SLOVENSKI STANDARD
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Neporušitvene preiskave - Termografsko preskušanje - Aktivna termografija z laserskim vzbujanjem

Non-destructive testing - Thermographic testing - Active thermography with laser excitation

Zerstörungsfreie Prüfung - Thermografische Prüfung - Aktive Thermografie mit Laser-Anregung

Essais non destructifs - Analyse thermographique - Thermographie active avec excitation laser

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19.100	Neporušitveno preskušanje	Non-destructive testing

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English Version

Non-destructive testing - Thermographic testing - Active thermography with laser excitation

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (prEN 17501:2020) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This document is currently submitted to the CEN Enquiry.

1 Scope

This document determines the guidelines and the specifications for non-destructive testing using active thermography with laser excitation.

Active thermography with laser excitation is mainly applicable, but not limited to different materials (e.g. composites, metals, ceramics) and to:

- the detection of surface-breaking discontinuities, particularly cracks;
- the detection of discontinuities located just below the surface or below coatings with an efficiency that diminishes rapidly with a few mm depth;
- the detection of disbonds and delamination parallel to the examined surface;
- the measurement of thermal material properties, like thermal diffusivity;
- the measurement of coating thickness.

The requirements for the equipment, for the verification of the system, for the surface condition of the part to be tested, for the scanning conditions, for the recording, the processing and the interpretation of the results are specified. Acceptance criteria are not defined.

Active thermography with laser excitation can be applied in industrial production as well as in maintenance and repair (vehicle parts, engine parts, power plant, aerospace, etc.).

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.

EN 16714-1, *Non-destructive testing — Thermographic testing — Part 1: General principles*

EN 16714-2, *Non-destructive testing — Thermographic testing — Part 2: Equipment*

EN 16714-3, *Non-destructive testing — Thermographic testing — Part 3: Terms and definitions*

EN 17119, *Non-destructive testing — Thermographic testing — Active thermography*

EN ISO 9934-2, *Non-destructive testing — Magnetic particle testing — Part 2: Detection media (ISO 9934-2)*

EN 12464-1, *Light and lighting — Lighting of work places — Part 1: Indoor work places*

CEN/TR 14748, *Non-destructive testing — Methodology for qualification of non-destructive tests*

DIN 54184, *Non-destructive testing — Pulse thermography using optical excitation*

VDI/VDE 5585-1, *Technical temperature measurement — Temperature measurement with thermographic cameras — Metrological characterization*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 16714-3 and EN 17119 and the following apply.

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

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

3.1
laser
light amplification by stimulated emission of radiation used as light source for thermal excitation in laser thermography

3.2
scanning system
system which provides relative movement of the shaped laser beam, the surface of the test object and/or the IR camera

3.3
flying spot technique
scanning of the shaped laser beam on the surface of the test object

3.4
spot diameter
full width at half maximum of the irradiation profile of the laser beam at the target plane

3.5
scanning speed
relative velocity of the laser spot at the target plane

3.6
illumination pattern
spatial distribution of the laser irradiation at the target plane

4 Qualification and certification of personnel

The competence of the test personnel using this document shall be demonstrated according to EN ISO 9712 or an equivalent formalized system and the following:

- the relevant standards, rules, specifications, test instructions and description of the methods;
- the type of equipment and its operation;
- the mounting, design, structure and operation of the objects under test;

The test personnel shall have sufficient knowledge about the test object and about the possible diagnostic findings.

5 Principle of laser thermography and instrumental setup

5.1 General

Laser thermography is a technique of active thermography. A very basic experimental setup is given in Figure 1. The absorption of laser radiation at the surface generates the heat flux into the test object (also called photothermal effect). The illumination pattern of the laser can be designed to deliver a focused spot, a line, or an area (e.g. square or circle). The presence of a discontinuity inside or on the surface of the test object alters the heat flux in a specific way. As a result, the shape and symmetry of the induced heat flux pattern allows the testing to be optimized to different classes of discontinuities, like, e.g. planar and volume defects or linear cracks or measurement of material properties that influence the diffusion of heat. The resulting temporal evolution of the thermal radiation distribution on the surface during or after laser illumination is acquired by an infrared (IR) camera, and converted to a signal that can be analysed by different signal processing algorithms. One advantage of applying a laser as thermal energy source is that a large spatial distance between source and test object surface can be achieved (of typically some centimetres up to several metres). A further advantage when utilizing a laser is given by its narrow emission spectrum, which can be clearly separated from the IR camera detection range. This characteristic facilitates the reflection configuration without using additional filters.

Typically, high-power lasers with an output power of several watts to kilowatts are used. Due to focusing to, e.g. a spot or a line, a high irradiance (MW to GW per m^2) can be achieved. In order to test the entire test object surface, the illumination needs to be scanned over the test object surface by a relative movement between test object, laser, and/or IR camera.

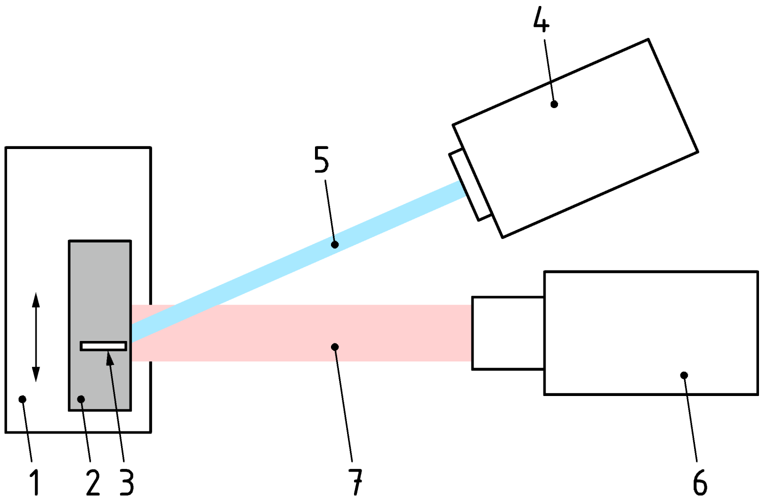
NOTE As laser sources, continuous as well as pulsed laser systems can be used.

Since lasers typically allow very high modulation rates (kHz-range is easily achievable), different temporal excitation and testing modes can be implemented.

The quality of the thermographic signal depends on a number of experimental setup and test object parameters. In the following a list of preferable prerequisites to improve signal quality (i.e. signal to noise ratio and contrast to noise ratio of detected discontinuity) is given:

- high laser power and/or irradiance;
- high and spatially homogenous spectral absorptance of the test object at the laser wavelength;
- high and spatially homogenous spectral emissivity of the test object at the IR camera wavelength;
- high temporal and mechanical stability between the devices moving relatively, i.e. the laser, the scanning system and the IR camera;
- high responsivity and low NETD of the IR camera.

If, for instance, the absorptance or emissivity of the test object surface is not spatially homogenous, this leads to in homogeneously distributed thermal radiation which can be misinterpreted as a defect indication. In this case an additional coating of the surface might be applied.



Key

1	Scanning system	5	Laser beam
2	Test object	6	IR camera
3	Discontinuity	7	Thermal radiation
4	Laser		

Figure 1 — Schematic of laser thermography with movement of the test object

5.2 Typical configurations of excitation

5.2.1 General

According to EN 17119, laser thermography can be performed in static as well as in dynamic configuration and with different types of temporal and spatial excitation.

5.2.2 Laser thermography in static configuration (without relative movement)

Laser thermography can be realized without any relative movement between illumination, test object and IR camera. In this case, one or many thermogram(s) of the whole scene are acquired at the time(s) of interest. The thermogram or thermogram sequence acquired can then be processed to indicate if any discontinuity is present in the test object. In particular, pulse and lock-in thermographic testing techniques that do not rely on a relative movement and that apply either a very short optical impulse or a periodic optical excitation can be implemented using a laser as optical energy source.

5.2.3 Laser thermography in dynamic configuration (with relative movement)

Laser thermography can be realized with relative movement between illumination, test object and IR camera. In this case, the IR camera is set to view either the area where the illumination is present, or an area where the illumination is no longer present but where its thermal impact is still visible (time-lag). The thermogram or thermogram sequence acquired can then be processed to indicate if any discontinuity is present in the test object.

5.2.4 Laser thermography with different temporal excitations

Depending on the specific laser used, different temporal excitation modes can be implemented. In particular, if a very short laser impulse is used, this resembles the pulse thermographic testing technique using optical sources. Another known temporal technique is lock-in thermographic testing using an optical source whose irradiance is periodically modulated, e.g. by a sine, a triangle or a rectangular function. Laser sources allow for continuous wave (cw) operation and can be modulated up to very high modulation rates (>10 kHz-range). Hence lasers can be applied for all known temporal excitation techniques and can, in addition to that, be used up to very high modulation frequencies as well as for arbitrary temporal excitation functions.

5.2.5 Laser thermography with different spatial excitations

Depending on the specific laser used, different spatial excitation modes can be implemented. A focused laser spot can be used e.g. for the flying spot technique, where the test object is continuously or randomly scanned with a laser spot. In this case 3D heat transfer shall be considered. A focused laser line can be used for techniques where the test object is continuously or randomly scanned with a laser line. In this case only 2D heat transfer shall be taken into account. A widened laser beam can be used to illuminate a larger area homogeneously. Depending on the size of this area, only 1D heat transfer in depth direction shall be considered.

Illumination patterns like spots or lines cannot only be used to locate and quantify discontinuities, but can also be exploited to determine the directional dependence on thermal material properties, e.g. the thermal diffusivity.

5.3 Laser and laser optics requirements

5.3.1 Laser irradiance and wavelength

The laser system used for inspection shall meet the specific requirements of the thermographic testing task. For a specified IR camera the main parameters determining the minimum detectable temperature increase on the test object surface by the IR camera are the irradiance of the laser radiation and the optical and thermal material properties of the test object. Concerning the irradiance of the laser radiation, the relationship with the temperature increase is linear. This means that the choices of laser output power and focusing optics directly influence the achievable temperature increase. In addition, the spectral absorptance of the test object at the laser wavelength determines how much of the incident radiant energy is converted into heat. Therefore, if the absorptance is small, as it is for instance for polished metals or partially transparent polymers, the laser irradiance shall be accordingly high. In the best case, the laser wavelength is chosen to be at maximum of the spectral absorptance of the test object. Additionally, the laser wavelength should be outside the spectral sensitivity range of the IR camera to avoid damaging the detector and to avoid that the partially reflected laser radiation from the test object can be confused with the thermal radiation from the test object. Besides the irradiance and test object absorptance, the thermal material properties of the test object (i.e. thermal conductivity k, specific heat c_p, and density ρ) determine the gained temperature increase due to laser heating. For the two limiting cases of pulse and lock-in thermography, the temperature rise ΔT is proportional to $(k*c_p*\rho)^{-1/2}$. This means that for highly thermally conducting materials only a small temperature rise is generated. Accordingly, the laser irradiance shall be chosen high enough in order to compensate for a sufficient temperature rise during testing.

NOTE For maximum laser power it should be considered that the test object is not destructed by e.g. melting, oxidation, illumination induced colour changes or ageing of polymers. These effects are influenced not only by the laser irradiance, but also by pulse length, thermal and optical material properties, chemical composition etc.

5.3.2 Spatial illumination shapes

5.3.2.1 General

The illumination pattern shall be chosen accordingly to the specific spatial and temporal excitation mode used for testing. This can be performed by optical beam shaping devices.

Generally, fibre, solid state and gas lasers have a higher beam quality than diode lasers and can be focused to a smaller width. For focused laser spots, the spot size is only given within the depth of field of the laser optics.

If the laser radiation is brought to the system by an optical fibre, this fibre and any additional optics should be set so that the laser beam has a shape compatible with the inspection.

5.3.2.2 Spot

A round-shaped focused or collimated laser spot can be generated by an optical lens or mirror system. In dependence on the type of laser and the optics used, different spot sizes can be obtained.

5.3.2.3 Straight line

A straight line-shaped focused laser can be generated by a cylinder lens or lens system. In dependence on the type of laser and optics used, different line lengths, widths and shapes can be obtained. In this case, the sensitivity of the detection is better for discontinuities whose orientation is parallel to the laser line.

5.3.2.4 Area

A homogeneous illumination of a larger area is obtained by lens systems. If the laser source has to be used for pulse or lock-in thermography, the dimension of the illuminated area shall be considerably larger than the thermal diffusion length. Otherwise this configuration refers to the photothermal or flying spot technique. A top-hat beam profile shall be chosen in favour of a Gaussian beam profile to avoid lateral heat flows.

5.3.2.5 Pattern

Specific illumination patterns, deviating from the above mentioned shapes, can be generated by, e.g. laser arrays, lens arrays or diffractive optical elements. The shape of the patterns can be optimized to certain types of discontinuities.

5.3.3 Switchable laser for lock-in thermography and other temporal techniques

In all temporal excitation techniques, and especially in those which correlate the temporal excitation function with the temporal temperature response of the test object, the irradiance of the laser shall be controlled as exactly as possible. A common approach is to control the output power of the laser system by an external function generator via an analogue voltage input, which can be triggered by the IR camera. For best performance, the output power should have a linear relationship with the controlling voltage such that the signal processing algorithm can be applied directly. If there is no linear relationship, the characteristic curve of the laser (i.e. output power vs. controlling voltage) shall be taken into account properly by the user. Concerning the temporal behaviour, the laser switch on and switch off times shall be taken into account for the maximum possible modulation frequency.

5.3.4 Safety

The most important European standards on laser safety, safety of optical radiation and protection measures are listed in the following:

- EN 60825 Safety of laser products contains several relevant parts, e.g.:
  - EN 60825-1 Safety of laser products — Part 1: Equipment classification and requirements
  - EN 60825-4 Safety of laser products — Part 4: Laser guards
- EN ISO 11553 Safety of machinery — Laser processing machines contains several relevant parts, e.g.:
  - EN ISO 11553-1 Safety of machinery — Laser processing machines — Part 1: General safety requirements

  - EN ISO 11553-2 Safety of machinery — Laser processing machines — Part 2: Safety requirements for hand-held laser processing devices

Eye protection:

- EN 207 Personal eye-protection equipment — Filters and eye-protectors against laser radiation (laser eye-protectors)
- EN 208 Personal eye-protection — Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors)
- EN 12254 Screens for laser working places — Safety requirements and testing
- EN 62471 Photobiological safety of lamps and lamp systems

During testing, the workplace shall be illuminated adequately and appropriately according to EN 12464-1. If necessary, protective measures related to the working safety regulations and regulations for artificial optical radiation are expected to be considered.

During testing, it shall be ensured that there are no flammable materials in the vicinity of the equipment and the investigated object.

Further on, there is a risk of burning on heated parts of the radiation sources, of the test object and of further objects within the beam path.

5.4 Scanning system requirement

5.4.1 General

The scanning system should allow the laser to reach the whole area to be inspected from one or multiple positions of the laser, the IR camera and/or the test object while keeping the laser beam and the inspection IR camera in focus. The maximum scanning speed is linked to the laser power density and IR camera frame rate.

According to the application, the movement of any part of the scanning system will be step-by-step or continuous.