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

Part 1:
Terminology and fundamental aspects

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

Partie 1: Terminologie et aspects fondamentaux

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Foreword

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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 15367-1 was prepared by Technical Committee ISO/TC 172, Optics and optical instruments, Subcommittee SC 9, Electro-optical systems.

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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: Hartmann-Shack sensors*

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Introduction

It is important, when designing, operating or maintaining a laser system, to be able to ensure repeatability, predict the propagation behaviour of the laser beam and to assess the safety hazards. There are four sets of parameters that could be measured for the characterization of a laser beam:

— power (energy) density distribution (ISO 13694);

— beam width, divergence angle and beam propagation factor (ISO 11146);

— phase distribution (ISO 15367);

— spatial beam coherence.

This part of ISO 15367 defines the terminology and symbols to be used when making reference to or measuring the phase distribution in a transverse plane of a laser beam. It specifies the procedures required for the measurement of

— the azimuth of the principal planes of the phase distribution;

— the magnitude of astigmatic aberrations;

— evaluation of the wavefront aberration function and the RMS wavefront deformation.

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A useful technique for qualitative assessment of a beam is visual inspection of the fringe pattern in interferograms or an isometric view of a wavefront surface. However, more quantitative methods are needed for quality assurance and transfer of process technology. The measurement techniques indicated in this part of ISO 15367 allow numerical analysis of the phase distribution in a propagating beam and can provide recordable quantitative results.

While it is quite possible to ascribe other conventional aberrations (e.g. coma or spherical aberration) as well as astigmatism to a laser beam, these are not commonly used. Departure of the wavefront of a beam from some ideal surface is a more common indication of quality. On the other hand, rotational asymmetry has a much wider range of effects in a laser beam than is usually associated with astigmatism imposed on a beam of optical radiation by conventional optical systems. For this reason, various forms and characteristics of astigmatism in beams are now defined in detail.

The provisions of this part of ISO 15367 allow a test report to be commissioned with measurements or analysis of a selection of beam characteristics. Measurements of astigmatism are important to system designers who wish to specify optical elements for the correction of astigmatic beams. The measurement techniques defined in this part of ISO 15367 can also be used to assess any residual astigmatism after the addition of corrective elements and to aid with alignment.

A major application of phase distribution measurements comes with the possibility of combining those measurements with a simultaneous measurement of the power (energy) density distribution (ISO 13694) at the same location in the path of a beam. Digital processing of the data can reveal much more detailed characteristics of the propagating beam than can measurements of the power (energy) envelope resulting from calculation of the beam propagation ratio (ISO 11146). The more detailed information can be important to assessors of laser damage and safety hazards as well as process development engineers when it is necessary to know the power (energy) density distribution at the process interaction point.

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

Part 1:
Terminology and fundamental aspects

1 Scope

This part of ISO 15367 specifies methods for the measurement of the topography of the wavefront of a laser beam by measurement and interpretation of the spatial distribution of the phase of that wavefront across a plane approximately perpendicular to its direction of propagation. Requirements are given for the measurement and analysis of phase distribution data to provide quantitative wavefront parameters and their uncertainty in a test report.

The methods described in this part of ISO 15367 are applicable to the testing and characterization of a wide range of beam types from both continuous wave and pulsed lasers. Definitions of parameters describing wavefront deformations are given together with methods for the determination of those parameters from phase distribution measurements.

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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 9334, *Optics and optical instruments — Optical transfer function — Definitions and mathematical relationships*

ISO 10110-5, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 5: Surface form tolerances*

ISO 11145, *Optics and optical instruments — Laser and laser-related equipment — Vocabulary and symbols*

ISO 11146, *Lasers and laser-related equipment — Test methods for laser beam parameters — Beam widths, divergence angle and beam propagation factor*

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

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

IEC 60825, (All parts), *Safety of Laser Products*

IEC 61040, *Power and energy measuring detectors, instruments and equipment for laser radiation*

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3 Terms and definitions

For the purposes of this document, the definitions given in ISO 9334, ISO 10110-5, ISO 11145, ISO 11146, ISO 13694 and IEC 61040 as well as the following apply.

3.1 General definitions

3.1.1
average wavefront shape
$w(x,y;z_m)$
continuous surface $w(x,y)$ that is normal to the time average direction of energy propagation in the electromagnetic field at the measurement plane $z = z_m$

NOTE 1 In the case of highly coherent radiation, the continuous surface $w(x,y)$ is a surface of constant phase. The phase distribution $\Phi(x,y)$ is then related to the wavefront distribution according to

$$\Phi(x,y) = \frac{2\pi}{\lambda} \cdot w(x,y)$$

where λ is the mean wavelength of the light.

NOTE 2 A continuous surface does not always exist.

3.1.2
wavefront surface
continuous surface $w(x,y)$ that minimizes the power density weighted deviations of the direction of its normal vectors to the direction of the energy flow vectors in the measurement plane

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NOTE $w(x,y)$ is the surface that minimizes the expression

$$\iint E(x,y,z_m) \left| \hat{\vec{P}}_\perp(x,y,z_m) - \vec{\nabla}_\perp w(x,y,z_m) \right|^2 \mathrm{d}x\mathrm{d}y$$

where

$\hat{\vec{P}}_\perp(x,y,z) = \dfrac{\hat{\vec{P}}_\perp(x,y,z_m)}{E(x,y,z_m)}$ is the normalized transverse Poynting vector;

$\vec{\nabla}_\perp = \begin{pmatrix} \partial x \\ \partial y \end{pmatrix}$ is the transverse, two-dimensional gradient or Nabla operator.

3.1.3
phase
Φ
fraction of a wave period that has elapsed relative to that at a nominated origin

NOTE Phase is expressed in radians, modulo 2π.

3.1.4
measurement plane
z_m
axial location along the beam axis of the transverse plane in which the wavefront shape/surface is measured

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3.1.5
mechanical axes
x, *y*, *z*
orthogonal transverse axes defined by the construction axes of the laser or the measuring system

NOTE The origin of the mechanical axis system should be identified and be coincident with some accessible and obvious location on the beam axis, be it a manufacturer's specification on the laser or reproducible location on the measuring instrument. The orientation of the transverse axes can be those associated with the laser or the vertical and horizontal axes in the measurement environment.

3.1.6
principal planes of wavefront shape/surface propagation
x′z and *y′z*
planes containing the principal axes of the wavefront and the beam axis

NOTE The principal planes of wavefront propagation will not necessarily coincide with the *xz* and *yz* planes of the laboratory system.

3.1.7
wavefront shape/surface co-ordinate system
x′, *y′*, *z*
co-ordinate system used as reference axes for denoting the orientation of the principal axes of the astigmatic wavefront shape/surface relative to the mechanical axes of the measuring environment

NOTE The *x*', *y*' and *z* axes define the orthogonal space directions of wavefront shape/surface in the beam axis system. The *x*' and *y*' axes are transverse to the beam and define the transverse plane. The origin of the *z*-axis is in a mechanical reference *xy* plane defined either by the manufacturer of the laser (e.g. the front of the laser enclosure) or by the measuring system. A schematic diagram of the axes system is shown in Figure 1.

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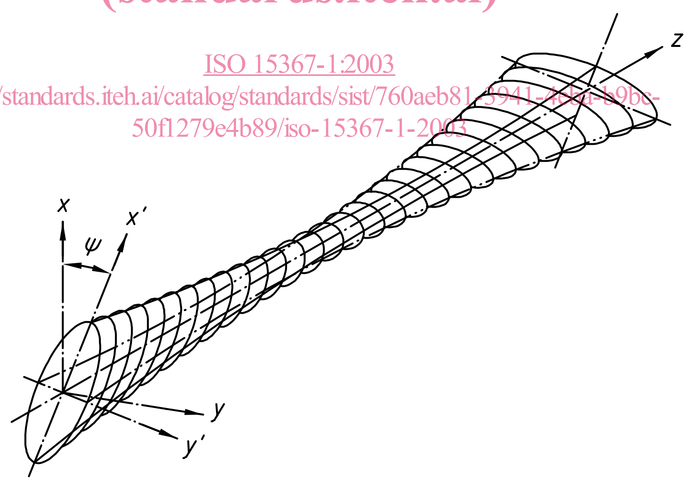

Figure 1 — The co-ordinate system of an astigmatic wavefront relative to the mechanical axes

3.1.8
wavefront azimuth angle
Ψ
angle between the principal planes of the wavefront shape/surface and the mechanical axes

See Figure 1.

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3.2 Definitions associated with power (energy) density distribution

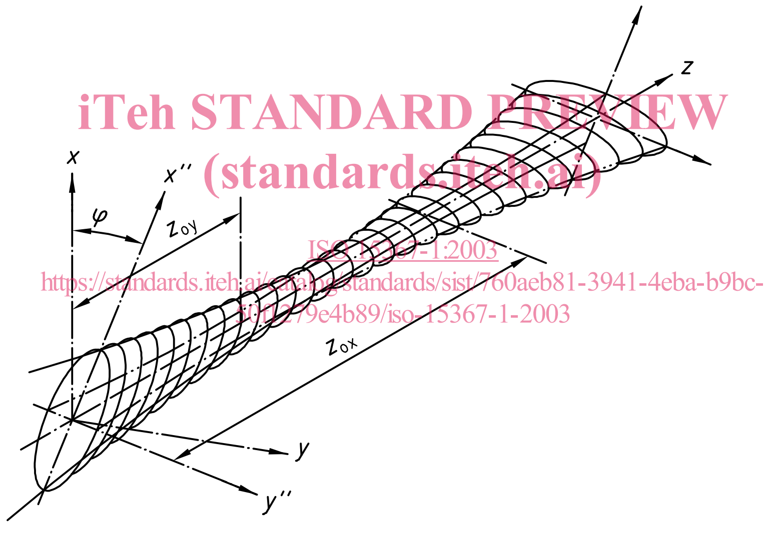
3.2.1
power (energy) density distribution co-ordinate system
x", *y*", *z*
co-ordinate system used as reference axes for denoting the orientation of the principal axes of the astigmatic power (energy) density distribution relative to the mechanical axes of the measuring environment

NOTE The defining parameters of the power (energy) density distribution of a simple astigmatic beam are shown in Figure 2. Means for the evaluation of the major and minor beam widths and their azimuth angle are contained in ISO 11146.

3.2.2
power (energy) density distribution azimuth angle
$\varphi(z)$
angle between the principal planes of propagation of the power (energy) density distribution and the mechanical axes

See Figure 2.

NOTE 1 For simple astigmatic beams, φ remains constant.



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NOTE 2 The waist locations z_{0x} and z_{0y} are shown for both the beam axes

Figure 2 — Co-ordinates of the beam axis system for the power (energy) density distribution

3.3 Definitions associated with astigmatism

3.3.1
astigmatism
property of a laser beam having non-circular power (energy) density profiles in most planes under free space propagation or having a phase twist

NOTE An outline description of astigmatic properties and the requirement to extend their descriptions beyond those used conventionally to describe astigmatic properties of optical elements is contained in Annex A.

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3.3.2
simple astigmatism
property of the beam in which the transverse power (energy) density distribution does not possess rotational symmetry but whose principal planes of wavefront shape/surface and power (energy) density distribution are orthogonal and fixed in space, whose azimuth angles are equal ($\varphi = \psi$)

See Figures 1 and 2.

3.3.3
general astigmatism
property of a laser beam having non-circular power (energy) density distributions in most planes and where the orientation of the principal axes of power (energy) density distributions changes during propagation

NOTE For coherent general astigmatic beams, the azimuth angles of the power (energy) density distribution and wavefront differ in any plane.

3.3.4
astigmatic waist separation
Δz_a
axial distance between the beam waist locations in the orthogonal principal planes of a beam possessing simple astigmatism

NOTE Astigmatic waist separation is also known as astigmatic difference.

3.3.5
astigmatic wavefront curvature
$C_{x'}, C_{y'}$
values of the maximum and minimum orthogonal curvature of the wavefront of a beam at a specified location.

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NOTE 1 Curvature is the reciprocal of the radius of curvature.

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NOTE 2 The difference between the two radii of curvature becomes essentially identical with both the astigmatic focal difference and astigmatic waist separations when measurements are made in the farfield of the laser beam.

3.4 Definitions related to the characteristics and topography of the wavefront.

3.4.1
measured wavefront
$w_m(x, y)$
surface resulting from analysis of the measured phase distribution data

3.4.2
corrected wavefront
$w_c(x, y)$
theoretical surface derived by removing the effects of the average linear trend in the x- and y-direction (average tilt and average tip) from the measured wavefront

NOTE The analytic definition can be summarized as:

$$w_c(x,y) = w_m(x,y) - x\overline{\beta}_x - y\overline{\beta}_y$$