INTERNATIONAL STANDARD

ISO 13694

Third edition
2018-11

Optics and photonics — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution

Optique et photonique — Lasers et équipements associés aux lasers — Méthodes d'essai de distribution de la densité de puissance (d'énergie) du faisceau laser

Reference number
ISO 13694:2018(E)

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Published in Switzerland

Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Laser and electro-optical systems*.

This third edition cancels and replaces the second edition (ISO 13694:2015), which has been technically revised. The main changes compared to the previous edition are as follows:

a) the definition of beam ellipticity has been harmonized with ISO 11145 and ISO 11146-1;

b) the term “second linear moments” has been replaced by “second moments”;

c) the term “field of view” has been replaced by “aperture”;

d) Clause 9 was rewritten; the paragraphs on clip-levels were corrected to reflect that they are no longer intended for noise cancelation;

e) the entries “Fitted distribution type”, “Roughness of fit R”, and “Goodness of fit G” have been removed from the Test Report;

f) the term “aspect ratio” has been removed from the test report.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Many applications of lasers involve using the near-field as well as the far-field power (energy) density distribution of the beam. The power (energy) density distribution of a laser beam is characterized by the spatial distribution of irradiant power (energy) density with lateral displacement in a particular plane perpendicular to the direction of propagation. In general, the power (energy) density distribution of the beam changes along the direction of propagation. Depending on the power (energy), size, wavelength, polarization, and coherence of the beam, different methods of measurement are applicable in different situations. Five methods are commonly used: camera arrays (1D and 2D), apertures, pinholes, slits, and knife edges.

According to ISO 11145, it is possible to use two different definitions for describing and measuring the laser beam diameter. One definition is based on the measurement of the encircled power (energy); the other is based on determining the spatial moments of the power (energy) density distribution of the laser beam.

The use of spatial moments is necessary for calculating the beam propagation factor, K, and the beam propagation ratio, M^2, from measurements of the beam widths at different distances along the propagation axis. ISO 11146-1 describes this measurement procedure. For other applications, other definitions for the beam diameter can be used. For some quantities used in this document the first definition (encircled power (energy)) is more appropriate and easier to use.

Optics and photonics — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution

1 Scope

This document specifies methods by which the measurement of power (energy) density distribution is made and defines parameters for the characterization of the spatial properties of laser power (energy) density distribution functions at a given plane.

The methods given in this document are intended to be used for the testing and characterization of both continuous wave (cw) and pulsed laser beams used in optics and optical instruments.

This document provides definitions of terms and symbols to be used in referring to power density distribution, as well as requirements for its measurement. For pulsed lasers, the distribution of time-integrated power density (i.e. energy density) is the quantity most often measured.

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 11145, *Optics and photonics — Laser and laser-related equipment — Vocabulary and symbols*

ISO 11146-1, *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 1: Stigmatic and simple astigmatic beams*

ISO 11554, *Optics and photonics — Lasers and laser-related equipment — Test methods for laser beam power, energy and temporal characteristics*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and IEC 61040 and the following apply.

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

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Measured quantities

3.1.1
power density distribution
$E(x, y, z)$
set of all power densities at location z of a certain cw beam with non-negative values for all transverse coordinates (x, y)

3.1.1.1
power density
$E(x_P, y_P, z)$
portion of the beam power at location z which impinges on the area δA at the location $P(x_P, y_P)$ divided by the area δA in the limit $\delta A \rightarrow 0$

[SOURCE: ISO 11145:2018, 3.13.6, modified —Notes to entry omitted.]

3.1.2
energy density distribution
$H(x, y, z)$
set of all energy densities at location z of a certain pulsed beam with non-negative values for all transverse coordinates (x, y)

$$H(x,y,z) = \int E(x,y,z) \mathrm{d}t$$

3.1.2.1
energy density
$H(x_P, y_P, z)$
<pulsed laser beam> portion of the beam energy (time-integrated power) at location z which impinges on the area δA at the location $P(x_P, y_P)$ divided by the area δA in the limit $\delta A \rightarrow 0$

$$H(x_P, y_P, z) = \int E(x_P, y_P, z) \mathrm{d}t$$

[SOURCE: ISO 11145:2018, 3.13.4, modified — Notes to entry omitted and Formula added.]

3.1.3
power
$P(z)$
rate of energy transfer in a continuous wave (cw) beam at location z

$$P(z) = \iint E(x,y,z) \mathrm{d}x\mathrm{d}y$$

3.1.4
pulse energy
$Q(z)$
energy in one pulse measured at location z

$$Q(z) = \iint H(x,y,z) \mathrm{d}x\mathrm{d}y$$

[SOURCE: ISO 11145:2018, term 3.13.3 modified — Included "Measured at location z" and formula Q(z)]

3.1.5
maximum power (energy) density
$E_{max}(z)$ $[H_{max}(z)]$
maximum of the spatial power (energy) density distribution function $E(x, y, z)$ $[H(x, y, z)]$ at location z

3.1.6
location of the maximum
(x_{max}, y_{max}, z)
location of $E_{max}(z)$ or $H_{max}(z)$ in the xy plane at location z

Note 1 to entry: (x_{max}, y_{max}, z) cannot be uniquely defined when measuring with detectors having a high spatial resolution and a relatively small dynamic range.

3.1.7
clip-level power (energy) density
$E_{\eta CL}(z)$ [$H_{\eta CL}(z)$]
fraction η of the *maximum power (energy) density* (3.1.5) at location z

$$E_{\eta CL}(z) = \eta E_{max}(z)$$

$$H_{\eta CL}(z) = \eta H_{max}(z)$$

$$0 \le \eta < 1$$

Note 1 to entry: When no confusion is possible, the explicit dependence on z is dropped in the text description using some quantities, but not in the definitions or in the Formulae involving the quantities.

3.2 Characterizing parameters

3.2.1
clip-level power (energy)
$P_\eta(z)$ [$Q_\eta(z)$]
integral of the power (energy) distribution at location z, evaluated by summing only over locations (x,y) for which $E(x, y, z) > E_{\eta CL}(z)$ [$H(x, y, z) > H_{\eta CL}(z)$]

3.2.2
fractional power (energy)
$f_\eta(z)$
fraction of the *clip-level power (energy)* (3.2.1) for a given η to the total power (energy) in the distribution at location z

$$f_\eta(z) = \frac{P_\eta(z)}{P(z)} \quad \text{for cw-beams}$$

$$f_\eta(z) = \frac{Q_\eta(z)}{Q(z)} \quad \text{for pulsed beams}$$

$$0 \le f_\eta(z) \le 1$$

3.2.3
beam centroid
$\left(\bar{x}(z), \bar{y}(z)\right)$
coordinates of the first-order moments of a power(energy) distribution of a beam at location z

$$\bar{x}(z) = \frac{\iint x \cdot E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}{\iint E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}$$

$$\bar{y}(z) = \frac{\iint y \cdot E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}{\iint E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}$$

where the integration shall be performed over an area such that at least 99 % of the beam power (energy) is captured

Note 1 to entry: The power density E is replaced by the energy density H for pulsed lasers.

Note 2 to entry: For a more detailed definition, see ISO 11145 and ISO 11146-1.

3.2.4
beam widths

$d_{\sigma x}(z)$, $d_{\sigma y}(z)$

widths $d_{\sigma x}(z)$ and $d_{\sigma y}(z)$ of the beam in the respective *x* and *y* directions at *z*, equal to four times the square root of the second moments of the power (energy) density distribution about the centroid

Note 1 to entry: For a more detailed definition, see ISO 11145 and ISO 11146-1.

Note 2 to entry: The provisions of ISO 11146-1 apply to definitions and measurements of:

a) second moment beam widths $d_{\sigma x}$ and $d_{\sigma y}$;

b) beam widths $d_{x,u}$ and $d_{y,u}$ in terms of the smallest centred slit width that transmits *u* % of the total power (energy) density (usually *u* = 86,5);

c) scanning narrow slit measurements of beam widths $d_{x,s}$ and $d_{y,s}$ in terms of the separation between positions where the transmitted *power density* (3.1.1.1) is reduced to 0,135 E_p, where E_p is the peak power (energy) density;

d) measurements of beam widths $d_{x,k}$ and $d_{y,k}$ in terms of the separation between 0,84 *P* and 0,16 *P* obscuration positions of a movable knife-edge, where *P* is the maximum, unobstructed power (energy) recorded by the large area detector behind the knife-edge plane;

e) correlation factors which relate these different definitions and methods for measuring beam widths.

3.2.5
beam ellipticity

$\varepsilon(z)$

parameter for quantifying the circularity or squareness of a power (energy) distribution at *z*

$$\varepsilon(z) = \frac{d_{\sigma y}(z)}{d_{\sigma x}(z)}$$

where the direction of *x* is chosen to be along the major axis of the distribution, such that $d_{\sigma x} \geq d_{\sigma y}$

Note 1 to entry: If $\varepsilon \geq 0{,}87$, elliptical distributions can be regarded as circular.

Note 2 to entry: In case of a rectangular distribution, ellipticity is often referred to as aspect ratio.

Note 3 to entry: Technically identical to ISO 11146-1 and ISO 11145.

Note 4 to entry: In contrast to the definition given here, in literature the term ellipticity is sometimes related to $1 - \frac{d_{\sigma y}(z)}{d_{\sigma x}(z)}$. The definition given here has been chosen to be in concordance with the same definition of ellipticity in ISO 11146-1 and ISO 11145.

3.2.6
beam cross-sectional area

$A_\sigma(z)$

<second moment of power (energy) density distribution function> area of a beam with circular cross-section

$$A_\sigma = \left(\frac{\pi}{4}\right) \cdot d_\sigma(z)^2$$

or elliptical cross-section

$$A_\sigma = \left(\frac{\pi}{4}\right) \cdot d_{\sigma x}(z) \cdot d_{\sigma y}(z)$$

Note 1 to entry: For clarity, the term “beam cross-sectional area” is always used in combination with the symbol and its appropriate subscript: A_u or A_σ.

[SOURCE: ISO 11145:2018, 3.6.2]

3.2.7
clip-level irradiation area
$A_\eta^i(z)$
irradiation area at location z for which the power (energy) density exceeds the *clip-level power (energy) density* (3.1.7)

Note 1 to entry: To allow for distributions of all forms, for example hollow “donut” types, the clip-level irradiation area is not defined in terms of the *beam widths* (3.2.4) $d_{\sigma x}$ or $d_{\sigma y}$.

Note 2 to entry: See *clip-level power (energy) density* (3.1.7).

3.2.8
clip-level average power (energy) density
$E_{\eta\text{ave}}(z)$, $[H_{\eta\text{ave}}(z)]$
spatially averaged power (energy) density of the distribution at location z, defined as the weighted mean

$$E_{\eta\text{ave}}(z)=\frac{P_\eta(z)}{A_\eta^{\text{i}}(z)} \quad \text{for cw-beams}$$

$$H_{\eta\text{ave}}(z)=\frac{Q_\eta(z)}{A_\eta^{\text{i}}(z)} \quad \text{for pulsed beams}$$

Note 1 to entry: $E_{\eta\text{ave}}(z)$ and $E_{\eta\text{CL}}(z)$ (see 3.1.7) refer to different parameters.

3.2.9
flatness factor
$F_\eta(z)$
ratio of the clip-level average power (energy) density to the maximum power (energy) density of the distribution at location *z*

$$F_\eta(z)=\frac{E_{\eta\text{ave}}(z)}{E_{\max}(z)} \quad \text{for cw-beams}$$

$$F_\eta(z)=\frac{H_{\eta\text{ave}}(z)}{H_{\max}(z)} \quad \text{for pulsed beams}$$

$$0 < F_\eta \le 1$$

Note 1 to entry: For a power (energy) density distribution having a perfectly flat top $F_\eta = 1$.

3.2.10
beam uniformity
$U_\eta(z)$
normalized root mean square (rms) deviation of power (energy) density distribution from its clip-level average value at location *z*

$$U_\eta(z)=\frac{1}{E_{\eta\text{ave}}(z)}\sqrt{\frac{1}{A_\eta^{\text{i}}(z)}\iint\left[E(x,y,z)-E_{\eta\text{ave}}(z)\right]^2\text{d}x\text{d}y} \quad \text{for cw-beams}$$

$$U_\eta(z)=\frac{1}{H_{\eta\text{ave}}(z)}\sqrt{\frac{1}{A_\eta^{\text{i}}(z)}\iint\left[H(x,y,z)-H_{\eta\text{ave}}(z)\right]^2\text{d}x\text{d}y} \quad \text{for pulsed beams}$$