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Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power [energy] density distribution

Optique et instruments d'optique — Lasers et équipements associés aux lasers — Méthodes d'essai de distribution de la densité de puissance [d'énergie] du faisceau laser

Reference number
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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.

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

International Standard ISO 13694 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems*.

Introduction

Many applications of lasers involve using the near-field as well as the far-field power [energy] density distribution of the beam[1]. 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 times-diffraction-limit factor 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 may be used. For some quantities used in this International Standard, the first definition (encircled power [energy]) is more appropriate and easier to use.

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[1] For the purposes of this International Standard, "near-field" is defined as the radiation field of a laser at a distance z from the beam waist which is less than the Rayleigh-length z_R. "Far-field" is defined in ISO 11145.

Optics and optical instruments — 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 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 — Laser and laser-related equipment — Vocabulary and symbols.*

ISO 11146:1999, *Lasers and laser-related equipment — Test methods for laser beam parameters — Beam widths, divergence angle and beam propagation factor.*

ISO 11554:1998, *Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power, energy and temporal characteristics.*

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 Measured quantities

3.1.1
power density
$E(x,y,z)$
part of the beam power at location z which impinges on the area δA at the location (x,y) divided by the area δA

3.1.2
energy density

$H(x,y,z)$

<pulsed laser beam> part of the beam energy (time-integrated power) at location z which impinges on the area δA at the location (x,y) divided by the area δA

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

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

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

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

$(x_{\mathrm{max}}, y_{\mathrm{max}}, z)$

location of $E_{\mathrm{max}}(z)$ or $H_{\mathrm{max}}(z)$ in the xy plane at location z

NOTE $(x_{\mathrm{max}}, y_{\mathrm{max}}, z)$ may not be uniquely defined when measuring with detectors having a high spatial resolution and a relatively small dynamic range.

3.1.7
threshold power [energy] density

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

a fraction η of the maximum power [energy] density at location z

$E_{\eta\mathrm{T}}(z) = \eta E_{\mathrm{max}}(z)$ for cw-beams;

$H_{\eta\mathrm{T}}(z) = \eta H_{\mathrm{max}}(z)$ for pulsed beams;

$0 \leq \eta < 1$

NOTE Usually the value of η chosen is such that $E_{\eta\mathrm{T}}$ or $H_{\eta\mathrm{T}}$ is just greater than detector background noise peaks at the time of measurement. Subclause 9.3 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., may also dictate the choice of η.

3.2 Characterizing parameters

3.2.1

effective power [energy]

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

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

3.2.2

fractional power [energy]

$f_\eta(z)$

fraction of the effective power [energy] 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

centre of gravity

centroid position

$(\bar{x}, \bar{y})$

first linear moments at location z

NOTE For a more detailed definition, see ISO 11145.

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 For a more detailed definition, see ISO 11145 and ISO 11146.

NOTE 2 The provisions of ISO 11146 apply to definitions and measurement 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 $d_{x,\mathrm{s}}$ and $d_{y,\mathrm{s}}$ in terms of the separation between positions where the transmitted power density is reduced to 0,135E_P;

d) measurements of beam widths $d_{x,\mathrm{k}}$ and $d_{y,\mathrm{k}}$ in terms of the separation between 0,84P and 0,16P obscuration positions of a movable knife-edge;

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

3.2.5

beam ellipticity [eccentricity]

$\xi(z)$ $[e(z)]$

parameter for quantifying the circularity or squareness (aspect ratio) of a distribution at z

beam ellipticity $\xi(z) = \dfrac{d_{\sigma y}}{d_{\sigma x}}$;

beam eccentricity $e(z) = \dfrac{\sqrt{d^2{}_{\sigma x} - d^2{}_{\sigma y}}}{d_{\sigma x}}$

where the direction of x is chosen to be along the major axis of the distribution so $d_{\sigma x} \geq d_{\sigma y}$.

NOTE If $e \leq 0{,}5$ or $\xi \geq 0{,}87$, rotationally symmetric distributions can be regarded as circular and rectangular-types as square.

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
effective irradiation area

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

irradiation area at location z for which the power [energy] density exceeds the threshold power [energy] density

NOTE 1 To allow for distributions of all forms, for example hollow "donut" types, the effective irradiation area is not defined in terms of the beam widths $d_{\sigma x}$ or $d_{\sigma y}$.

NOTE 2 See threshold power [energy] density (3.1.7).

3.2.8
effective average power [energy] density

$E_\eta(z)$ $[H_\eta(z)]$

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

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

$H_\eta(z) = \dfrac{Q_\eta}{A_\eta^{\mathrm{i}}}$ for pulsed beams

NOTE $E_\eta(z)$ and $E_{\eta\mathrm{T}}(z)$ (see 3.1.7) refer to different parameters.

3.2.9
flatness factor

$F_\eta(z)$

ratio of the average power [energy] density to the maximum power [energy] density of the distribution at location z

$F_\eta(z) = \dfrac{E_\eta}{E_{\mathrm{max}}}$ for cw-beams;

$F_\eta(z) = \dfrac{H_\eta}{H_{\mathrm{max}}}$ for pulsed beams

$0 < F_\eta \leq 1$

NOTE 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 from its average value at location z

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

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

NOTE 1 $U_\eta = 0$ 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 By using integration over the beam area between set threshold 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 equations in 3.2.2 and 3.2.10, statements such as: "Using a setting $\eta = 0{,}3$, 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⟩

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

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

where ΔE_{FWHM} [ΔH_{FWHM}] is the full-width at half-maximum (FWHM) of the peak near $E_{\max}$ [$H_{\max}$] of the power [energy] density histogram $N(E_{\mathrm{i}})$ [$N(H_{\mathrm{i}})$], i.e. the number of (x,y) locations at which a given power [energy] density E_{i} [H_{i}] is recorded.

NOTE $0 < U_P(z) < 1$; $U_P(z) \rightarrow 0$ as distributions become more flat-topped.

3.2.12
edge steepness

$s(z)$

normalized difference between effective irradiation areas $A_{0,1}^{\mathrm{i}}(z)$ and $A_{0,9}^{\mathrm{i}}(z)$ with power [energy] density values above $0{,}1E_{\max}(z)$ [$0{,}1H_{\max}(z)$] and $0{,}9E_{\max}(z)$ [$0{,}9H_{\max}(z)$] respectively

$$s(z) = \frac{A_{0,1}^{\mathrm{i}}(z) - A_{0,9}^{\mathrm{i}}(z)}{A_{0,1}^{\mathrm{i}}(z)}$$

$0 < s(z) < 1$

NOTE $s(z) \rightarrow 0$ as the edges of the distribution become more vertical.