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

Lasers et équipements associés aux lasers — Méthodes d'essai des paramètres des faisceaux laser — Largeurs du faisceau, angle de divergence et facteur de propagation du faisceau

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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 3.

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.

International Standard ISO 11146 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems*.

Annexes A and B form a normative part of this International Standard. Annex C is for information only.

Introduction

Any radially symmetric laser beam requires three parameters for characterization:

a) location of the beam waist z_0;

b) waist diameter $d_{\sigma 0}$; and

c) the far-field divergence angle Θ_σ for the beam under test.

With these three values, one can predict the beam diameter at any plane along the propagation axis. To a first approximation (for divergence angles less than 0,8 rad), the beam propagates as

$$d_\sigma{}^2(z) = d_{\sigma 0}{}^2 + (z - z_0)^2 \cdot \Theta_\sigma{}^2 \tag{1}$$

The beam propagates according to equation (1) provided the second moments of the power (energy) density distribution function are used for the definition of beam widths and divergences. The propagation is described by a beam propagation factor K or a times-diffraction-limit factor M^2 which can be derived from the above basic data. The relationship between K and M^2, respectively, the actual waist diameter $d_{\sigma 0}$ and the divergence angle Θ_σ, is:

$$K = \frac{1}{M^2} = \frac{4\lambda_0}{\pi} \cdot \frac{1}{n \cdot d_{\sigma 0} \cdot \Theta_\sigma} = \frac{4\lambda}{\pi} \cdot \frac{1}{d_{\sigma 0} \cdot \Theta_\sigma} \tag{2}$$

where

K	is the beam propagation factor;
M^2	is the times-diffraction-limit factor;
λ_0	is the wavelength in vacuum ;
λ	is the wavelength in medium with index of refraction n,
Θ_σ	is the divergence angle,
$d_{\sigma 0}$	is the waist diameter,
n	is the index of refraction.

NOTE 1 The accuracy of measurement of beam propagation factors is expected to be in the region of 10 %. It is not consistent with divergence angles (full angle according to ISO 11145) above 0,8 rad.

The product

$$n \cdot d_{\sigma 0} \cdot \Theta_\sigma = \frac{4\lambda_0}{K\pi} = \frac{M^2 4\lambda_0}{\pi} \tag{3}$$

describes the propagation of laser beams and is invariant throughout the propagation of the beam as long as aberration-free and non-aperturing optical systems are used.

For non-radially symmetric beams, the values of seven parameters are required for characterization:

— locations of the beam waists z_{0x} and z_{0y}

— waist widths $d_{\sigma 0x}$ and $d_{\sigma 0y}$;

— far-field divergence angles $\Theta_{\sigma x}$ and $\Theta_{\sigma y}$; and

— azimuth angle φ between the x-axis of the beam axes system and the x'-axis of the laboratory system. The x-axis of the beam axes system coincides with the principal axis of the laser beam closest (within ±45°) to the arbitrary x' coordinate.

In analogy to equation (3), the propagation of non-radially symmetric beams, which are however still characterizable using two principal axes orthogonal to each other, can be described independently for the x- and y-axes using K_x and K_y as beam propagation factors, or M_x^2 and M_y^2 as times-diffraction-limit factors, respectively.

NOTE 2 Beams that suffer from general astigmatism (twisted beams) require three additional parameters for their characterization. The propagation in the x-z plane is not necessarily independent of the propagation characteristics in the y-z plane and not necessarily along the propagation path will a generally astigmatic beam exhibit a circular power density distribution. The measurement of generally astigmatic beams is outside the scope of this International Standard.

In this International Standard, the second moments of the power (energy) density distribution function are used for the determination of beam widths. However, there may be problems experienced in the direct measurement of this property in the beams from some laser sources. In this case, other indirect methods of measurement of second moment may be used as long as comparable results are achievable.

In annex A, three alternative methods for beam width measurement and their correlation with the method used in this International Standard are described. These methods are:

- Variable aperture method
- Moving knife-edge method
- Moving slit method

The problem of the dependence of the measuring result on the truncation limits of the integration has been investigated and evaluated by an international round robin carried out in 1997. The results of this round robin testing were taken into consideration in this document.

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1 Scope

This International Standard specifies methods for measuring beam widths (diameter), divergence angles and beam propagation factors of laser beams.

These methods may not apply to highly diffractive beams such as those produced by unstable resonators or passing through hard-edged apertures.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 11145:1994, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols.*

IEC 61040:1990, *Power and energy measuring detectors — Instruments and equipment for laser radiation*.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 11145 and IEC 61040, and the following apply:

3.1
energy density
$H(x,y)$
that part of the beam energy which impinges on the area δA at the location x, y divided by the area δA

3.2
power density
$E(x,y)$
that part of the beam power which impinges on the area δA at the location x, y divided by the area δA

3.3
beam waist locations
z_0, z_{0x}, z_{0y}
positions where beam widths reach their minimum values along the axis of propagation

See Figure 1.

NOTE The locations are expressed as the distances to the beam waists (inside or outside the resonator) from a reference plane defined by the manufacturer e.g. the front of the laser enclosure.