SLOVENSKI STANDARD
SIST EN ISO 15367-2:2005

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Laserji in laserska oprema – Preskusne metode za ugotavljanje oblike valovne fronte laserskega žarka – 2. del: Shack-Hartmannovi senzorji (ISO 15367-2:2005)

Lasers and laser-related equipment - Test methods for determination of the shape of a laser beam wavefront - Part 2: Shack-Hartmann sensors (ISO 15367-2:2005)

Laser und Laseranlagen - Prüfverfahren für die Bestimmung der Wellenfrontform von Laserstrahlen - Teil 2: Shack-Hartmann-Sensoren (ISO 15367-2:2005)

Lasers et équipements associés aux lasers - Méthodes d'essai pour la détermination de la forme du front d'onde du faisceau laser - Partie 2: Senseurs Shack-Hartmann (ISO 15367-2:2005)

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31.260	Optoelektronika, laserska oprema	Optoelectronics. Laser equipment

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EN ISO 15367-2

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English version

Lasers and laser-related equipment - Test methods for determination of the shape of a laser beam wavefront - Part 2: Shack-Hartmann sensors (ISO 15367-2:2005)

Lasers et équipements associés aux lasers - Méthodes d'essai pour la détermination de la forme du front d'onde du faisceau laser - Partie 2: Senseurs Shack-Hartmann (ISO 15367-2:2005)

Laser und Laseranlagen - Prüfverfahren für die Bestimmung der Wellenfrontform von Laserstrahlen - Teil 2: Shack-Hartmann-Sensoren (ISO 15367-2:2005)

This European Standard was approved by CEN on 21 February 2005.

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Foreword

This document (EN ISO 15367-2:2005) has been prepared by Technical Committee ISO/TC 172 "Optics and optical instruments" in collaboration with Technical Committee CEN/TC 123 "Lasers and laser-related equipment", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2005, and conflicting national standards shall be withdrawn at the latest by September 2005.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Endorsement notice

The text of ISO 15367-2:2005 has been approved by CEN as EN ISO 15367-2:2005 without any modifications.

INTERNATIONAL STANDARD

ISO 15367-2

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Lasers and laser-related equipment — Test methods for determination of the shape of a laser beam wavefront —

Part 2:
Shack-Hartmann sensors

Lasers et équipements associés aux lasers — Méthodes d'essai pour la détermination de la forme du front d'onde du faisceau laser —

Partie 2: Senseurs Shack-Hartmann

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15367-2 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

ISO 15367 consists of the following parts, under the general title *Lasers and laser-related equipment — Test methods for determination of the shape of a laser beam wavefront*:

- *Part 1: Terminology and fundamental aspects*
- *Part 2: Shack-Hartmann sensors*

Introduction

Characterization of the beam propagation behaviour is necessary in many areas of both laser system development and industrial laser applications. For example, the design of resonator or beam delivery optics strongly relies on detailed and quantitative information over the directional distribution of the emitted radiation. On-line recording of the laser beam wavefront can also accomplish an optimization of the beam focusability in combination with adaptive optics. Other relevant areas are the monitoring and possible reduction of thermal lensing effects, on-line resonator adjustment, laser safety considerations, or “at wavelength” testing of optics including Zernike analysis.

There are four sets of parameters that are relevant for the laser beam propagation:

- power (energy) density distribution (ISO 13694);
- beam widths, divergence angles and beam propagation ratios (ISO 11146-1 and ISO 11146-2);
- wavefront (phase) distribution (ISO 15367-1 and this part of ISO 15367);
- spatial beam coherence (no current standard available).

In general, a complete characterization requires the knowledge of the mutual coherence function or spectral density function, at least in one transverse plane. Although the determination of those distributions is possible, the experimental effort is large and commercial instruments capable of measuring these quantities are still not available. Hence, the scope of this standard does not extend to such a universal beam description but is limited to the measurement of the wavefront, which is equivalent to the phase distribution in case of spatially coherent beams. As a consequence, an exact prediction of beam propagation is achievable only in the limiting case of high lateral coherence.

A number of phase or wavefront gradient measuring instruments are capable of determining the wavefront or phase distribution. These include, but are not limited to, the lateral shearing interferometer, the Hartmann and Shack-Hartmann wavefront sensor, and the Moiré deflectometer. In these instruments, the gradients of either wavefront or phase are measured, from which the two-dimensional phase distribution can be reconstructed.

In this document, only Hartmann and Shack-Hartmann wavefront sensors are considered in detail, as they are able to measure the wavefront of both fully coherent and partially coherent beams. A considerable number of such instruments are commercially available.

The main advantages of the Hartmann technique are

- wide dynamic range,
- high optical efficiency,
- suitability for partially coherent beams,
- no requirement of spectral purity,
- no ambiguity with respect to 2π increment in phase angle,
- wavefronts can be acquired/analysed in a single measurement.

Instruments which are capable of direct phase or wavefront measurement, as, e.g. self-referencing interferometers, are outside the scope of this part of ISO 15367.

Lasers and laser-related equipment — Test methods for determination of the shape of a laser beam wavefront —

Part 2:
Shack-Hartmann sensors

1 Scope

This part of ISO 15367 specifies methods for measurement and evaluation of the wavefront distribution function in a transverse plane of a laser beam utilizing Hartmann or Shack-Hartmann wavefront sensors. This part of ISO 15367 is applicable to fully coherent, partially coherent and general astigmatic laser beams, both for pulsed and continuous operation.

Furthermore, reliable numerical methods for both zonal and modal reconstruction of the two-dimensional wavefront distribution together with their uncertainty are described. The knowledge of the wavefront distribution enables the determination of several wavefront parameters that are defined in ISO 15367-1.

2 Normative references

The following referenced documents are indispensable for the application 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 11145, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 13694, *Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution*

ISO 15367-1:2003, *Lasers and laser-related equipment — Test methods for determination of the shape of a laser beam wavefront — Part 1: Terminology and fundamental aspects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and ISO 15367-1 as well as the following apply.

3.1
array element spacing

d_x, d_y

distance between the centres of adjacent pinholes or lenslets in x and y direction

3.2
sub-aperture screen to detector spacing

L_H

spacing of the sub-aperture screen (lenslet array or Hartmann screen) to the detector array

NOTE For Shack-Hartmann sensors this is often set to the lenslet focal length.

3.3
lenslet focal length

f

focal length of the lenslets for a Shack-Hartmann sensor

3.4
sub-aperture width

d_s

aperture width of the pinholes of a Hartmann screen or lenslets of a Shack-Hartmann array, respectively

3.5
angular dynamic range

β_max

maximum usable angular range of Hartmann or Shack-Hartmann sensors

NOTE For square apertures, the angular dynamic range is given by

$$\beta_\mathrm{max} = \frac{d_x}{2L_\mathrm{H}} - \frac{\lambda}{d_x}$$

3.6
wavefront measurement repeatability

$w_\mathrm{r,rms}$

root-mean-square (r.m.s.) difference between single subsequent measurements $w_n(x, y)$ of the same wavefront and the average wavefront $\bar{w}(x, y)$

$$w_\mathrm{r,rms} = \frac{1}{k}\sum_{n=1}^{k}\sqrt{\frac{\sum\limits_{x}\sum\limits_{y} E_n(x,y)\left[w_n(x,y)-\bar{w}(x,y)\right]^2}{\sum\limits_{x}\sum\limits_{y} E_n(x,y)} - \left(\frac{\sum\limits_{x}\sum\limits_{y} E_n(x,y)\left[w_n(x,y)-\bar{w}(x,y)\right]}{\sum\limits_{x}\sum\limits_{y} E_n(x,y)}\right)^2}$$

where

n is the number of the measurement;

k is the number of samples taken;

$$\bar{w}(x,y) = \frac{\sum\limits_{n=1}^{k} E_n(x,y) \times w_n(x,y)}{\sum\limits_{n=1}^{k} E_n(x,y)}$$

3.7
wavefront measurement accuracy

$w_\mathrm{a,rms}$

average of the r.m.s. difference between a reference wavefront w_r and the tilt-corrected wavefront $w_{\mathrm{tc},n}$ after various amounts of tilt θ_n have been applied to the reference wavefront

$$w_\mathrm{a,rms} = \frac{1}{k}\sum_{n=1}^{k}\sqrt{\frac{\sum\limits_{x}\sum\limits_{y} E_n(x,y)\left[w_{\mathrm{tc},n}(x,y)-w_\mathrm{r}(x,y)\right]^2}{\sum\limits_{x}\sum\limits_{y} E_n(x,y)}}$$