INTERNATIONAL STANDARD

ISO 13694

Second edition
2015-11-15

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 13694:2015(E)

COPYRIGHT PROTECTED DOCUMENT

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

This second edition cancels and replaces the first edition (ISO 13694:2000), which has been technically revised with the following changes:

a) the definition of power density distribution E (x, y, z) has been revised, a definition of the power density E (x_0, y_0, z) has been added;

b) the definition of energy density distribution H (x, y, z) has been revised, a definition of the energy density H (x_0, y_0, z) has been added;

c) the term "threshold power [energy] density" has been replaced by "clip-level power [energy] density". The index "T" indicating "threshold" has been replaced by "CL" accordingly;

d) the term "effective power [energy]" has been replaced by "clip-level power [energy]";

e) in 3.2.5, the formula for beam ellipticity has been revised;

f) the term "effective irradiation area" has been replaced by "clip-level irradiation area";

g) the notation $E_\eta(z)$ $[H_\eta(z)]$ indicating the clip-level average power [energy] density has been replaced by $E_{\eta\mathrm{ave}}(z)$, $[H_{\eta\mathrm{ave}}(z)]$;

h) Figure 1 has been revised taking into account the items a) and g) of this list.

It also incorporates the corrigendum ISO 13694:2000/Cor 1:2005.

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.

This International Standard 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.

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 describes this measurement procedure. For other applications, other definitions for the beam diameter can be used. For some quantities used in this International Standard, the first definition (encircled power [energy]) is more appropriate and easier to use.

The International Organization for Standardization (ISO) draws attention to the fact that it is claimed that compliance with this document can involve the use of patents concerning the inclusion of negative noise values in background evaluation of CCD camera images as described in 8.3.2.

ISO takes no position concerning the evidence, validity, and scope of this patent right.

The holder of this patent right (U.S. No. 5,418,562 and 5,440,562, and PCT WO 94/27401) has assured ISO that they are willing to negotiate licenses under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with ISO. Information can be obtained from:

Spiricon Inc.

Laser Beam Diagnostics

2600 North Main

Logan, UT 84341

USA

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

1 Scope

This International Standard 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 International Standard 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.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 (all parts), *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios*

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.

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
$E(x_0, y_0, z)$
part of the beam power at location z which impinges on the area δA at the location (x_0, y_0) divided by the area δA $(\delta A \to 0)$

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

$H(x_0, y_0, z)$

$\langle$ pulsed laser beam $\rangle$ part of the beam energy (time-integrated power) at location z which impinges on the area δA at the location (x_0, y_0) divided by the area δA $(\delta A \to 0)$

$$H(x_0,y_0,z)=\int E(x_0,y_0,z)\mathrm{d}t$$

3.1.3

power

$P(z)$

power 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 a pulsed beam at location z

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

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

$E_{\eta\mathrm{CL}}(z)$ $[H_{\eta\mathrm{CL}}(z)]$

fraction η of the *maximum power [energy] density* (3.1.5) at location z

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

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

$$0 \leq \eta < 1$$

Note 1 to entry: Notations $E_{\eta\mathrm{T}}$ or $H_{\eta\mathrm{T}}$ and the names threshold power [energy] density, respectively, can be used instead of $E_{\eta\mathrm{CL}}$ or $H_{\eta\mathrm{CL}}$ and the names clip-level power [energy] density, respectively, when $E_{\eta\mathrm{CL}}$ or $H_{\eta\mathrm{CL}}$ is just greater than detector background noise peaks at the time of measurement. 8.3 describes background noise subtraction methods used to determine detector zero levels. Circumstances such as the application involved, distribution type, detector sensitivity, linearity, saturation, baseline, offset level, etc., can also dictate the choice of η.

Note 2 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 equations involving the quantities.

3.2 Characterizing parameters

3.2.1
clip-level power [energy]

$P_\eta(z)$ $[Q_\eta(z)]$

$P(z)$ $[Q(z)]$ evaluated by summing only over locations (x,y) for which $E(x,y,z) > E_{\eta\,\mathrm{CL}}(z)$ $[H(x,y,z) > H_{\eta\,\mathrm{CL}}(z)]$

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

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

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

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

3.2.3
centre of gravity
centroid position

$\left(\bar{x}(z), \bar{y}(z)\right)$

first-order moments of a power[energy] distribution at location z

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

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 x and y directions at z, equal to four times the square root of the second linear 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.

Note 2 to entry: The provisions of ISO 11146 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 $E_{p,}$;

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 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] density distribution at z

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

Note 1 to entry: The direction of x is chosen to be along the major axis of the distribution so $d_{\sigma x} \geq d_{\sigma y}$.

Note 2 to entry: If $\varepsilon \geq 0{,}87$, elliptical distributions can be regarded as circular. In case of a rectangular beam profile, ellipticity is often referred to as aspect ratio.

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

3.2.6
beam cross-sectional area

$A_\sigma(z)$

$A_\sigma = \pi\, d_\sigma^2 / 4$ for beam with circular cross-section;

$A_\sigma = (\pi / 4)\, d_{\sigma x} d_{\sigma y}$ for beam with elliptical cross-section.

3.2.7
clip-level irradiation area

$A_\eta^{\mathrm{i}}(z)$

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

$E_{\eta \mathrm{ave}}(z)$, $[H_{\eta \mathrm{ave}}(z)]$

spatially averaged power [energy] density of the distribution at location z, defined as the weighted mean:

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

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

Note 1 to entry: $E_{\eta\mathrm{ave}}(z)$ and $E_{\eta\mathrm{CL}}(z)$ (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*

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

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

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

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 (r.m.s.) deviation of power [energy] density distribution from its clip-level average value at location *z*

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

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

Note 1 to entry: $U_\eta = 0$ indicates a completely uniform distribution having a profile with a flat top and vertical edges, U_η is expressed as either a fraction or a percentage.

Note 2 to entry: By using integration over the beam area between set clip-level limits, this definition allows for arbitrarily shaped beam footprints to be quantified in terms of their uniformity. Hence uniformity measurements can be made for different fractions of the total beam power [energy] without specifically defining a windowing aperture or referring to the shape or size of the distribution. Thus using the formulae in 3.2.2 and 3.2.10, statements such as: “Using a setting η = 0,3, 85 % of the beam power [energy] was found to have a uniformity of ±4,5 % r.m.s. from its mean value at *z*” can be made without reference to the distribution shape, size, etc.

3.2.11
plateau uniformity

$U_p(z)$

⟨ for distributions having a nearly flat-top profile ⟩

$$U_p(z) = \frac{\Delta E_{\mathrm{FWHM}}}{E_{\max}} \quad \text{for cw-beams;}$$

$$U_p(z) = \frac{\Delta H_{\mathrm{FWHM}}}{H_{\max}} \quad \text{for pulsed beams}$$