*NETD*)

6.3.1 General

The noise equivalent temperature difference indicates the contribution to the measurement uncertainty which is caused by high-frequency temporal instrument noise. It corresponds to the temperature difference of a blackbody where the signal-to-noise ratio of the thermographic camera is 1. In the case of the noise equivalent temperature difference of a single detector element, the coverage probability is always 68,3 % (standard uncertainty).

6.3.2 Required parameters

The noise equivalent temperature difference strongly depends on the radiation temperature of the object to be measured, on the selected measuring time (integration time, image recording time and/or refresh rate) and on potential image averaging, which therefore always have to be indicated together with the *NETD*. In the case of interchangeable objectives or filters, the objective and filter used shall be indicated; in the presence of switchable measuring temperature ranges, the measuring temperature range used shall be indicated. If the *NETD* depends on the internal instrument temperature, this dependency should be measured. In this case, the internal instrument temperature shall be stated with the *NETD*. Finally, the distance to the reference radiator, the focussing conditions and the ambient temperature shall be stated with the *NETD* if the result depends on these parameters. If not stated otherwise, it is assumed that the *NETD* was measured with the aperture of the reference radiator in focus.

In the case of fixed and known attribution of the exposure time, these shall be indicated as parameters.

NOTE If the camera is able to perform an internal non-uniformity-correction (NUC), this can be applied just before the *NETD* measurement. This will generally improve the *NETD*.

6.3.3 Examples of indications

a) *NETD*: 0,05 °C (at a radiator temperature of 30 °C, refresh rate: 25 Hz, measuring temperature range: −20 °C to 120 °C, internal instrument temperature 23 °C ± 5 °C).

b) *NETD*: 20 mK (at a radiator temperature of 30 °C, integration time: 1 ms, focal length: 30 mm).

c) *NETD*: typical 40 mK (mean value of all detector elements at a radiator temperature of 30 °C, refresh rate: 50 Hz).

6.3.4 Test condition, method and procedure for noise equivalent temperature difference

6.3.4.1 General

Owing to different equipment characteristics, not all thermographic cameras allow real-time recording as is required by test method (A). In this case, it is possible to use test method (B), in accordance with OIML R141. Whereas test method (A) determines indications of the time-dependent signal-to-noise ratio for each image element, method (B) only allows the statement of an expected value for the mean noise equivalent temperature difference of the thermographic camera. In this case, the value shall be clearly identified as a mean value.

6.3.4.2 Test method (A) for noise equivalent temperature difference (*NETD*)

1) The thermographic camera is prepared in accordance with the specifications given in 6.1 and placed centrally in front of a homogeneous reference radiator of known radiation temperature (referring to an emissivity set to 1). The short-term variations in the temperature of the reference radiator during the measuring time shall be negligible with respect to the *NETD* to be measured.
2) The integration time and/or the refresh rate shall hereby be set in accordance with the value laid down in the specification of the instrument to be tested.
3) With the software provided by the manufacturer, at least 100 consecutive values are measured and recorded for the pixels oriented towards the reference radiator; hereby, the total measuring time shall amount to at least 100 times the exposure time. From the measured temperature values, the standard deviation is calculated for each individual image element (image pixel). Slow changes in the mean value of all image elements (drift) shall be corrected mathematically if they cannot be eliminated by reducing the measuring time.
4) If the simultaneous exposure of all image elements is not possible, several sequences shall be carried out with different positions of the reference radiator in the image.
5) The *NETD* is the designated standard deviation where 90 % of all measured individual standard deviations of the single image elements are less or equal. If applicable, relative proportions that deviate from this value shall be indicated. As an alternative, it is possible to indicate the arithmetic mean value of the measured individual standard deviations of all single image elements and its scattering instead. In this case, the value shall be clearly identified as a mean value.

NOTE The quantitative measurement conditions in step 3), i.e. the number of frames used for the *NETD* calculation, can be determined differently by manufacturers and sellers of thermographic cameras, if the statistical significance is maintained.

6.3.4.3 Test method (B) for noise equivalent temperature difference (*NETD*)

1) The thermographic camera is prepared in accordance with 6.1 and positioned centrally in front of a homogeneous reference radiator of known radiating temperature (referring to an emissivity set to 1). The short-term variations in the temperature of the reference radiator during the measuring time shall be negligible with respect to the *NETD* to be measured.
2) The integration time and the refresh rate shall hereby be set in accordance with the value laid down in the specification of the instrument to be tested.
3) Two individual images are recorded rapidly one after the other, but with a minimum interval corresponding to the detection time. For each image element, the difference between the indicated temperature values is determined.

$$\Delta T_{i,j} = T_{i,j}^{(1)} - T_{i,j}^{(2)} \quad (1)$$

where

$T_{i,j}^{(1)}$ is the indicated temperature value of image element i,j in the first thermographic image;

$T_{i,j}^{(2)}$ is the indicated temperature value of image element i,j in the second thermographic image.

The mean $NETD$ is computed from:

$$NETD = \frac{\sqrt{2}}{2}\sqrt{\sum_{i=1}^{n_\mathrm{h}}\sum_{j=1}^{n_\mathrm{v}}\frac{(\Delta T_{i,j} - \overline{\Delta T})^2}{n_\mathrm{h} \cdot n_\mathrm{v}}} \qquad (2)$$

where:

$\Delta T_{i,j}$ is the difference between the indicated temperature values of image element i,j;

$\overline{\Delta T}$ is the mean temperature difference between the image's mean values;

n_h is the horizontal number of image elements;

n_v is the vertical number of image elements.

6.4 Measuring distance (d)

6.4.1 General

The measuring distance describes a fixed distance or, more often, a distance range for which the thermographic camera allows a focussed image of the object to be measured. The reference point for stating the measuring distance has to be given by the manufacturer (e.g. an edge of the instrument housing).

6.4.2 Required parameters

In the case of interchangeable objectives, the objective used shall be indicated.

6.4.3 Examples of indications

a) Measuring distance: 0,2 m to ∞.

b) Measuring distance: 60 mm.

6.4.4 Test condition, method and procedure for measuring distance

The distance between a reference radiator with a sharply limited edge (e.g. cooled diaphragm) and the thermographic camera is varied within the limits in which a subsequent focussing on a sharp image is possible. Measurements shall be done under the focussed conditions where the signal gradient at the boundary of the sharp edge is maximum. Both limits for the (minimum and the maximum) distance are determined as the minimum and the maximum measuring distances.

For focussing in the far range, it is important that the reference radiator has a sufficiently large surface. Since this cannot always be guaranteed, a suitable object, providing a sharply limited temperature edge, may also be used.

6.5 Field of view (FOV)

6.5.1 General

The field of view describes the area of the image that is detected by the thermographic camera, both in horizontal and in vertical directions. The values are indicated combining both directions or as single values (FOV_h or FOV_v) in angle unit.

6.5.2 Required parameters

In the case of interchangeable objectives, the appurtenant objective shall be indicated together with its focal length or designation as well as the respective measuring distance.

NOTE The field of view angle is a constant quantity only for distances that are large enough compared to the objective's focal length.

6.5.3 Examples of indications

Image field of view: 30° × 23°.

6.5.4 Test condition, method and procedure for field of view

FOV is determined by horizontal and/or vertical shifting of a reference radiator with a small aperture within the object plane, the thermographic camera being focussed. The positions of the reference radiator exactly at the edges of the thermographic image are determined. With the distance between the object plane and the optical main plane the field of view is calculated. Instead of a small-scale reference radiator, it is also possible to use a cooled diaphragm in front of a large-area reference radiator. The distance to the reference radiator should be at least 20 times the focal length.

If the main plane of the objective used is not known, it is alternatively possible to measure the size of the field of view from two different distances, which shall, however, correspond to at least ten times the focal length, and to determine the angle using the rule of proportion.

6.6 Number of image elements

The number of image elements describes the number of individually measured values, indicated as horizontal and vertical number of image elements, provided by the thermographic camera, which, in their totality, represent the thermographic image the user can see.

The number is determined by the design chosen by the manufacturer and requires no test.

NOTE Partial overlay of images occurs already inside the thermographic camera in order to increase the number of image elements issued. The number of image elements does, therefore, not necessarily correspond to the detector format used (6.7).

An example of indication of number of image elements is: 320 × 240.

6.7 Detector format used (number of detector elements used)

The detector format used shall not in each case be the same as the number of image elements provided by the camera.

EXAMPLE

a) Scanning thermographic cameras or line scanners in which sequential scanning is carried out by means of a mobile optical element.

b) Resolution increase by images overlay from several individual images with slight spatial shift.

c) Resolution decrease by averaging across several detector elements.

In the event of deviations between the number of image elements issued and the detector format used, this needs to be indicated separately. This parameter is determined by the manufacturer and requires no test measurement.

An example of indications of detector format is: 320 × 240 detector elements.

6.8 Instantaneous field of view (*IFOV*)

6.8.1 General

This designation originates from scanning thermographic cameras and describes the image field area of the detector detected at the instant of an individual scan. Thermographic cameras with a matrix detector use imaging objectives that often do not image orthomorphically. Especially with wide-angle lenses, the field of view angle of the individual detector element therefore depends on its position. For a thermographic camera with a matrix detector, the mean *IFOV* is calculated: it is indicated in the angle unit mrad, as a quotient of *FOV* and of the number of image elements $n_{\mathrm{h,v}}$, referring to a horizontal (h) and a vertical (v) orientation, respectively:

$$IFOV_{\mathrm{h,v}} = \frac{FOV_{\mathrm{h,v}}}{n_{\mathrm{h,v}}} \tag{3}$$

From the *IFOV* indication in mrad and the distance of the object d in m, an approximation of the idealized measurement field χ_{Ideal} can be calculated in mm:

$$\chi_{\mathrm{Ideal}} = d \cdot IFOV \tag{4}$$

This may on no account be confused with the minimum size of an object to be measured for a temperature measurement.

6.8.2 Required parameters

The objective used shall always be indicated.

6.8.3 Example of indications

IFOV: 1,5 mrad (objective with the focal length 25 mm).

6.8.4 Test condition, method and procedure for instantaneous field of view

The mean *IFOV* is calculated in accordance with Equations (3) and (4), from the reference *FOV* referring to the respective orientation, divided by the number of image elements in that direction. The result is indicated in the angle unit mrad.

A full calculation of the position-dependent *IFOV* is only possible if all optics data are known.

6.9 Slit response function (SRF)

6.9.1 General

The slit response function describes the relative change in the indicated measured value in radiation units while narrowing a slit-shaped diaphragm in front of a homogeneously temperature-stabilized radiator. The slit response function is a quantitative description of the influence of the size of the object to be measured on the measured value indicated as a function of a defined reference direction (horizontal or vertical).

Due to imaging defects of the optics and to diffraction – but also to thermal cross-talk between the individual detector elements – the projection of a detector element is never fully in agreement with the theoretically calculated image. The slit response function describes this behaviour quantitatively in one axis.

NOTE Even in the event of an ideal image, a very small object with projected detector element size would not, coincidentally, be imaged strictly on one detector element, but could occupy all possible intermediary positions.

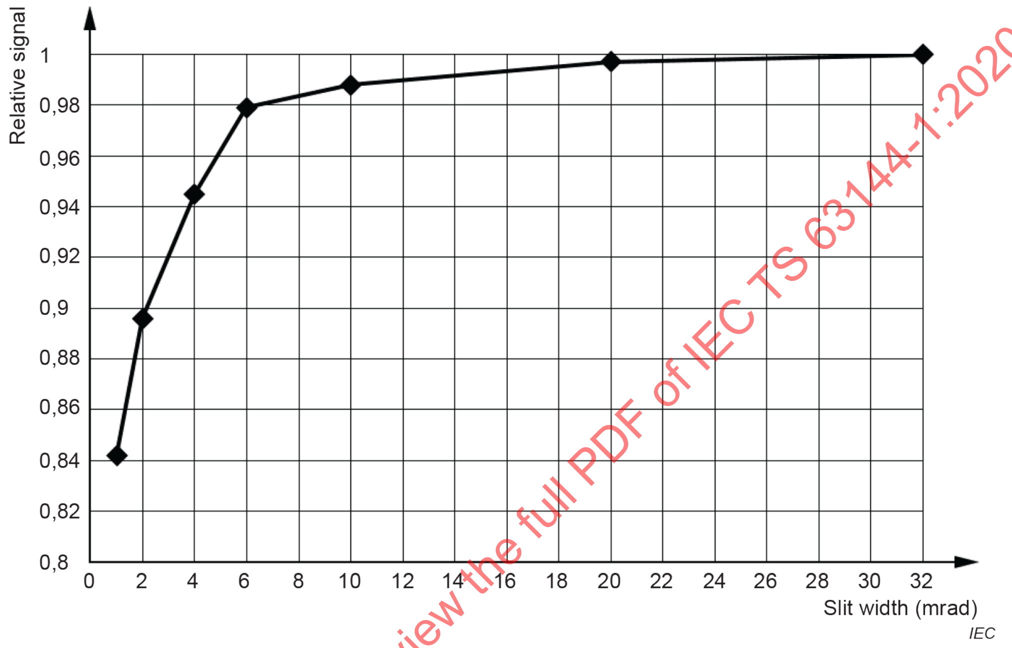
6.9.2 Required parameters

The measuring distance may influence the slit response function; this distance should therefore be indicated. In the case of interchangeable objectives, the objective used shall be indicated. The temperature of the reference radiator used shall be indicated.

6.9.3 Examples of indications

a) SRF: 90 % at 3 mrad (measuring distance: 500 mm, temperature of the reference radiator: 100 °C).

b) Graphical presentation, see Figure 2:



Slit response function for a thermographic camera with $IFOV$ = 1,6 mrad at a measuring distance 500 mm and a temperature of the reference radiator of 100 °C.

Figure 2 – Slit response function

6.9.4 Test condition, method and procedure for slit response function

1) The thermographic camera is prepared in accordance with 6.1 and placed centrally in front of a homogeneous reference radiator of known temperature (with a reference radiator/diaphragm signal ratio of at least 5:1 in radiation units and a signal-to-noise ratio of at least 50:1). An adjustable temperature-stabilized slit is first oriented to the horizontal image axis and the thermographic camera is focussed on it. The distance between the thermographic camera and the slit is determined.

2) The slit is set to a gap width corresponding to the $IFOV$ and the position of the slit relative to the camera is adjusted in such a way that a maximum signal is measured. Instead of the adjustment, it is also possible to measure with a slightly skewed slit and then to analyse the maxima.

3) The slit is opened up to a maximum width which is at least 20 times the $IFOV$. The thermographic camera is switched to the function "indication of radiation-proportional values". If this is not possible, the temperature indication is written down with the emissivity set to 1 and then converted into radiation-proportional quantities by means of Planck's function, knowing the spectral range of the camera. Since the slit response function indicates relative changes, relative radiation-proportional quantities suffice.

4) The slit width is progressively reduced, and the respective maximum of the radiation value inside the slit is written down. The slit width hereby measured is converted into an angle in mrad, the measuring distance being known.

5) The relative change, in relation to the measured value at maximum slit width, can be either indicated in the form of individual values (e.g. decrease down to 50 %, decrease down to 90 %) or represented as a full measurement curve.

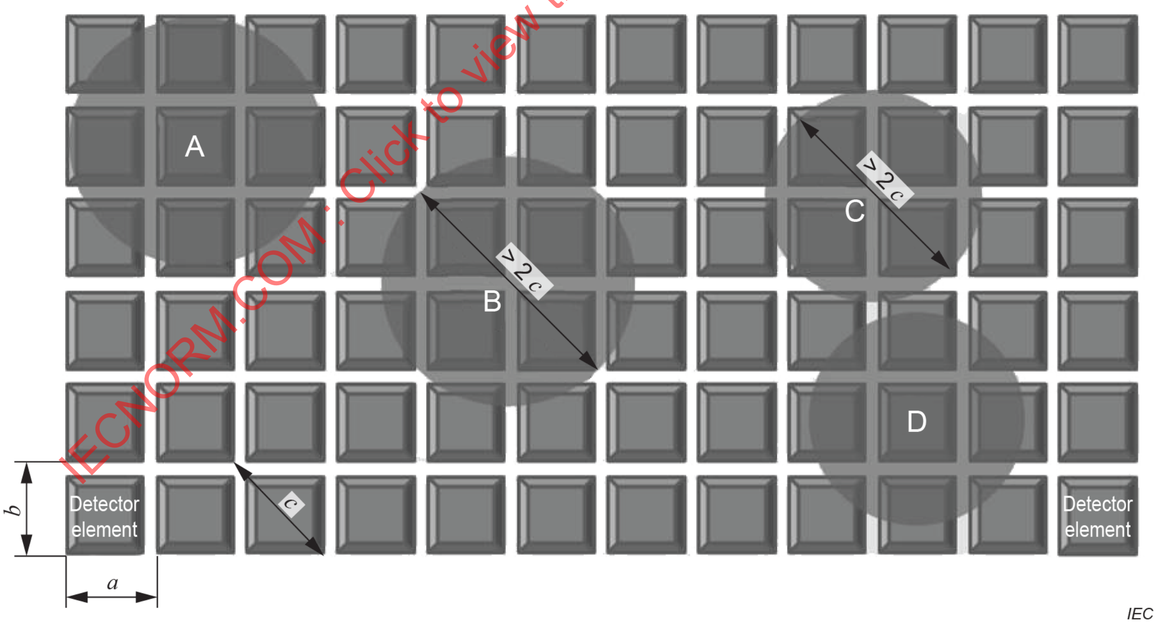
6) The steps 2) to 5) are repeated for the vertical orientation of the slit.

6.10 Minimum field of view for temperature measurement ($MFOV_T$)

6.10.1 General

Even supposing that ideal optics and ideal detectors are used, measuring the temperature accurately without any special edge conditions for a circular test object requires a minimum size of more than 2 c, where c is the diagonal of a complete single detector element with its radiation-sensitive and radiation-insensitive areas. Figure 3 shows various borderline cases. In examples A and B of Figure 3, the diagonal of the measured spot is only just larger than 2 c.

In case A, the measured spot is located exactly in the centre above the radiation-sensitive part of a detector element. This particular detector element is irradiated over its full radiation-sensitive surface and supplies an exact measurement value. The eight other neighbouring detector elements supply a wrong measurement value of the radiation, since they are only partly irradiated. In case B, the measured spot is located exactly between the detector elements. Here, four detector elements are fully irradiated. At least eight other detector elements are partly irradiated and do not supply any exploitable results. In examples C and D of Figure 3, the diameter of the measured spot is only just smaller than 2 c. If its centre is located exactly between the detector elements (case C), none of the detector elements is fully irradiated anymore. If it is oriented more favourably, i.e. exactly above a detector element (case D), it is still possible to obtain one single correct measured value. Detector elements located at the limits between two measuring fields do not supply exploitable measurement results. In the case of small measuring fields, the number of border elements is larger than the number of exploitable detector elements.



The measuring spots are represented as circles. The active (radiation-sensitive) parts of the detector elements are dark and the radiation-insensitive parts are light.

Figure 3 – Minimum size of a measuring spot for temperature measurement

In practice, resolution loss always occurs owing to diffraction, chromatic aberrations, diffusion on flawed optical materials and signal cross-talk in the detector.

To describe the minimum size of the object to be measured for a quantitative temperature measurement with a given uncertainty, it is possible to indicate the smallest measurable field of view of the measurement (minimum field of view for temperature measurement – $MFOV_{\mathrm{T}}$).

The latter can also be indicated via an optical factor f_{Optic} with:

$$MFOV_{\mathrm{T}} = f_{\mathrm{Optic}} \cdot IFOV \tag{5}$$

The optical factor f_{Optic} is usually larger than 3.

The minimum field of view for temperature measurement $MFOV_{\mathrm{T}}$ indicates the field of view at which the radiation signal has decreased to a specified value from the initial value owing to the progressive closing of a circular diaphragm. The relation between the radiation measured and the temperature of the object to be measured is non-linear. Table A.1 shows the change in the indicated temperature at a relative change in the radiative interchange between the thermographic camera and the object to be measured of approximately 1 %.

6.10.2 Required parameters

The measuring distance can influence the spatial resolution; this distance should therefore be indicated. In the case of interchangeable objectives, the objective used shall be indicated. Which proportion the radiation signal decreases to at the given field of view shall also be indicated. The fraction value should be at least 90 %; typical values are 90 %, 95 % and 98 %. The temperature of the reference radiator used shall be indicated. The $MFOV_{\mathrm{T}}$ should be determined in the centre of the field-of-view of the camera. As the $MFOV_{\mathrm{T}}$ is generally depending on the selected area within the field-of-view it should be stated if the $MFOV_{\mathrm{T}}$ is not determined in the centre.

6.10.3 Example of indications

$MFOV$: 2 mrad for a signal decrease down to 90 % (at a measuring distance of 500 mm and a radiator temperature of 100 °C).

6.10.4 Test condition, method and procedure for minimum field of view for temperature measurement

1) The thermographic camera is prepared in accordance with 6.1 and placed centrally in front of a homogeneous reference radiator of known temperature (with a reference radiator/diaphragm signal ratio of at least 5:1 in radiation units and a signal-to-noise ratio of at least 50:1). An adjustable temperature-stabilized iris diaphragm is positioned centrally and the thermographic camera is focussed on it. The distance between the thermographic camera and the diaphragm is determined.
2) The diaphragm is opened up to a diameter which is at least 20 times the $IFOV$. The thermographic camera is switched to the function "indication of radiation-proportional values". If this is not possible, the temperature indication is written down with the emissivity set to 1 and then converted into radiation-proportional quantities by means of Planck's function, knowing the spectral range of the camera. Since relative changes are investigated, relative radiation-proportional quantities suffice. As a simplifying alternative, it is also possible to use Annex A to determine the temperature value which corresponds to a given decrease in the radiance (e.g. down to 90 %).
3) The iris diaphragm's aperture is progressively closed and the maxima of the radiance measured values in the thermographic image of the iris diaphragm are written down. Hereby, the iris diaphragm's diameter is decreased until the specified radiation proportion or the temperature value calculated under item 2) is indicated. The aperture diameter measured is converted into an angle in mrad, the measuring distance being known.

4) Measurements 2) and 3) are repeated at least five times with the aperture being slightly (i.e. a few *IFOVs*) shifted. The maximum field of view of this series of measurements is indicated at which the radiation signal measured has decreased down to the specified value. A full measurement curve describing the radiation decrease as a function of the field of view of the aperture may be indicated. For this purpose, the maximum field of view of each individual measurement of the repeated measurement series should be indicated.

During the measurement, the iris diaphragm shall not be oriented towards faulty image elements.

6.11 Spectral range

6.11.1 General

The spectral range indicates the lower and upper limits of the wavelength range over which the thermographic camera converts radiation into a measurement signal. For the spectral range, the upper and lower limits are indicated at which the relative responsivity has increased or decreased to 50 % of the maximum value. It is also possible to indicate the mean wavelength as well as a full width at half maximum. When determining the spectral responsivity, all elements of the optical system of the thermographic camera are taken into account.

NOTE For very narrow-band spectral ranges, it can make sense to also indicate the maximum and minimum wavelengths at a clearly lower signal, e.g. 10 %, as well as the percentage of the signal decrease.

6.11.2 Examples of indications

a) Spectral range: 8 µm to 14 µm.

b) Spectral range: 5 µm (FWHM 0,6 µm).

6.11.3 Test condition, method and procedure for spectral range

A test procedure to determine the spectral range is not part of this document. The spectral range is determined by the manufacturer.

6.12 Emissivity setting

6.12.1 General

The range and the resolution of the emissivity setting for considering the emissivity of the observed object shall be specified by the manufacturer and do not require any test provisions.

The setting may apply to the full image, but it may also be possible to adjust them separately for individual sections of the image.

6.12.2 Examples of indications

a) Emissivity setting: 0,2 to 1,0 with a resolution of 0,01.

b) Emissivity setting: 0,1 to 1,0 with a resolution of 0,01 (adjustable separately for each image element).

6.12.3 Test condition, method and procedure for emissivity setting

Checking the function of the emissivity correction is not part of this document. Details on how to proceed are available from the manufacturer.

6.13 Influence of the internal instrument temperature

6.13.1 General

The technical data, for example the measurement uncertainty and the *NETD*, shall be generally valid over the complete operating range of the instrument, i.e. apply to internal temperature, ambient temperature and ambient humidity, unless otherwise stated. If the measurement uncertainty is not valid for the whole internal temperature range of the instrument, an additional temperature parameter shall be indicated to describe the additional measurement uncertainty in the event of a deviation of the internal temperature from a specified internal reference temperature. This parameter is given as the absolute or relative increase in the uncertainty of the measured value.

6.13.2 Required parameters

For the indication of the additional uncertainty, the reference temperature shall also be indicated.

6.13.3 Examples of indications

a) Influence of the internal temperature: 0,2 °C/°C (23 °C, 600 °C); additional uncertainty of the measured temperature at deviation of the internal temperature by 1 °C, based on an internal reference temperature of 23 °C at an indicated temperature of 600 °C.

b) Influence of the internal temperature: 0,2 %/°C (23 °C); additional relative uncertainty compared to the current measured value at a deviation of the internal temperature by 1 °C based on an internal reference temperature of 23 °C.

6.13.4 Test condition, method and procedure for influence of the internal instrument temperature

1) The thermographic camera is prepared in an air-conditioned testing chamber or in a temperature-regulated housing in accordance with 6.1 and then placed centrally in front of a reference radiator of known temperature. The measurement is first carried out at an internal temperature of the camera corresponding to the reference internal temperature indicated by the manufacturer's specifications. The indicated temperature of the reference radiator and the temperature indicated by the thermographic camera are written down.
2) The ambient temperature is changed in such a way that the minimum internal temperature of the thermographic camera according to the manufacturer's specifications is nearly reached. Sufficient time shall be given for thermal stabilizing processes, in accordance with the manufacturer's specifications; the stabilizing time of the thermographic camera may hereby be considerably longer than those of the air-conditioned testing chamber. The indicated temperature of the reference radiator and the temperature indicated by the thermographic camera are written down. Condensation of water vapour shall be prevented, for example by purging with dehumidified air or nitrogen.
3) The ambient temperature is increased in such a way that the maximum internal temperature of the thermographic camera according to the manufacturer's specifications is nearly reached. The values are, as in 2), written down, taking stabilizing times into account.
4) The changes in the indicated temperatures of the reference radiator in measurement situations 6.13.4, 2) and 3) are calculated as an additional contribution to the measurement uncertainty with regard to the reference internal temperature and are then compared with the specifications concerning the admissible influence of the internal temperature.
5) The measurement uncertainties of the reference radiator and of the internal temperature measurement shall hereby be taken into account as additional sources of uncertainty. If the internal temperature of the thermographic camera is not accessible, it is only possible to use the ambient temperature in the air-conditioned testing chamber or in the housing as a comparison value, which considerably limits the meaningfulness of this test.

The temperature sensors for temperature control of the testing chamber need to be traceably calibrated.

If the camera is able to perform an internal non-uniformity correction, this correction should always be performed after the camera has thermally stabilized at its internal temperature.

NOTE In addition to the measurement uncertainty, the *NETD* of the camera can depend on the internal temperature and can be determined with this test method in accordance with 6.3.

6.14 Influence of the humidity

6.14.1 General

The technical data, for example the measurement uncertainty and the $NETD$, shall be generally valid over the complete operating range of the instrument, i.e. apply to internal temperature, ambient temperature and ambient humidity, unless otherwise stated. If the measurement uncertainty is not valid for the whole operating humidity range of the instrument, an additional parameter shall be indicated to describe the additional measurement uncertainty in the event of a deviation of the current humidity from a specified reference humidity. This parameter is given as the absolute or relative increase in the uncertainty of the measured value.

As a rule no additional uncertainty should occur in this context as the wavelength range of the camera should not be sensitive to air humidity and/or a correction function depending on the measuring distance should be made available by the manufacturer for the influence of humidity.

6.14.2 Required parameters

For the indication of the additional uncertainty, the reference humidity and the measuring distance shall be indicated.

6.14.3 Example of indications

Humidity influence: 0,1 °C/% relative humidity (50 % relative humidity, 10 m) additional uncertainty of the measured temperature for a measuring distance of 10 m at a change in the relative humidity by 1 % based on a relative humidity of 50 %.

6.14.4 Test condition, method and procedure for influence of the humidity

Determining the dependence of the measurement uncertainty on the humidity, especially for longer measuring distances, requires sophisticated apparatuses to create defined air conditions. This document does not state any recommendation about how to carry out these measurements since determining the influence of humidity should not be part of the routine metrological characterization of thermographic cameras as this is disproportionately time-consuming. As a rule, the manufacturer should provide a correction function for the influence of air humidity on the measured temperature. This correction depends on the spectral range of the camera, the measuring distance, ambient temperature and measured temperature.

6.15 Long-term stability

6.15.1 General

The long-term stability is the reproducibility of measurements repeated over a period of at least three months. Similar to a measurement uncertainty, it is defined and its value should be indicated either at a rate in °C/month or in °C.

6.15.2 Required parameters

Since the long-term stability depends on the image frequency, the integration time and the internal temperature of the thermographic camera as well as on the measured temperature, measuring temperature range and on the ambient temperature, these parameters shall be indicated. Since the value to be indicated is formed based on the values of an imperfect detector element matrix, a statement concerning the proportion (in %) of image elements complying with this value is to be made.

6.15.3 Example of indication

Long-term stability: 3 °C (95 %) over three months 1 °C /month (95 %) for a radiator temperature of 50 °C, at an image frequency of 50 Hz, an integration time of 1 ms and an internal temperature of 20 °C.

6.15.4 Test condition, method and procedure for long-term stability

1) The thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous reference radiator of known temperature.
2) The temperature of the reference radiator is stabilized at a temperature within the measuring temperature range of the thermographic camera.
3) The total measuring time of a measurement series should be at least 100 times the imaging time (1/framerate), but also at least 10 times the response time of the thermographic camera. For the image elements that are oriented towards the reference radiator, at least 100 consecutive measured values are recorded. From the values of the measured temperature, the arithmetic mean of each image element is formed. If the simultaneous exposure of all image elements is not possible, a measuring spot of a sufficient size (at least ten times the $MFOV$ or thirty times the $IFOV$) should be used. If a non-uniformity correction (shutter alignment) is necessary, it should be carried out prior to the measurements.
4) The test sequences 1) to 3) are repeated over a period of at least three months, at least once per month at the same temperature of the reference radiator. The thermographic camera shall be turned off between the test sequences. The manufacturer is allowed to perform an accelerated test in agreement with a procedure based on his technical know-how and on his experience. The informative value of the accelerated test shall be checked by means of comparison measurements using the standard procedure and carried out at regular intervals.
5) For all image elements, the difference between the maximum and the minimum mean value of the measured temperatures obtained in the test interval are determined. The long-term stability results from the value of the maximum difference. If this value is divided by the whole period in which the measurements have been carried out, the long-term stability can also be indicated as a rate (in °C/month). The long-term stability of the radiation temperature of the reference radiator should be significantly better than the long-term stability of the thermographic camera. For the test, the reference radiator shall be set in such a way that the thermographic camera indicates neither its own internal temperature, nor the ambient temperature. The ambient conditions should, similar to the conditions for calibration, be complied with; it is intended that the latter will be described in detail in the future Part 2 of IEC 63144.

The ambient conditions shall correspond to those prevailing at calibration and be complied with for the whole duration of the long-term test. The ambient conditions shall be carefully documented. Owing to the low number of measurements (i.e. no coverage probability can be indicated), this test should not be deemed excessively significant.

NOTE The quantitative measurement conditions in step 3), i.e. the number of frames used for the arithmetic mean calculation, can be determined differently by manufacturers and sellers of thermographic cameras, if the statistical significance is maintained.

The manufacturer may perform the test method as a type test and does not have to perform the test on every individual thermographic camera (routine production test) based on his technical know-how and experience.

6.16 Short-term stability

6.16.1 General

The short-term stability is the reproducibility of measurements repeated over a period of at least 3 hours. It should be indicated either as a rate in °C/h or as the maximum temperature deviation within a short period of time of several hours.

6.16.2 Required parameters

Since the short-term stability depends on the image frequency, the integration time and the internal temperature of the thermographic camera as well as on the measured temperature, measuring temperature range, on the ambient temperature and on the coverage probability chosen, these parameters shall be indicated. Since the value to be indicated is formed based on the values of an imperfect detector element matrix, a statement concerning the proportion (in %) of image elements complying with this value is to be made.

6.16.3 Example of indication

Short-term stability: 0,25 °C/h (95 %) 1 °C (95 %) over 4 h ± 0,5 °C (95 %) over 4 h for a radiator temperature of 50 °C, at an image frequency of 50 Hz and an internal temperature of 20 °C.

6.16.4 Test condition, method and procedure for short-term stability

1) The thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous reference radiator of known temperature.
2) The temperature of the reference radiator is stabilized at a temperature within the measuring temperature range of the thermographic camera.
3) The total measurement duration of a measurement series should be at least three hours within which at least 10 measurement sequences are evenly distributed over the measurement time. The measuring time of each individual measurement sequence corresponds at least to 100 times the imaging time (1/framerate) of the thermographic camera. For the image elements that are oriented towards the reference radiator, at least 100 consecutive measured values are recorded. If the simultaneous exposure of all image elements is not possible, a measuring spot of a sufficient size (at least ten times the $MFOV$ or thirty times the $IFOV$) should be used. If a non-uniformity correction (shutter alignment) is necessary, it should be carried out prior to the measurements. The thermographic camera shall not be switched off for the whole duration of the measurement. In the breaks between individual measurements, the objective should be covered to prevent an undesired heating up of the thermographic camera.
4) From the measured values of each measurement sequence the arithmetic mean value is determined from all homogeneously irradiated image elements.
5) For all image elements, the difference between the maximum and the minimum mean value of the measured temperatures obtained over the whole measurement duration are determined. The short-term stability results from the value of the maximum difference. If this value is divided by the whole measurement duration, the short-term stability can also be indicated as a rate (in °C/h). If the short-term stability is to be indicated as a positive or negative value, then only half of the calculated difference should be indicated. The short-term stability of the reference radiator should be significantly better than the short-term stability of the thermographic camera. For the test, the reference radiator shall be set in such a way that the thermographic camera indicates neither its own internal temperature, nor the ambient temperature. The ambient conditions should, similar to the conditions for calibration, be complied with; it is intended that the latter will be described in detail in future IEC TS 63144-2.

NOTE The quantitative measurement conditions in step 3), i.e. the number of frames used for the arithmetic mean calculation, can be determined differently by manufacturers and sellers of thermographic cameras, if the statistical significance is maintained.

6.17 Repeatability

6.17.1 General

The repeatability is twice the standard deviation of measurements repeated under the same conditions within a time span of at least three minutes. The repeatability is twice the $NETD$. The repeatability indicates the proportion of the measurement uncertainty, determined from the measurements, which were repeated under the same conditions within a short time from each other. In the case of simple thermographic cameras, the repeatability can be limited owing to the achievable temperature resolution.

6.17.2 Required parameters

The measuring temperature, the image frequency and the integration time of the thermographic camera shall be indicated together with the repeatability. Since the repeatability of certain thermographic cameras depends on their internal temperature or on the ambient temperature, these temperatures shall be indicated for these cameras. Since the value to be indicated is formed based on the values of an imperfect detector element matrix, a statement concerning the proportion (in %) of image elements complying with this value is to be made.

6.17.3 Example of indication

Repeatability: 0,1 °C (95 %) for a radiator temperature of 50 °C, at an image frequency of 50 Hz, an integration time of 1 ms and an internal instrument temperature of 23 °C.

6.17.4 Test condition, method and procedure for repeatability

1) The thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous reference radiator of known temperature.
2) The temperature of the reference radiator is stabilized at a temperature within the measuring temperature range of the thermographic camera. The greatest expected noise amplitudes may not exceed the limits of the measuring temperature range.
3) The total measuring duration of a measurement series should be at least three minutes and correspond to at least 100 times the imaging time (1/framerate) of the thermographic camera. For the pixels that are oriented towards the reference radiator, at least 100 consecutive values of measured temperature are recorded. If the simultaneous exposure of all image elements is not possible, a measuring spot of a sufficient size (at least ten times the $MFOV$ or thirty times the $IFOV$) should be used.
4) From the measured values, the standard deviation is formed for each individual image elements. The repeatability is twice the standard deviation where 95 % of all measured individual standard deviations of the single image elements are less or equal. If the thermographic camera is significantly heated up by the reference radiator, a shorter measuring duration should be selected. The noise caused by the reference radiator or by additional metrological equipment should be significantly smaller than the noise of the thermographic camera. The bandwidth of the thermographic camera should not be limited by the bandwidth of the electronic readout and data acquisition devices. If an automatic non-uniformity correction (shutter alignment) of the thermographic camera falls within the measurement interval, this condition should be repeated in all measurement series.

NOTE The quantitative measurement conditions in step 3), i.e. the number of frames used for the standard deviation calculation, can be determined differently by manufacturers and sellers of thermographic cameras, if the statistical significance is maintained.

6.18 Interchangeability (spread of production)

6.18.1 General

The interchangeability (spread of production) is half the maximum deviation between the measurement results of two thermographic cameras of the same type which are operated under identical conditions. The measurement results of any two thermographic cameras of the same type that are operated under identical conditions therefore deviate by less than twice the value of the interchangeability. The numerical value of the interchangeability does not necessarily correspond to the value of the measurement uncertainty. The interchangeability is an important characteristic for production monitoring in the event that a thermographic camera has to be replaced with another one of the same type.

6.18.2 Required parameters

The measured temperature, the image frequency and the integration time of the thermographic camera shall be indicated together with the interchangeability. Since the interchangeability of certain thermographic cameras depends on their internal temperature or on the ambient temperature, these temperatures shall be indicated for these cameras. Since the value to be indicated is formed based on the values of an imperfect detector element matrix, a statement concerning the proportion (in %) of image elements complying with this value is to be made.

6.18.3 Example of indication

Interchangeability: 0,5 °C (95 %) for a radiator temperature of 50 °C, at an image frequency of 50 Hz, an integration time of 1 ms and an internal instrument temperature of 23 °C.

6.18.4 Test condition, method and procedure for interchangeability (spread of production)

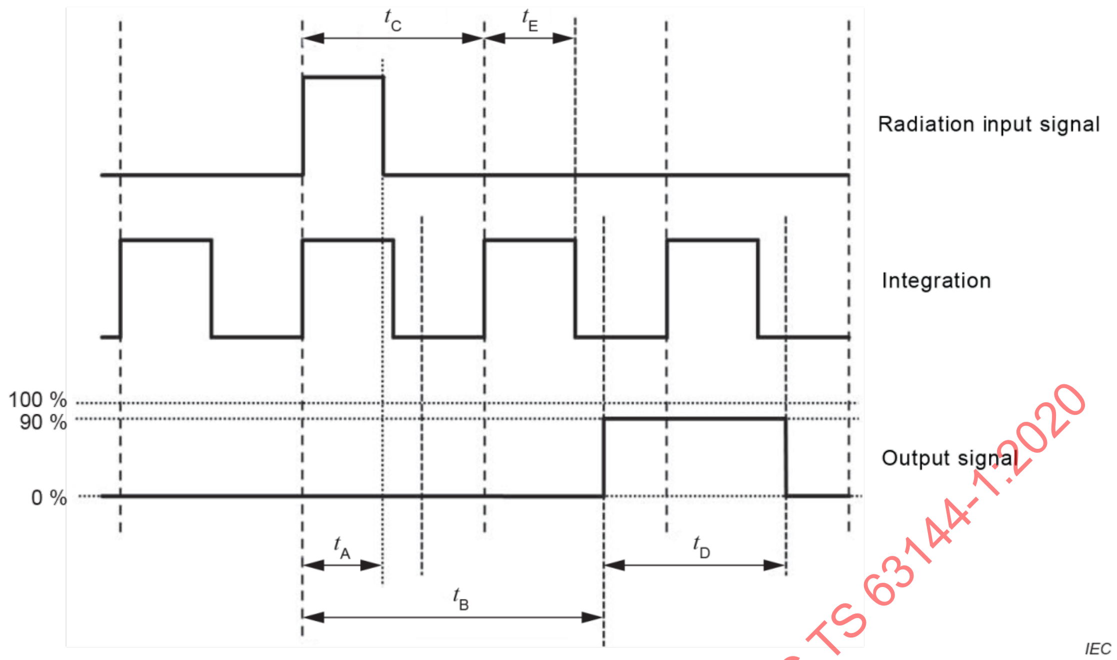
1) At least three thermographic cameras of the same type are required to determine the interchangeability.
2) The first thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous reference radiator of known temperature.
3) The temperature of the reference radiator is stabilized at a temperature within the measuring temperature range of the thermographic camera. The greatest expected noise amplitudes may not exceed the limits of the measuring temperature range.
4) The duration of a measurement series shall be at least 100 times the imaging time (1/framerate), but also at least 10 times the response time of the thermographic camera. For the pixels that are oriented towards the reference radiator, at least 100 consecutive values of measured temperature are recorded. If the simultaneous exposure of all image elements is not possible, a measuring spot of a sufficient size (at least ten times the $MFOV$ or thirty times the $IFOV$) should be used. If a non-uniformity correction (shutter alignment) is necessary, it should be carried out prior to the measurements.
5) The test sequence 2) to 4) is carried out for at least two further thermographic cameras of the same type. The temperature of the reference radiator shall be stabilized to the same temperature during each individual test sequence.
6) For all image elements, the difference between the maximum and the minimum mean value of the measured temperatures of all thermographic cameras are determined. The interchangeability is the value of half the maximum difference. Identical and stable ambient conditions shall be ensured during the test of all thermographic cameras. During the test, the temperature stability of the reference radiator shall be significantly better than the interchangeability of the thermographic cameras.

NOTE The quantitative measurement conditions in step 4), i.e. the number of frames used for the maximum and minimum mean value calculation, can be determined differently by manufacturers and sellers of thermographic cameras, if the statistical significance is maintained.

6.19 Response time

6.19.1 General

The response time is the time interval between the instant of an abrupt change in the value of the input parameter (measured temperature/measured radiation) and the instant from which the output signal of the thermographic camera remains within specified limits of its final value. Hereby, the output signal is a measured value that is accessible to the user from outside the thermographic camera and can, for example, be determined as an electric voltage, a digital signal or as an image. If the response times for increasing and decreasing temperature jumps for a thermographic camera differ from each other, then both values should be indicated. The response time depends on the type of detector technology used and on the signal processing within the thermographic camera until the output signal is available. Fundamental differences exist between synchronized and unsynchronized image acquisition, as well as between quantum detectors and thermal detectors. In the case of synchronized image acquisition, there is, in contrast to the unsynchronized acquisition, a constant temporal interval between the input signal and integration. Figure 4 shows the time curve with the resulting response time t_B and exposure time t_A for a thermographic camera with a quantum detector in synchronized operation, without phase shift or in the best possible case in unsynchronized operation. Figure 5 shows, for the same thermographic camera, the worst possible case in unsynchronized operation.

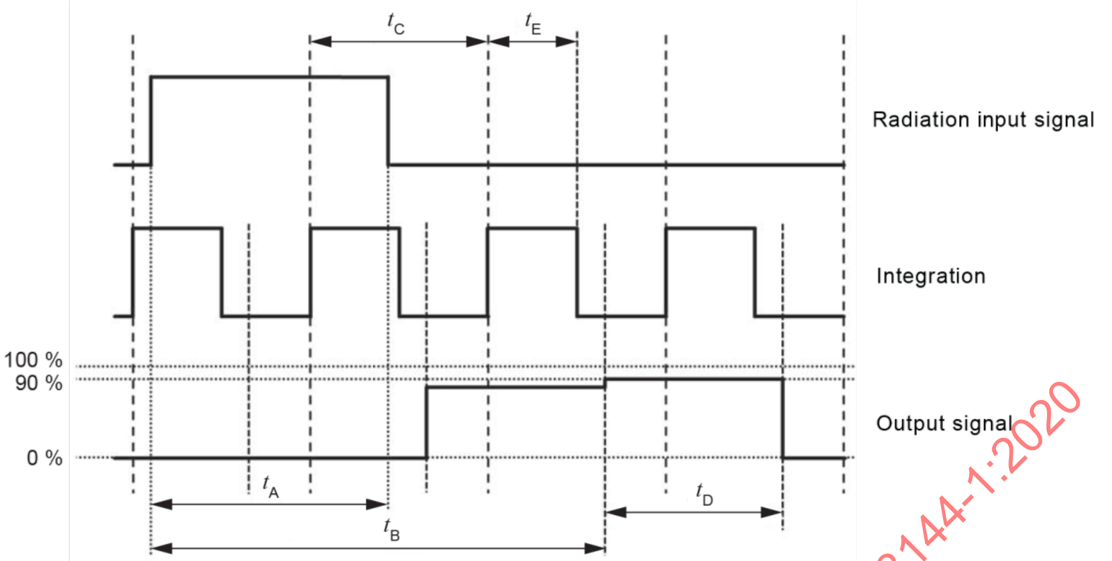


Key

t_A exposure time
t_B response time
t_C image recording time
t_D imaging time
t_E integration time

Time curve of synchronous signal acquisition for one image element (without phase shift) respectively asynchronous image acquisition in the best possible case for a thermographic camera equipped with a quantum detector.

Figure 4 – Synchronous signal acquisition for a quantum detector



Key

t_A exposure time

t_B response time

t_C image recording time

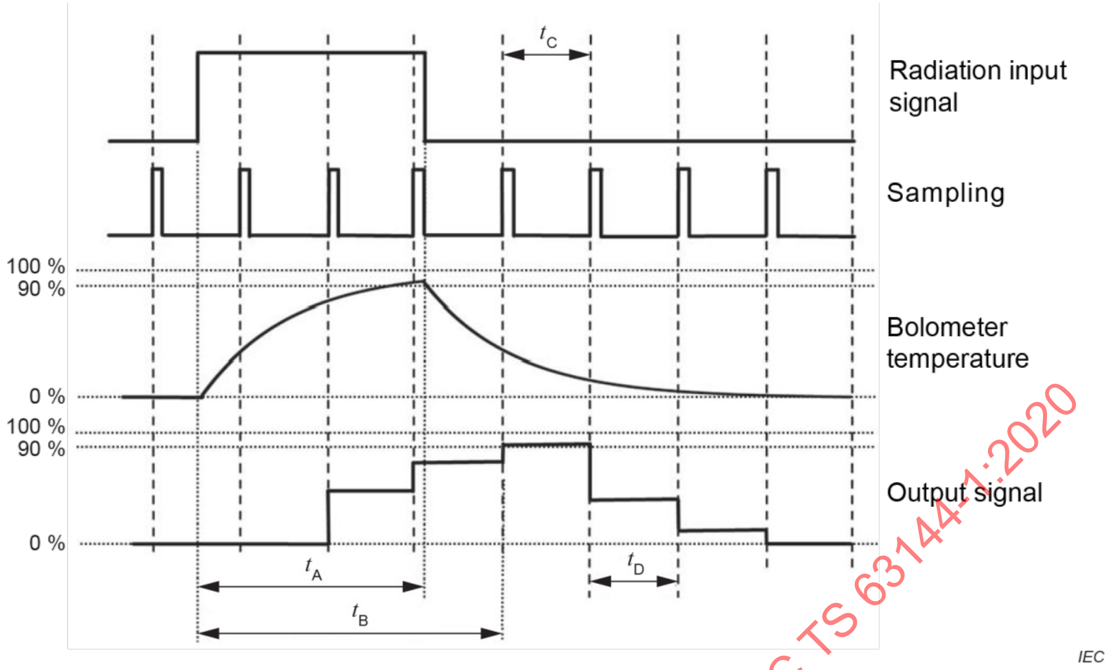
t_D imaging time

t_E integration time

Time curve of asynchronous signal acquisition in the worst possible case for a thermographic camera equipped with a quantum detector.

Figure 5 – Asynchronous signal acquisition for a quantum detector

For thermographic cameras equipped with a thermal detector (microbolometer), the integration does not play any role. The radiation signal is continuously converted into a temperature of the detector element; the conversion can be well described by means of a first-order low-pass filter. For microbolometers, the thermal time constant typically lies around 10 ms. The continuous signal is periodically sampled; the combination of the thermal low-pass filter and sampling determines the minimum possible response and exposure times. Figure 6 shows unsynchronized operation at a sampling period that equals the thermal time constant in the temporally best case. Figure 7 shows the same in the worst case.



Key

t_A exposure time

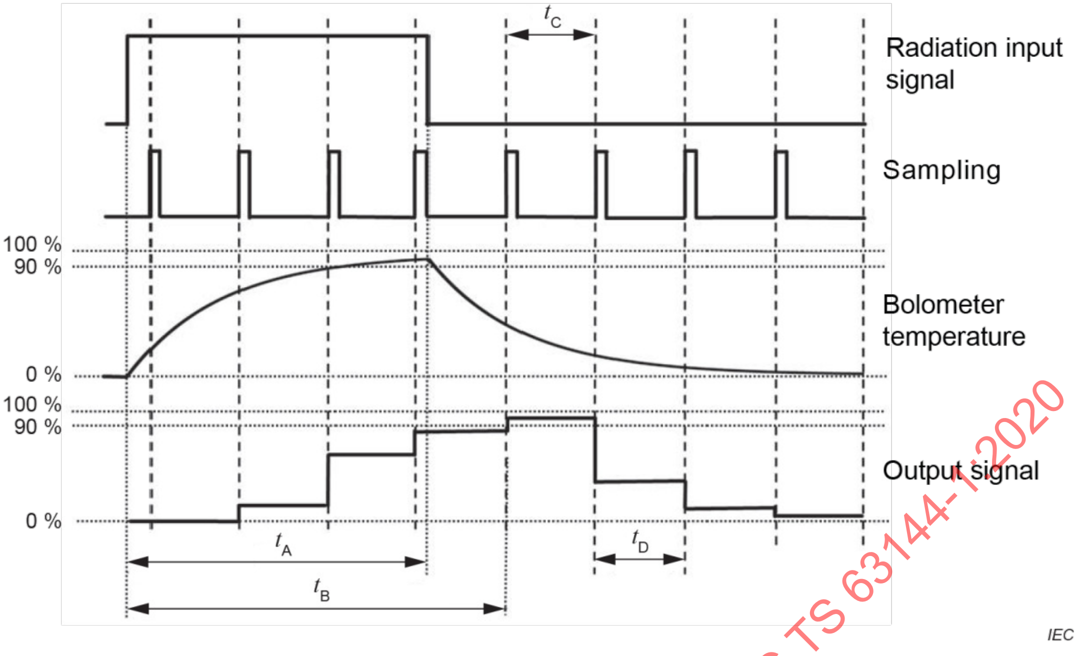
t_B response time

t_C image recording time

t_D imaging time

Time curve of the asynchronous signal acquisition in the best possible case for a thermographic camera equipped with a thermal detector (microbolometer); assumption: the image recording period corresponds to the thermal time constant of the detector.

Figure 6 – Asynchronous signal acquisition for a thermal detector (best case)



Key

t_A exposure time

t_B response time

t_C image recording time

t_D imaging time

Time curve of the asynchronous signal acquisition in the worst case for a thermographic camera equipped with a thermal detector (microbolometer); assumption: the image recording period corresponds to the thermal time constant of the detector.

Figure 7 – Asynchronous signal acquisition for a thermal detector (worst case)

NOTE 1 Further delay times can occur owing to additional signal and image processing outside the thermographic camera; these are only exemplarily taken into account in the representations shown. Different modes of operation or output signals can therefore result in different values of the response time.

NOTE 2 The relative change in the bolometer temperature owing to the radiation signal as it is represented in Figure 6 and Figure 7 does not correspond to the actual bolometer temperature, which is, in addition, significantly influenced by the sampling.

6.19.2 Required parameters

For the given response time, the size of the temperature jump (start and end value) as well as the limits at which the measurements take place shall be indicated. The chosen integration time and refresh rate have to be given. If differences occur for different types of output signals, then the corresponding output signal shall be indicated.

6.19.3 Example of indication

Response time: 5 ms, synchronized for 90 % of the maximum value at a temperature jump from 25 °C to 95 °C in the measuring temperature range from 20 °C to 100 °C, based on the digital image signal with an integration time of 5 ms.

6.19.4 Test condition, method and procedure for response time

The test method describes a procedure allowing the time required to reach 90 % of the full deflection of a thermographic camera with synchronized image acquisition to be determined, corresponding to an abrupt change in the incident radiance, starting from a thermal radiation at ambient temperature to reach a radiance close to the upper limit of the measuring temperature range. The response time can also be defined as another percentage of the full deflection, for example 99 % (see IEC TS 62492-1:2008, 4.1.1.16.3). In this case, the test method shall be adapted correspondingly.

1) The thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous and temporally stable radiation source of known temperature. The inhomogeneity and the temporal instability of the radiation source shall be better than 1 % during the measuring time of the test procedure. There are two possibilities:
   – A shutter is installed in front of a reference radiator; it shall open quickly enough (max. 10 % of the response time).
   – The radiation source is a two-dimensional and quickly variable radiation source with an appropriate wavelength. The rising time of the radiation source shall be smaller than 10 % of the response time of the thermographic camera. This can be achieved, for example, by means of an LED (or diode laser) which is operated with a pulse generator and is located, for instance, behind an integrating sphere or a beam expansion device.
2) The shutter is opened so that it does not cover the reference radiator or the radiation source is switched on in continuous operation, and the signal output of the thermographic camera is recorded with a fast image acquisition device (e.g. the control computer of the thermographic system). In the case of a thermal radiator, the thermographic camera will now indicate the true temperature. In the case of an LED, its power supply current shall be adjusted until the desired temperature indication is reached. The temperature indicated shall not exceed the measuring temperature range of the thermographic camera. The value indicated at the beginning of the measuring range is determined by closing the shutter so that it covers the reference radiator or by setting the radiation source to a value that corresponds to the starting temperature. The 100 % value is the difference between the two measurement values (e.g. the measured stationary values corresponding to the reference radiator with shutter open and shutter closed).
3) Now, a radiation pulse is generated by opening the shutter for a short time or by switching the radiation source on for a short time between its lower and upper reference radiance. The thermographic camera records these as output signal pulses. Hereby, the radiation pulses shall be long enough to measure the temperature jump determined under 2) as an output signal, and they shall be at least three times as long as the imaging time.
4) The response time is now the time measured between the start of the radiation pulse and the instant when 90 % of the stationary value of the output signal pulse are reached.
5) Using a thermographic camera with quantum detectors and synchronized image acquisition results in a response time with less dispersion, whereas the values determined for the response time with an unsynchronized image acquisition system may differ by one imaging time. Each measurement shall therefore be repeated over a large number of pulses (at least 50), until a reliable value for the maximum response time is reached. This maximum value is the value to be stated.
6) Attention shall be paid to using the test method only while the thermographic camera is operated in the temperature mode; no (possibly automatic) correction or calibration routine may take place at the same time.

6.20 Exposure time

6.20.1 General

The exposure time is the time span in which the abruptly varied input quantity (measured temperature/measured radiation) shall be applied for the output signal of the thermographic camera to reach a specified percentage of the stationary value for a continuous input quantity. Hereby, the output signal is a measured value which is accessible to the user from outside the thermographic camera and can, for example, be determined as an electric voltage, a digital signal or as an image. Indicating the exposure time is important for thermographic cameras whose response time exhibits a significant delay time and which are used to measure fast temperature changes. The exposure time, similar to the response time, depends on the type of detector technology used and on the signal processing within the thermographic camera and until the output signal is available. The following parameters in the figure captions of Figure 4 to Figure 7 contains more details.

6.20.2 Required parameters

For the given exposure time, the size of the temperature jump (start and end value) as well as the limits at which the measurements take place shall be indicated. The chosen integration time and refresh rate have to be given.

6.20.3 Example of indication

Exposure time: 60 ms (unsynchronized) for 90 % of the maximum value at a temperature jump from 25 °C to 95 °C in the measuring temperature range from 0 °C to 120 °C, based on the analogue image signal with a refresh rate of 50 Hz.

6.20.4 Test condition, method and procedure for exposure time

The test method describes a procedure allowing the time required to reach 90 % of the full deflection of a thermographic camera to be determined, corresponding to an abrupt change in the incident radiance, starting from a thermal radiation at ambient temperature to reach a radiance close to the upper limit of the measuring temperature range. The response time can also be defined as another percentage of the full deflection, for example 99 %. In this case, the test method shall be adapted correspondingly.

1) The thermographic camera is prepared in accordance with 6.1 and then placed centrally in front of a homogeneous and temporally stable radiation source of known temperature. The inhomogeneity and the temporal instability of the radiation source shall be better than 1 % during the measuring time of the test procedure. There are two possibilities:
   – A shutter is installed in front of a reference radiator; it shall open and shut quickly enough (max. 10 % of the response time).
   – The radiation source is a two-dimensional and quickly variable radiation source with an appropriate wavelength. The rising time of the radiation source shall be smaller than 10 % of the response time of the thermographic camera. This can be achieved, for example, by means of an LED (or diode laser) which is operated with a pulse generator and is located, for instance, behind an integrating sphere or a beam expansion device.
2) The shutter is opened so that it does not cover the reference radiator and/or the radiation source is switched on in continuous operation, and the signal output of the thermographic camera is recorded with a fast image acquisition device (e.g. the control computer of the thermographic system). In the case of a thermal radiator, the thermographic camera shall now indicate the true temperature. In the case of an LED, its power supply current shall be adjusted until the desired temperature indication is reached. The temperature indicated shall not exceed the measuring temperature range of the thermographic camera. The temperature indication for the starting temperature close to the ambient temperature is determined by closing the shutter, so that it covers up the reference radiator or by setting the radiation source to a value corresponding to the starting temperature. The 100 % value is the difference between both measurements (e.g. the measured stationary values corresponding to the reference radiator with shutter open and shutter closed).
3) Now, a radiation pulse is generated by opening the shutter for a short time or by switching the radiation source on for a short time between its lower and upper reference radiance. The thermographic camera records these as output signal pulses. Hereby, the radiation pulses shall be long enough to measure the temperature jump determined under 2) as an output signal.
4) Now, the pulse width of the radiation source is progressively reduced until the temperature indication is only a certain proportion of the stationary signal (e.g. 90 % of the maximum indication). The current pulse width is now the exposure time.
5) Using a thermographic camera with quantum detectors and synchronized image acquisition results in an exposure time with less dispersion, whereas the values determined for the exposure time with an unsynchronized image acquisition system may differ by one imaging time. Each measurement shall therefore be repeated over a large number of impulses (at least 50), until a reliable value for the maximum exposure time is reached. This maximum value is the value to be stated.