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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

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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).

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).

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b) the term “second linear moments” has been replaced by “second moments”;

c) the term “field of view” has been replaced by “aperture”;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
$(\bar{x}(z), \bar{y}(z))$
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

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

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

$$0 < F_\eta \leq 1$$

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

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

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

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
$U_p\,(z)$
quantitative measure for the homogeneity of nearly flat-top profiles

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

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

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 $N(E_{\text{i}})$ [$N(H_{\text{i}})$], i.e. the number of (x, y) locations at which a given power (energy) density E_{i} [H_{i}] is recorded

Note 1 to entry: $0 < U_p\,(z) < 1$; $U_p\,(z) \rightarrow 0$ as distributions become more flat-topped.

3.2.12
edge steepness
$s_{\eta,\varepsilon}\,(z)$
normalized difference between *clip-level irradiation areas* (3.2.7) $A_\eta^{\text{i}}(z)$ and $A_\varepsilon^{\text{i}}(z)$ with *clip-level power (energy) density* (3.1.7) values above $\eta\,E_{\max}(z)$ [$\eta\,H_{\max}(z)$] and above $\varepsilon\,E_{\max}(z)$ [$\varepsilon\,H_{\max}(z)$] respectively

$$s_{\eta,\varepsilon}(z) = \frac{A_\eta^{\text{i}}(z) - A_\varepsilon^{\text{i}}(z)}{A_\eta^{\text{i}}(z)}$$

$$0 \le \eta < \varepsilon < 1$$

$$0 < s_{\eta,\varepsilon}(z) < 1$$

Note 1 to entry: $s_{\eta,\varepsilon}\,(z) \rightarrow 0$ as the edges of the distribution become more vertical.

Note 2 to entry: η is typically set to 10 %, ε to 90 % of the maximum power (energy) density.

Note 3 to entry: Parameters $E_{\max}$, $E_{\eta\text{ave}}$, P_η, A_η^{i}, F_η, and U_η, are illustrated in Figure 1 for a uniform *power density distribution* (3.1.1) in one dimension.

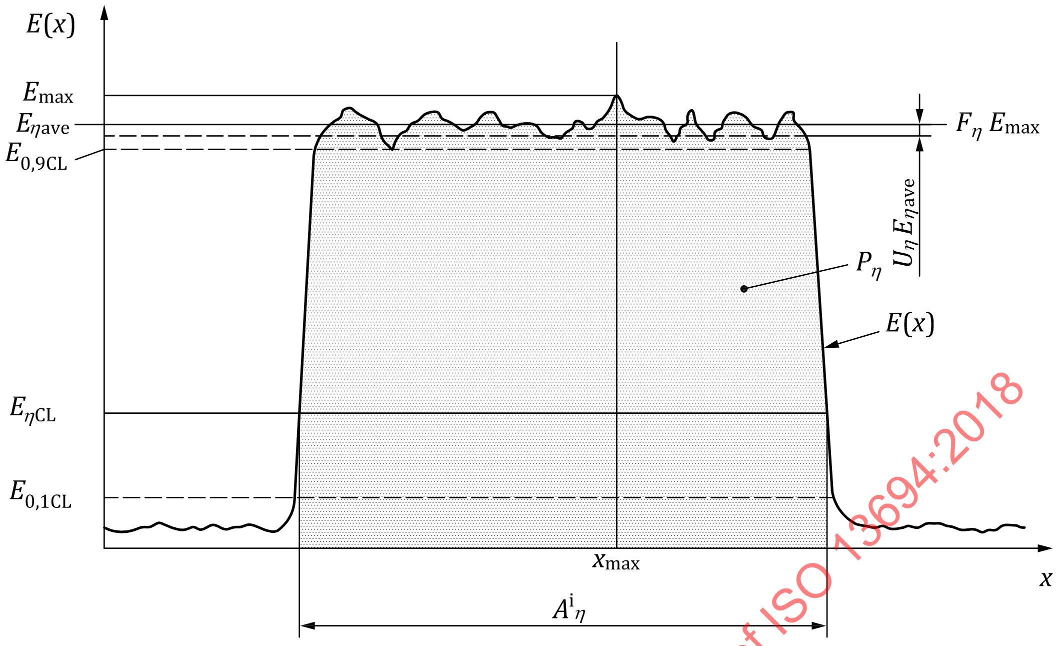

Figure 1 — Illustration for a uniform power density distribution *E(x)* in one dimension

4 Coordinate system

The *x*, *y*, *z* Cartesian axes define the orthogonal space directions in the beam axes system. The *x* and *y* axes are transverse to the beam and define the transverse plane. The beam propagates along the *z* axis. The origin of the *z* axis is in a reference *xy* plane defined by the laser manufacturer, e.g. the front of the laser enclosure. For elliptical beams, the principal axes of the distribution coincide with the *x* and *y* axes, respectively. In cases for which the principal axes of the distribution are rotated with respect to the laboratory coordinate system, the provisions of ISO 11146-1 describing coordinate rotation through an azimuth angle ϕ into the laboratory system shall apply.

5 Characterizing parameters derived from the measured spatial distribution

In definitions 3.2.7 to 3.2.12, summation integrals shall be computed over all locations (x,y) for which $E(x,y,z) > E_{\eta\text{CL}}(z)$ or $H(x,y,z) > H_{\eta\text{CL}}(z)$. Before using a clipping procedure, it is necessary to apply proper background subtraction to the measured signal. Usually the value of η is chosen such that $E_{\eta\text{CL}}$ (or $H_{\eta\text{CL}}$) is just greater than detector background noise peaks at the time of measurements.

NOTE Since practical laser beams have a finite lateral size and detectors, which measure their power density distribution, a finite spatial resolution, definitions in this document used for computations would more precisely contain discrete finite sums rather than continuous integrals. Finite integrals are used because they have a more compact form than summations and it is common practice to do so. For further information on the choice of practical integration limits, refer to Clause 9.

6 Test principle

First the power (energy) density distribution *E* (*x*, *y*, *z*) [*H* (*x*, *y*, *z*)] at the location *z* is measured by positioning a spatially resolving detector of irradiance [fluence] directly in the beam. The detector plane is either placed directly at *z* normal to the beam propagation direction or a suitable optical imaging system is used to relay the plane at *z* onto the detector. A stationary power (energy) density distribution is required to be measured. For lasers with temporally fluctuating parameters that characterize the beam power (energy) density distribution, a mean power (energy) density shall be used. Following the measurement of *E* (*x*, *y*, *z*) [*H* (*x*, *y*, *z*)] parameters that characterize the power (energy) density distribution are then calculated from definitions given in 3.2.

7 Measurement arrangement and test equipment

7.1 General

For measuring the power (energy) density distribution of laser beams, any measuring device can be used which provides high spatial resolution and high dynamic range.

Methods commonly used to quantify laser beam power (energy) density distributions include 1D and 2D matrix camera arrays, single- and dual-axis scanning pinholes, single-axis scanning slits or knife edges, transmission through variable apertures (power-in-a-bucket measurements) and 2D densitometry by reflectance, fluorescence, phosphorescence, and film exposure.

7.2 Preparation

The laser beam and the optical axis of the measuring system should be coaxial. Suitable optical alignment devices are available for this purpose. Any pointing variations of the beam during the measurements period shall be verified not to affect the accuracy required of the measurement.

Optical elements such as beam splitters, attenuators, relay lenses shall be mounted such that the optical axis runs through their geometric centres. Care should be taken to avoid systematic errors. Reflections, external ambient light, thermal radiation, or air draughts are all potential sources of error.

The aperture of the optical system shall be such that it accommodates the entire cross-section of the laser beam. Clipping or diffraction loss shall be smaller than 1 % of the total beam power or energy.

After the initial preparation is complete, an evaluation to determine if the entire laser beam reaches the detector surface shall be made. For testing this, apertures of different diameters can be introduced into the beam path in front of each optical component as well as the detector itself. The aperture which reduces the laser power by 5 % should have a diameter less than 0,8 times the aperture of the optical component.

7.3 Control of environment

Suitable measures, such as mechanical and acoustical isolation of the test set-up, shielding from extraneous radiation, temperature stabilization of the laboratory, choice of low-noise amplifiers, shall be taken to ensure that the contribution to the total probable error in the parameter to be measured is low.

Care should be taken to ensure that the atmospheric environment in high power (energy) laser beam paths does not contain gases or vapours that can absorb the laser radiation and cause thermal distortion to the beam power (energy) density distribution that is being measured.

7.4 Detector system

Measuring parameters of the power (energy) density distribution requires the use of a detector system having a high spatial resolution and signal-to-noise ratio for detecting radiation at the laser wavelength. The accuracy of the measurement is directly related to the spatial resolution of the detector system and its signal-to-noise ratio. The following points shall be observed and, where appropriate, recorded.

— The saturation level, the signal-to-noise ratio and the linearity of the detector system to the input laser power (energy) shall be determined from manufacturers' data or by measurement at the wavelength of the laser to be characterized. Any wavelength dependency, non-linearity, or non-uniformity of the detector locally or across its aperture shall be minimized or corrected by use of a calibration procedure.

— The dynamic range of the sensor shall be greater than 100:1.

— To provide adequate spatial resolution, more than 2 500 spatially non-overlapping (x,y) data points shall register a signal.

— Care shall be taken to ascertain the power (energy) density damage thresholds of the detector surface for the wavelength and pulse duration of interest, so that they are not exceeded by the laser beam.

— The provisions of ISO/TR 11146-3 describing variable aperture, scanning slit, and knife-edge methods for measuring beam widths apply also to measuring beam amplitude distributions at z.

— When using a scanning device to measure the power (energy) density distribution function, care shall be taken to ensure that the laser output is spatially and temporally stable during the complete scanning period.

— When measuring pulsed laser beams, to ensure beam parameters do not change during the sampling interval, the trigger time delay and sampling interval shall be measured and specified in the test report.

7.5 Beam-forming optics, optical attenuators, and beam splitters

If the cross-section of the laser beam is greater than the detector area or if the plane located at z is inaccessible to the detection system, a suitable optical system shall be used to image the cross-section area of the laser beam at z onto the detector surface. In such cases, the optical (de)magnification of the imaging system shall be recorded.

Optical components shall be selected appropriate to the laser wavelength and be free of aberration. An attenuator can be required to reduce the laser power (energy) density at the surface of the detector. Optical attenuators shall be used when the laser output power (energy) density exceeds the detector's working (linear) range or the damage threshold. Any wavelength, polarization, and angular dependency, non-linearity or non-uniformity of the optical attenuator shall be minimized or corrected by use of a calibration procedure.

None of the optical elements used shall significantly influence the relative power (energy) density distribution. When imaging the laser beam onto the detector surface the (de)magnification factor shall be taken into account during the evaluation procedure.

Care shall be taken to ensure that effects such as stray reflections, scattering or interference of laser beam are not introduced by the detector or detection system at a level sufficient to affect the measured power (energy) density distribution. For example, in the case of matrix detectors such spurious effects can be introduced into the measurements by the sensor window – in which case an appropriate remedial measure would be either to apply antireflective coating or to remove the window altogether.

8 Test procedure

8.1 Equipment preparation

If not defined otherwise by the manufacturer, a warm-up period of 1 h shall be allowed for both the laser and the sensor device before the measurements. Operating conditions shall be chosen as specified by the manufacturer.

Tuning between the detector output signal and the data acquisition electronics shall be performed by adjusting the background level in such a way that, after blocking the beam for all positions (x,y), a background signal $E_B(x,y)>0$ [or $H_B(x,y)>0$] is registered.

In order to allow for compensation of positive and negative noise amplitudes in the computation of beam parameters (see 8.3.2), it should be checked that negative noise peaks in the signal are not clipped by the detection system.

The gain of the detector electronic readout system shall be adjusted to enable the full linear dynamic range of the measuring system to be used. Tuning of the signal height with respect to the dynamic range of the measuring system shall be performed by use of attenuators (see 7.5) and/or gain control of the detector electronics to ensure the signal-to-noise ratio is at least 100:1.

8.2 Detector calibration procedure

8.2.1 Spatial calibration

Spatial calibration shall be carried out, for example by placing an aperture or other obscuration of known size in the beam at z normal to the beam propagation direction and measuring its equivalent size as recorded on the detector. When relay optics are used to image the plane at z onto the detector surface, the size of obscuration chosen shall be such that diffraction effects in its image are effectively eliminated by the choice of resolving power of the imaging system. In arrangements that place the sensor head directly at z, the obscuration device shall be placed effectively in contact with the sensor so that edge diffraction effects are minimized.

8.2.2 Power (energy) calibration

If absolute values for the power (energy) density distribution are required, power (energy) calibration shall be achieved by first recording the uncalibrated distribution $E'(x,y)$ [or $H'(x,y)$] and then computing P', the uncalibrated total integral power density [Q', the uncalibrated total integral energy density]:

$$P' = \iint E'(x,y)\,\mathrm{d}x\mathrm{d}y \quad \text{for cw-beams} \tag{1}$$

$$Q' = \iint H'(x,y)\,\mathrm{d}x\mathrm{d}y \quad \text{for pulsed beams} \tag{2}$$

An independent measurement of the total beam power P [pulse energy Q] in the distribution is then performed according to IEC 61040 and ISO 11554 using a suitably calibrated detector. Preferably the detector should be placed at the same position z. As long as no significant loss occurs along the beam path, this detector may be instead placed elsewhere in the beam. From this measurement, an absolute calibration of the power (energy) density distribution is provided:

$$E(x,y) = \frac{P}{P'} E'(x,y) \quad \text{for cw-beams} \tag{3}$$

$$H(x,y) = \frac{Q}{Q'} H'(x,y) \quad \text{for pulsed beams} \tag{4}$$

8.3 Data recording and noise correction

8.3.1 General

After unblocking the laser beam, the measured power (energy) density distribution $E_{\mathrm{meas}}(x,y)$ [or $H_{\mathrm{meas}}(x,y)$] shall be acquired and recorded. For pulsed lasers, the power density E shall be replaced by energy density H in the text of 8.3. In the case of pulsed lasers, care shall be taken that energy is accumulated during the full pulse duration.

At least 10 independent measurements in accordance with Clauses 8 and 9 shall be made, and the values and respective standard deviations shall be calculated and given in the test report. For laser beam profiles which are temporally fluctuating, time-averaged measurements of the distribution can be made by averaging at least 10 individual recordings of $E_{\mathrm{meas}}(x,y)$ [or $H_{\mathrm{meas}}(x,y)$].

Signals recorded as $E_{\mathrm{meas}}(x,y)$ [or $H_{\mathrm{meas}}(x,y)$] can be divided into the sum of two parts: the “true” power (energy) density distribution $E(x,y)$ [or $H(x,y)$] generated by the beam under test and a possibly inhomogeneous background map $E_B(x,y)$ generated by other sources such as external or ambient radiation or by the sensor device itself:

$$E_{meas}(x,y) = E(x,y) + E_B(x,y) \qquad (5)$$

When evaluating the beam parameters defined in 3.2.1 and 3.2.2 and 3.2.7 to 3.2.12, procedures for background correction shall be applied to prevent noise in the wings of the distribution dominating the integrals (summations) involved. This correction shall be carried out by subtracting either a background map or an average background from the registered signal. For detection systems having a constant background level across the full area of the sensor, average background level subtraction correction can be used according to 8.3.3. In all other cases, the subtraction of the complete background map as given in 8.3.2 is necessary.

8.3.2 Correction by background-map subtraction

Using the identical experimental arrangement, recording of a "dark image" background map $E_B(x,y)$ shall be carried out immediately prior to the acquisition of a power (energy) density distribution "signal map". For cw-lasers, the beam shall be blocked at the position in which the beam exits the laser enclosure; for pulsed lasers, data acquisition can be performed without triggering the laser.

Using background-map subtraction, the corrected distribution is given by Formula (6):

$$E(x,y) = E_{meas}(x,y) - E_B(x,y) \qquad (6)$$

In cases where temporally fluctuating residual ambient radiation is incident on the detector, which could distort the results, measurements of background and signal map should be performed in direct succession. For pulsed lasers or cw lasers with a fast shutter, this can be achieved using consecutive acquisition cycles of the detector system in combination with 'on-line' subtraction of the background.

As a result of the background subtraction, negative noise values can exist in the corrected power (energy) density distribution. These negative values shall be included in the further evaluation in order to allow compensation for positive and negative noise amplitudes.

Subtracting a background map does not always result in a baseline offset of zero. Even small baseline offsets can create large errors in the evaluation of parameters characterizing the measured power (energy) density distribution. Care shall be taken to minimize these baseline offset errors.

8.3.3 Correction by average background subtraction

For detection systems having a constant background level across the complete area of the sensor, correction of measured distributions by average background level subtraction can be used.

An average detector background level $\bar{E}_B$ across the area of the sensor is derived by recording and averaging across the detector at least $M \geq 10$ individual measurements of the background distribution $E_B(x,y)$:

$$\bar{E}_B = \frac{1}{MN} \sum_{i=1}^{N} \sum_{j=1}^{M} E_{B_{i,j}} \qquad (7)$$

where N is the total number of individual (x,y) data recording points on the detector.

Using average background subtraction, the corrected distribution is given by Formula (8):

$$E(x,y) = E_{meas}(x,y) - \bar{E}_B \qquad (8)$$

9 Evaluation

After the measurement of power (energy) density distributions according to the provisions of Clause 7 and Clause 8 and careful background correction according to the provisions of 8.3 the background corrected power (energy) density distributions shall be used to calculate the characterizing parameters defined in 3.2.

For the choice of integration limits to determine the parameters defined in 3.2.3 and 3.2.4 the provisions of ISO 11145 and ISO 11146-1 apply.

For the determination of all clip-level based parameters the clip-level power (energy) density shall be chosen above the maximum noise peaks of the background corrected power (density) distribution.

Since all parameters defined in 3.2.3 to 3.2.7 and 3.2.9 to 3.2.12 shall be insensitive to the laser power (pulse energy) used for measuring the power (energy) density distribution, self-consistency of the detection system can be verified by changing P [Q] uniformly by constant attenuation across the xy plane at z and checking that recomputed values remain within the desired measurement uncertainty.

10 Test report

The test result shall be documented and recorded. An example for a test report is given in Annex A for information.

Annex A
(informative)

Test report

NOTE The user of this document is allowed to copy the test report.

A.1 General information

Name of test organization____

Date_______________________________ Name of tester______________________________

a) Laser details and settings at test condition

Laser type_________________________ Manufacturer ____________________________

Model______________________________ Serial number____________________________

Wavelength(s)____________________ Polarization _______________________________

☐ cw Average power output___________

☐ Pulsed Average power output___________ Pulse repetition rate_____________

Pulse energy_____________________ Pulse duration____________________

Aperture setting___________________ Other information__________________________

b) Test location

Reference plane chosen____

Laboratory system x', y', z' chosen____

Detection plane relative to reference plane____

c) Detection system

Detection method	Detector	Specific detector properties
☐ Matrix camera	☐ CCD	Wavelength response__________
☐ Variable aperture	☐ CID	Spatial resolution_______________
☐ Scanning knife-edge	☐ Si diode	Detector area_____________________
☐ Scanning pinhole	☐ Pyroelectric	Dynamic range__________________
☐ Scanning slit	☐ PbS vidicon	Signal-to-noise ratio____________
☐ Variable slit	☐ Pyroelectric vidicon	Digitizer resolution______________
☐ Other (Specify)____	☐ Thermopile	Sampling time per data point______