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Non-destructive testing — Infrared thermography —

Part 1: Characteristics of system and equipment

Essais non destructifs — Thermographie infrarouge —

Partie 1: Caractéristiques du système et des équipements

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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

Foreword

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A list of all parts in the ISO 18251 series can be found on the ISO website.

Introduction

The industrial applications of infrared thermographic testing in non-destructive testing (NDT) are growing, along with a remarkable improvement in thermographic technologies. The effectiveness of any application of infrared thermographic testing depends upon proper and correct usage of the system and equipment. The purpose of this document is to provide the characterization description of system and equipment for infrared thermography in the field of industrial NDT. The development of this document resolves the lack of International Standards on infrared equipment and systems. The main interested parties who will benefit from this document are manufacturers and users of such equipment and systems.

Non-destructive testing — Infrared thermography —

Part 1: Characteristics of system and equipment

1 Scope

This document describes the main components, and their characteristics, constituting an infrared (IR) imaging system and related equipment used in non-destructive testing (NDT). It also aims to assist the user in the selection of an appropriate system for a particular measurement task.

The following items are specified:

— objective lens;

— detector;

— image processor;

— display;

— thermal stimulation source;

— accessories.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10878, *Non-destructive testing — Infrared thermography — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10878 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

4 IR system setup

Figure 1 represents an imaging arrangement including the IR system. The lens focuses an image of the object on the detector. The array of pixels in the detector produces electrical signals dependent on infrared radiation intensity. The electrical signals are processed to produce an image that is shown on a display and available for storage or further processing.

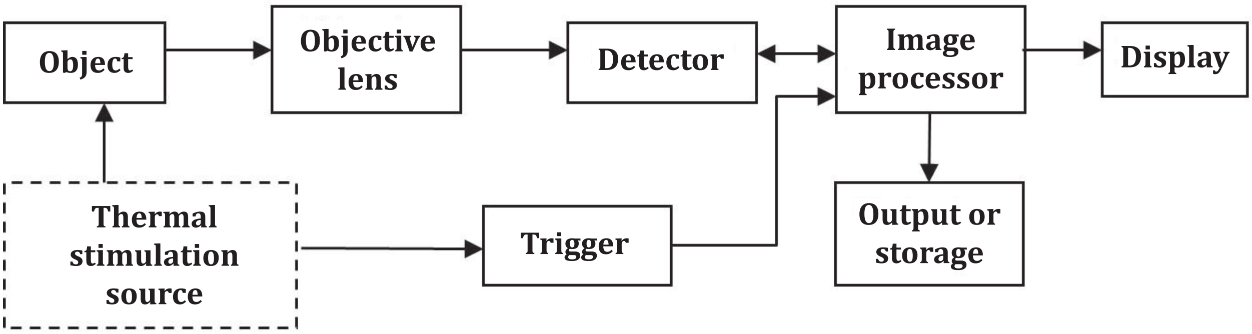

Figure 1 — IR system setup

5 Objective lens

5.1 General

The objective lens of an optical system is the element, or combination of elements, that focuses radiant energy from the object and forms the primary image.

Interchangeable lenses are used to reach a desired spatial resolution of the investigated object, or object detail.

5.2 Spectral response

IR-cameras are adapted to the transmission properties of the atmosphere for infrared radiation (atmospheric windows):

— Short Wave, SW: wavelength between approx. 0,8 µm and 2 µm;

— Mid Wave, MW: wavelength between approx. 3 µm and 5 µm;

— Long Wave, LW: wavelength between approx. 8 µm and 14 µm.

The spectral response of the IR-camera depends on the used detector. The transmission of the objective lens system should be adapted to the spectral response of the detector. The detector is selected according to the test problem.

5.3 Focal length (mm)

The focal length is the distance between optical centre of the lens and the focal plane point of the detector. The image of an observed object differs according to the focal length of the lens. A long focal length results in a smaller field of view and a larger image on the focal plane; this can be useful for increasing the working distance or visualizing fine details of an object.

5.4 Aperture f-number

The aperture defines the opening through which the rays come to a focus on the focal plane array. The effective size of the lens aperture affects the amount of radiant energy that passes through a lens. It is usually specified as an f-number, the ratio of the focal length to the effective aperture diameter. It strongly influences the sensitivity of the infrared detector. A larger aperture, a lower f-number, allows more radiant energy to reach the detector, increasing sensitivity of the system. These are “fast” apertures like f/1.1 or f/2. A smaller aperture, a higher f-number, allows less light that gets in. These are “slow” apertures like f/3 or f/4.5.

The lens aperture diameter needs to be greater than the detector diagonal to ensure that most of the radiant energy hitting the detector comes through the lens rather than from the internal parts of the system enclosure.

Detector aperture and lens aperture have to be carefully matched. It is beneficial to keep the lens system slightly faster than the detector in order to improve the ratio of rays accumulated by the lens system to the rays incoming from lens housing and other internal components.

5.5 Interchangeable object lenses

Interchangeable object lenses are used to adapt the camera system to special geometric requirements of measurement tasks (image section, required minimal resolution). There are typically standard object lenses, e.g. wide angle and telephoto lenses as well as accessory lenses for the measurement of large or small objects. For improved accuracy, each object lens shall be calibrated together with the camera.

6 Detector

6.1 General

The detector represents the core of the infrared camera since it senses infrared radiation and converts it to a usable electrical signal. Several characteristics affect the performance of the detector system. The type, number and arrangement of detector elements affect the sensitivity, thermal resolution, response time and spectral response of the imaging system.

6.2 Detector types

There are many different kinds of detectors available in infrared equipment, such as microbolometer, photoelectric, pyroelectric or quantum sensor, etc. These detectors are classified as two types: thermal detectors and quantum detectors. Thermal detectors, e.g. microbolometers or pyroelectric detectors, work at room temperature. Quantum detectors, e.g. photoelectric detectors or QWIP detectors, have to be cooled down to very low temperatures to reduce thermal noise. Quantum detectors have a higher sensitivity and they are easily compatible with higher frame modes of image acquisition.

6.3 Detector arrays

Infrared detectors can be single, linear arrays or two-dimensional arrays. Single element detectors require a scanning system to direct radiation from successive parts of the image at the detector in an organized two-dimensional scan that can be decoded into an image. Linear arrays can be used for producing images of moving objects, such as production lines. Two-dimensional detector arrays [focal plane array (FPA)] are capable of recording images without scanning.

6.4 Scanning systems

Mechanical scanning is achieved by moving mirrors, prisms, or polygons. Scanning cameras inherently provide homogeneous images without electronic correction mechanisms. However, the frame rate is limited due to the scanning. They are therefore less suitable to capture fast processes than FPA-cameras.

6.5 Working wavelength range

The working wavelength range depends on the detectors' material, objective lens and encapsulating window. For testing, it is selected according to the test condition and test object.

6.6 Number of pixels

A two-dimensional detector array typically consists of a rectangular array of sensors or elements. For a detector of M rows and N columns, the number of pixels is M × N. The number of pixels directly affects spatial resolution of the infrared camera.

6.7 Bad/dead pixel

A bad/dead pixel is a detector element that does not respond or responds slowly to changes in radiation intensity. Imaging systems may incorporate algorithms to provide data to replace signals from bad/dead pixels.

6.8 Detector operability

Detector operability represents the percentage of individual sensors delivering a proper and usable electrical signal.

6.9 Thermal time constant

As thermal detectors have a thermal capacity, they need a distinct time to respond to changes in radiation intensity. The thermal time constant for thermal detectors is the time required to change its body temperature by 63,2 % of a specific temperature span when the measurements are made under zero-power conditions in thermally stable environments. This is especially relevant in systems where the temperature is changing with time. The thermal time constant directly affects maximum frame rate, voltage sensitivity, noise equivalent power or NETD. In some applications, e.g. windowing, the maximum frame rate is higher than the thermal constant, and thus a lesser signal-to-noise ratio (SNR) is achieved.

6.10 Integration time

The integration time is the time that the detector accumulates radiation signal. It is determined by the storage capacity of electronic charge and the intensity of incoming infrared rays. As the extension of integration time, the SNR of the infrared focal plane will be improved, but the frame rate may be reduced. For convenience of use and to expand the application range, the integration time is designed to be adjustable in modern high-end cameras.

6.11 Temperature range

The dynamic range of the detector is the interval between the lowest and highest measurable temperatures. The range shall be specified for black-body temperatures (emissivity = 1). The detector may be damaged, exceeding the dynamic range. The dynamic range depends on integration time for quantum detectors.

7 Image processor

7.1 General

Image processor performs acquisition, analysis, processing, display and storage of thermal image.

7.2 Image acquisition

7.2.1 Timing acquisition

Timing is based on the system clock so that date, time and exposure interval can be acquired.

7.2.2 Trigger acquisition

Synchronizing external equipment with the imaging system requires the imaging system to respond to external trigger signals or to generate trigger signals based on image acquisition. This function is mainly used in active thermography including, for example, pulsed thermography, lock-in thermography, laser thermography or eddy current thermography.

7.2.3 Image freeze

Image freezing is the function that allows freezing the current view without long-term storage.

7.3 Image display

A monitor (display) is used to visualize the thermal image of the viewed scene. Typically, pseudo-colour image and grey-scale image are used with single frame display mode or continuous dynamic video play mode.

7.4 Image analysis

The image analysis usually includes

a) estimation of apparent temperature from the IR radiation intensity signal,

b) spot measurement of the temperature,

c) possibility of displaying the local minimum and maximum temperature in addition to the average,

d) isotherms colour-mark ranges of the same temperature if the emissivity is the same everywhere,

e) analysis of a time plot of a pixel or area irradiance, and

f) visualization of selected line profiles.

7.5 Image processing

7.5.1 General

The purpose of image processing is to enhance the image to prepare it for computer or visual analysis, but any signal processing will impact the results' quality.

7.5.2 Bad/dead pixel replacement

Bad/dead pixels are replaced using an algorithm based on surrounding pixel signals to improve the usability of images.

7.5.3 Non-uniformity correction

Non-uniformity correction is used to compensate for differences in detector element responses to improve the uniformity of the detector.

7.5.4 Image enhancement

Image processing methods mainly related to histogram adjust brightness, contrast and gamma correction, which can be performed all together or individually. Various other processes can be applied to thermal images to enhance the visibility of features that the operator intends to highlight.

7.5.5 Filtering

Spatial filtering, spectral filtering and frame averaging are used to reduce image noise. It can visibly improve the SNR.

7.5.6 Time correlated processing method

For sequences of thermal images captured by, for example, pulsed thermography, lock-in thermography, laser thermography or eddy current thermography, a time correlated processing method may be used to extract more useful information.

7.5.7 Visible-infrared image fusion

A common method of enhancing location of indications is blending or “fusion” of signals from visible light and infrared detectors.

7.6 Image recording

The system should record the image as a single frame or a series of frames at a suitable frame rate for replay as a video with a full dynamic range and record related parameters of associated equipment and test conditions. A note should be added on image data compression.

8 Thermal stimulation source

8.1 General

The active thermography requires an external energy source in order to thermally stimulate the material to test. Suitable energy source and excitation principle shall be chosen according to the object and testing purpose. There exists a variety of stimulation sources, for instance, but not limited to, optical radiation, hot gas generator, induction coil, vibration probe and cooling device. Pulse, step and harmonic are examples of excitation principles.

These relevant technical data regarding the NDT purpose shall be provided by the equipment excitation source supplier. For example, the technical data of laser source should be inclusive of, but not limited to, power (W), irradiation (W/m^2), wavelength (nm), pulse duration time (s) and beam size (mm^2).

8.2 Optical radiation devices

The heating principle of optical thermal stimulation is the absorption of optical radiation at the sample surface. Conventional optical radiation devices include laser and lamps which are used for excitation of the investigated object. Laser sources can also be applied to detect surface cracks which are open toward the surface. The cracks are disturbing the lateral heat diffusion of the area heated by the laser spot and thus can be detected by generating temperature steps at the surface. There exists a variety of lamps, for instance, but not limited to, flash lamp, halogen lamp and spot light. Flash lamps heat up the surface of the investigated object with very short light pulses (pulse thermography). The selection of lamps depends on the test piece and inspection objective.

8.3 Convective excitation devices

The heating principle of convective excitation is the transfer of heat between a moving fluid (gas, liquid) and a solid testing object. Usually, there are two kinds of convective excitation source: hot and cooling device. Hot gas generator may be an air jet, steam from boilers, etc. Hot fluids are used for convective heating of the investigated object. Cooling devices, such as air jets, water jets, liquid nitrogen jets or sudden contact with ice, dry ice, etc., are employed when the temperature of the object to be tested is already higher than ambient temperature.

8.4 Electromagnetic induction devices

The heating principle of electromagneticinduction is that an alternating magnetic field generates eddy currents in an electrically conductive material. Eddy current can result in heating of the conductive testing object. In contrast to 8.2 and 8.3 and depending on the material properties, the whole volume of the test object or a surface layer with a distinct thickness is heated. Electromagnetic induction devices are used for contactless heating of electrically conductive objects. The frequency, coil dimension, coil current, distance between the coil and sample, sample and coil geometry, sample electrical conductivity and magnetic permeability are the major parameters in induction thermography.

8.5 Mechanical excitation devices

The heating principle of mechanical excitation is based on the friction between the movements of the internal object. According to the law of conservation of energy, no energy is destroyed due to friction. Energy is transformed from kinetic energy to thermal energy. Objects can be excited by mechanical excitation (e.g. by vibration sources). Certain object areas are selectively heated up because of mechanical losses. Mechanical excitation can be useful for closed cracks in materials.

8.6 Advantages and drawbacks of thermal stimulation sources

Table 1 lists the advantages and drawbacks of common thermal stimulation sources.

Table 1 — Advantages and drawbacks of different thermal stimulation sources

Thermal stimulation source	Advantages	Drawbacks
Laser	Very high, stable and controllable energy density, uniformity, fast heating	Small heating area (it is possible to perform a linear scanning by deflection of the laser beam), safety issues related to the use of high-powered lasers
Flash lamp	Fast heating, large heating area, the whole temperature history curve can be recorded	Low energy density, non-uniformity, safety issues (eye protection) are required
Halogen lamp	Stable and controllable energy density, large heating area	Low energy density, non-uniformity
Spot light	Repeatable heating, high energy density, uniformity	Small heating area
Hot gas generator	Fast heating, large heating area, uniformity	Low energy density
Electromagnetic induction devices	Large heating area, high energy density	Conductive materials only
Vibration sources	Very large heating area, high selectivity, internal heating	Low energy density, non-uniformity, coupling problems

9 Integrated characteristics and functions of infrared systems and equipment

9.1 Integrated performance parameters

9.1.1 Noise equivalent temperature difference (NETD)

The NETD characterizes the ability of an IR-camera to resolve a temperature difference of a black body. It is an equivalent temperature value corresponding to a signal-to-noise ratio of unity (1). Therefore, except if data treatment is performed, it is not possible to measure a difference equal to the NETD.

The NETD varies with the measurement setting, for instance (but not limited to):

a) temperature of the object;

b) measurement range;

c) integration time (quantum detectors);

d) data averaging or not.

9.1.2 Minimum resolvable temperature difference (MRTD)

The MRTD characterizes the image quality of IR-cameras. It represents the ability of the combined system IR-camera and human observer to resolve small temperature differences of small structures (in relation to the whole image field). The results of MRTD measurements strongly depend on the observer and are therefore subjective.

9.1.3 Minimum detectable temperature difference (MDTD)

The MDTD characterizes the image quality of IR-cameras. It is the combined ability of an IR imaging system and a human observer to detect a target at a particular temperature and of unknown location against a vast uniform background having another temperature. The results of MDTD measurements strongly depend on the observer and are therefore subjective.

9.1.4 Field of view (FOV)

The field of view (also field of vision) is the angular extent of the observable world that is seen at any given moment, and it is described using an angle of cone or pyramid. The size of the FOV directly affects the image resolution. Under the condition of same detection distance, the bigger the FOV is, the bigger the detection area. Under the condition of same detection distance and same number of pixels, the bigger the FOV is, the lower the spatial resolution.

9.1.5 Instantaneous field of view (IFOV)

The instantaneous field of view (IFOV) is the angle seen by a single element of the detector array. It depends on the lens and the size of the pixel pitch.

9.1.6 Minimum working distance

For a calibrated instrument, the minimum working distance represents the smallest possible distance between the lens and the object, enabling both imaging and correct measurement. Imperfections in the optical system, such as (but not limited to) vignetting, may lead to a minimum imaging distance longer than the minimum working distance.

For a non-calibrated instrument, the minimum working distance represents the smallest possible distance between the lens and the object, enabling the potential of a clear image.

9.1.7 Maximum temperature measurement range

The temperature measurement range is the difference between the lowest and the highest measurable temperatures. The range should be specified for black-body temperatures (emissivity = 1). The total temperature range may consist of several partial measurement ranges that can be separately adjusted by the device. The use of optical components like spectral filters can alter/change the measurable temperature range.

9.1.8 Temperature measurement uniformity

The temperature measurement uniformity describes the uniformity of the displayed temperature distribution in case of a homogeneous thermal irradiation signal.

