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Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols

Optique et photonique — Lasers et équipements associés aux lasers — Vocabulaire et symboles

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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).

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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 fifth edition cancels and replaces the fourth edition ISO 11145:2016, which has been technically revised. The main changes compared to the previous edition are as follows:

a) the term beam position has been renamed “beam centroid” and defined formally as a first-order moment;

b) the term beam ellipticity has been clarified;

c) the term beam waist location has been included;

d) the term optical resonator has been included;

e) the term 10 % pulse duration has been generalized to a selected percentage pulse duration;

f) the formula in the term beam diameter has been adjusted;

g) the order of the terms has been adjusted.

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.

Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols

1 Scope

This document defines basic terms, symbols, and units of measurement for the field of laser technology in order to unify the terminology and to arrive at clear definitions and reproducible tests of beam parameters and laser-oriented product properties.

NOTE The laser hierarchical vocabulary laid down in this document differs from that given in IEC 60825–1. ISO and IEC have discussed this difference and agree that it reflects the different purposes for which the two standards serve. For more details, see informative Annex A.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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/

NOTE 1 The spatial distribution of the power (energy) density in a cross section of a laser beam does not always have circular symmetry. In this document, all terms related to these spatial distributions are split into those for beam cross sections with circular distributions and those for beam cross sections with non-circular distributions. A circular beam is characterized by its radius, w, or diameter, d. For a non-circular beam, the beam widths, d_x and d_y, for two orthogonal directions are given.

NOTE 2 The spatial distributions of laser beams do not have sharp edges. Therefore, the power (energy) values to which the spatial terms refer are defined. Depending on the application, different cut-off values can be chosen (for example $1/e$, $1/e^2$, 1/10 of the peak value).

NOTE 3 This document uses the subscript u to denote a percentage. For example, the percentage of the total beam power (energy) included in the value of a given parameter. When stating quantities marked by an index "u", "u" is replaced by the specific number, e.g. A_{90} for u = 90 %.

NOTE 4 The beam width $d_{x,u}$ (see 3.5.1) and the beam diameter d_u (see 3.3.1) can differ for the same value of u ($d_{x,u} \neq d_u$).

NOTE 5 In contrast to quantities defined by setting a cut-off value ["encircled power (energy)"], the beam widths and derived beam properties can also be defined based on the second moments of the power (energy) density distribution function (see 3.5.2). Only beam propagation ratios (see 3.10.2) that are calculated from beam widths and divergence angles derived from the second moments of the power (energy) density distribution function allow calculation of beam propagation. In this document, quantities based on the second moment are marked by a subscript "σ".

NOTE 6 A list of symbols is given in Annex B.

3.1 Beam position

3.1.1
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: The terms beam centroid, centre of gravity and beam position are equivalent, formerly the term beam position was used.

Note 3 to entry: These quantities are defined in the beam axis system *x,y,z*, in which *z* is the direction of propagation of the beam.

3.1.2
beam positional stability
$\Delta_x(z'), \Delta_y(z')$
four times the standard deviation of the measured beam positional movement at plane z'

$$\Delta_x(z') = 4\sqrt{\frac{\sum_{i=1}^{N}\left[\bar{x}(z')_i - \overline{\bar{x}(z')}\right]^2}{N-1}}$$

$$\Delta_y(z') = 4\sqrt{\frac{\sum_{i=1}^{N}\left[\bar{y}(z')_i - \overline{\bar{y}(z')}\right]^2}{N-1}}$$

where $\bar{x}(z')$ and $\bar{y}(z')$ are the beam centroids in the z' plane, $\overline{\bar{x}(z')}$ and $\overline{\bar{y}(z')}$ are the mean beam centroids in the z' plane, and *N* is the number of measurements

Note 1 to entry: The term "beam angular stability", sometimes referred to as "beam pointing stability", is defined in ISO 11670:2003.

[SOURCE: ISO 11670:2003, 3.6, modified — The NOTE has been deleted, the text after "at plane *z*'" has been added and Note 1 to entry has been added.]

3.2 Beam axis

3.2.1
beam axis
straight line connecting the centroids defined by the first spatial moments of the cross-sectional power (energy) density distribution function at successive locations in the direction of propagation (*z*) of the beam in a homogeneous medium

3.2.2
misalignment angle
$\Delta\vartheta$
deviation angle of the beam axis from the mechanical axis defined by the manufacturer

3.3 Beam diameter

3.3.1
beam diameter
$d_u(z)$
<encircled power (energy)> diameter of a circular aperture in a plane perpendicular to the beam axis that contains u % of the total beam power (energy)

Note 1 to entry: For clarity, the term "beam diameter" is always used in combination with the symbol and its appropriate subscript: d_u or d_σ.

3.3.2
beam diameter
$d_\sigma(z)$
<second moment of power (energy) density distribution function> diameter defined by using the second moment of the power (energy) density distribution function

$$d_\sigma(z) = 2\sqrt{2}\sigma(z)$$

where the second moment of the power density distribution function $E(x, y, z)$ of the beam z is given by

$$\sigma^2(z) = \frac{\iint \left(\left(x - \bar{x}(z)\right)^2 + \left(y - \bar{y}(z)\right)^2 \right) \cdot E(x,y,z) \cdot \mathrm{d}x\,\mathrm{d}y}{\iint E(x,y,z) \cdot \mathrm{d}x\,\mathrm{d}y}$$

where the first moments give the coordinates of the beam centroid $\left[\bar{x}(z), \bar{y}(z)\right]$

Note 1 to entry: For clarity, the term "beam diameter" is always used in combination with the symbol and its appropriate subscript: d_u or d_σ.

3.4 Beam radius

3.4.1
beam radius
$w_u(z)$
<encircled power (energy)> radius of a circular aperture in a plane perpendicular to the beam axis which contains u % of the total beam power (energy)

Note 1 to entry: For clarity, the term "beam radius" is always used in combination with the symbol and its appropriate subscript: w_u or w_σ.

Note 2 to entry: The beam radius is half the beam diameter $d_u(z)$.

3.4.2
beam radius
$w_\sigma(z)$
<second moment of power (energy) density distribution function> radius defined by using the second moment of the power (energy) density distribution function

$$w_\sigma(z) = \sqrt{2}\sigma(z)$$

Note 1 to entry: For a definition of the second moment $\sigma^2(z)$, see 3.3.2.

Note 2 to entry: For clarity, the term “beam radius” is always used in combination with the symbol and its appropriate subscript: w_u or w_σ.

Note 3 to entry: The beam radius is half the beam diameter $d_\sigma(z)$.

3.5 Beam width

3.5.1
beam width
$d_{x,u}(z)$, $d_{y,u}(z)$
<slit transmitted power (energy)> width of the smallest slit aligned with the x or y transverse axes of the power (energy) density distribution function, transmitting *u* % of the total beam power (energy) along x or y

Note 1 to entry: For circular Gaussian beams, $d_{x,95,4}$ and $d_{y,95,4}$ both equal $d_{86,5}$.

Note 2 to entry: For clarity, the term “beam width” is always used in combination with the symbol and its appropriate subscripts: $d_{\sigma x}$, $d_{\sigma y}$ or $d_{x,u}$, $d_{y,u}$.

3.5.2
beam width
$d_{\sigma x}(z)$, $d_{\sigma y}(z)$
<second moment of power (energy) density distribution function> width defined by using the second moment of the power (energy) density distribution function along *x* or *y*

$$d_{\sigma x}(z) = 4\sigma_x(z)$$

$$d_{\sigma y}(z) = 4\sigma_y(z)$$

where the second moments of the power density distribution function $E(x, y, z)$ of the beam at z are given by:

$$\sigma_x^2(z) = \frac{\iint (x - \bar{x}(z))^2 \cdot E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}{\iint E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}$$

$$\sigma_y^2(z) = \frac{\iint (y - \bar{y}(z))^2 \cdot E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}{\iint E(x,y,z) \cdot \mathrm{d}x\mathrm{d}y}$$

where $(x - \bar{x}(z))$ and $(y - \bar{y}(z))$ are the distances from the current point’s coordinates to the beam centroid $(\bar{x}(z), \bar{y}(z))$

Note 1 to entry: For clarity, the term “beam width” is always used in combination with the symbol and its appropriate subscripts: $d_{\sigma x}$, $d_{\sigma y}$ or $d_{x,u}$, $d_{y,u}$.

3.6 Beam cross-sectional area

3.6.1
beam cross-sectional area
$A_u(z)$
<encircled power (energy)> smallest completely filled area containing *u* % of the total beam power (energy)

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.

3.6.2
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.

3.6.3
beam ellipticity
$\varepsilon(z)$
parameter for quantifying the circularity or squareness of a power (energy) density distribution at z

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

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: 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 13694.

3.6.4
circular power density distribution
power density distribution having an ellipticity greater than or equal to 0,87

3.7 Beam waist

3.7.1
beam waist
portion of a beam where the beam diameter or beam width has a local minimum

3.7.2
beam waist location
z_{0x}, z_{0y}, z_0
location where the beam widths or the beam diameters reach their minimum values along the beam axis

Note 1 to entry: A particular beam can have multiple beam waist locations.

3.7.3
astigmatic beam waist separation
Δz_a
axial distance between the beam waist locations in the orthogonal principal planes of a beam possessing simple astigmatism

Note 1 to entry: Astigmatic beam waist separation is also known as "astigmatic difference".

[SOURCE: ISO 15367-1:2003, 3.3.4, modified — In the term, "beam" has been added.]

3.7.4
beam waist diameter
$d_{0,u}$
<encircled power (energy)> diameter d_u of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist diameter" is always used in combination with the symbol and its appropriate subscripts: $d_{0,u}$ or $d_{\sigma 0}$.

3.7.5
beam waist diameter
$d_{\sigma 0}$
<second moment of power (energy) density distribution function> diameter d_σ of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist diameter" is always used in combination with the symbol and its appropriate subscripts: $d_{0,u}$ or $d_{\sigma 0}$.

3.7.6
beam waist radius
$w_{0,u}$
<encircled power (energy)> radius w_u of the beam at the location of the beam waist, which is half the beam waist diameter $d_{0,u}$

Note 1 to entry: For clarity, the term "beam waist radius" is always used in combination with the symbol and its appropriate subscripts: $w_{0,u}$ or $w_{\sigma 0}$.

3.7.7
beam waist radius
$w_{\sigma,0}$
<second moment of power (energy) density distribution function> radius w_σ of the beam at the location of the beam waist, which is half the beam waist diameter $d_{\sigma 0}$

Note 1 to entry: For clarity, the term "beam waist radius" is always used in combination with the symbol and its appropriate subscripts: $w_{0,u}$ or $w_{\sigma 0}$.

3.7.8
beam waist width
$d_{x0,u}$, $d_{y0,u}$
<slit transmitted power (energy)> beam width $d_{x,u}$ or $d_{y,u}$ at the location of the beam waist in the x or y direction, respectively

Note 1 to entry: For clarity, the term "beam waist width" is always used in combination with the symbol and its appropriate subscripts: $d_{x0,u}$, $d_{y0,u}$ or $d_{\sigma x0}$, $d_{\sigma y0}$.

3.7.9
beam waist width
$d_{\sigma x0}$, $d_{\sigma y0}$
<second moment of power (energy) density distribution function> beam width $d_{\sigma x}$ or $d_{\sigma y}$ at the location of the beam waist in the x or y direction, respectively

Note 1 to entry: For clarity, the term "beam waist width" is always used in combination with the symbol and its appropriate subscripts: $d_{x0,u}$, $d_{y0,u}$ or $d_{\sigma x0}$, $d_{\sigma y0}$.

3.8 Divergence

3.8.1
divergence angle

Θ_u, $\Theta_{x,u}$, $\Theta_{y,u}$

<encircled, slit transmitted power (energy)> full angle formed by the asymptotic envelope of a diverging beam that propagates with increasing beam diameter (width)

Note 1 to entry: For circular cross-sections, the divergence angle Θ_u is determined from the beam diameter d_u. For non-circular cross-sections, the divergence angles $\Theta_{x,u}$ and $\Theta_{y,u}$ are separately determined from the respective beam widths in the x- and y-directions, $d_{x,u}$ and $d_{y,u}$.

Note 2 to entry: When specifying divergence angles, subscripts are used to indicate the relevant beam diameter (width).

EXAMPLE $\Theta_{x,50}$ indicates that beam width $d_{x,50}$ has been used.

Note 3 to entry: The definition of the coordinate systems as described here as well as the beam width definitions does not include the case of general astigmatism.

Note 4 to entry: For clarity, the term “divergence angle” is always used in combination with the symbol and its appropriate subscripts: Θ_σ, $\Theta_{\sigma x}$, $\Theta_{\sigma y}$ or Θ_u, $\Theta_{x,u}$, $\Theta_{y,u}$.

3.8.2
divergence angle

Θ_σ, $\Theta_{\sigma x}$, $\Theta_{\sigma y}$

<second moment of power (energy) density distribution function> full angle formed by the asymptotic envelope of a diverging beam that propagates with increasing beam diameter (width)

Note 1 to entry: For circular cross-sections, the divergence angle Θ_σ is determined from the beam diameter d_σ. For non-circular cross-sections, the divergence angles $\Theta_{\sigma x}$ and $\Theta_{\sigma y}$ are separately determined from the respective beam widths in the x- and y-directions, $d_{\sigma x}$ and $d_{\sigma y}$.

Note 2 to entry: The definition of the coordinate systems as described here as well as the beam width definitions do not include the case of general astigmatism.

Note 3 to entry: For clarity, the term “divergence angle” is always used in combination with the symbol and its appropriate subscripts: Θ_σ, $\Theta_{\sigma x}$, $\Theta_{\sigma y}$ or Θ_u, $\Theta_{x,u}$, $\Theta_{y,u}$.

3.8.3
effective f-number

ratio of focal length of an optical component to the beam diameter d_σ of the centred beam passing through that component

3.9 Rayleigh length

3.9.1
Rayleigh length

z_R, z_{Rx}, z_{Ry}

distance from the beam waist in the direction of propagation for which the beam diameter and beam width are equal to $\sqrt{2}$ times their respective values at the beam waist

Note 1 to entry: For the Gaussian fundamental mode:

$$z_R = \left(\frac{\pi}{4}\right)\frac{d_{\sigma 0}^{\;2}}{\lambda}$$

Note 2 to entry: Generally, the formula $z_R = d_{\sigma 0} / \Theta_\sigma$ is valid.

3.9.2
far field
radiation field of a laser at a distance z from the beam waist which is much greater than the Rayleigh length z_R

3.9.3
relative astigmatic beam waist separation
Δz_r
astigmatic beam waist separation divided by the arithmetic mean of the Rayleigh lengths z_{Rx} and z_{Ry}

$$\Delta z_r = \frac{2\Delta z_a}{z_{Rx} + z_{Ry}}$$

3.10 Beam parameter product

3.10.1
beam parameter product
product of the beam waist diameter and the divergence angle divided by 4

$$d_{\sigma 0} \cdot \Theta_\sigma / 4$$

Note 1 to entry: Beam parameter products for simple astigmatic beams can be given separately for the principal axes of the power (energy) density distribution.

3.10.2
beam propagation ratio
M^2
measure of how far the beam parameter product is from that of a perfect Gaussian beam

$$M^2 = \left(\frac{\pi}{\lambda}\right) \cdot \frac{d_{\sigma 0}\Theta_\sigma}{4}$$

Note 1 to entry: This quantity is equal to the ratio of the beam parameter product of the actual laser beam to the beam parameter product of the fundamental Gaussian beam (TEM_{00}), both beams with the same wavelength.

Note 2 to entry: The beam propagation ratio is unity for a theoretically perfect Gaussian beam, and has a value greater than one for any real beam.

3.10.3
beam propagation factor
K
reciprocal of the beam propagation ratio

$$K = 1/M^2$$

3.11 Coherence

3.11.1
coherence
characteristic of a beam of electromagnetic radiation where there is a deterministic (not random) phase relationship between each pair of points in the beam

3.11.2
temporal coherence
characteristic of a beam of electromagnetic radiation to have a degree of phase correlation between different moments in time at the same spatial point in the beam

3.11.3
spatial coherence
characteristic of a beam of electromagnetic radiation to have a degree of phase correlation between different spatial points in the beam at the same moment in time

3.11.4
coherence length
l_c
distance along the beam propagation direction within which the radiation emitted by the laser retains a significant phase correlation

Note 1 to entry: It is given by $c/\Delta\nu_H$ where c is the velocity of light and $\Delta\nu_H$ is the frequency bandwidth of the emitted laser light.

3.11.5
coherence time
τ_c
time interval within which the radiation emitted by the laser retains significant phase relationship

Note 1 to entry: It is given by $1/\Delta\nu_H$, where $\Delta\nu_H$ is the frequency bandwidth of the emitted laser light.

3.12 Polarization

3.12.1
polarization
restriction of electromagnetic field oscillation to certain directions

Note 1 to entry: This is a fundamental phenomenon which can be explained by the concept that electromagnetic radiation is a transverse wave, i.e. the oscillations are orthogonal to the direction of propagation. It is customary to consider these oscillations as being those of the electric field vector.

3.12.2
circular polarization
property of electromagnetic radiation in which the electric field vector is of constant amplitude and rotates about the direction of propagation at a frequency equal to the radiation frequency, in a homogeneous optical medium

3.12.3
elliptical polarization
property of electromagnetic radiation in which the electric field vector rotates about the direction of propagation at the radiation frequency and periodically oscillates in amplitude, in a homogeneous optical medium

Note 1 to entry: The terminal point of the electric field vector describes an ellipse.

3.12.4
linear polarization
property of electromagnetic radiation in which the electric field vector oscillates along a fixed direction

Note 1 to entry: The oscillation is confined to a plane containing the direction of propagation of the radiation, in a homogeneous optical medium.

Note 2 to entry: A laser beam is called "linearly polarized" if the degree of linear polarization is greater than 0,9 and the polarization direction is constant over time.

3.12.5
degree of linear polarization
p
ratio of the difference to the sum of beam powers *P* (energies *Q*) in two orthogonal directions of polarization

$$p = \frac{P_x - P_y}{P_x + P_y} \quad \text{or} \quad p = \frac{Q_x - Q_y}{Q_x + Q_y}$$

Note 1 to entry: The directions *x* and *y* are chosen as those for which the beam power (energy) is attenuated maximally and minimally, respectively, after transmission through a linear polarizer. The direction *x* is the polarization direction.

3.12.6
partial polarization
state in which a beam of electromagnetic radiation is neither completely polarized nor completely unpolarized

Note 1 to entry: A partially polarized beam can be regarded as being composed of two components, one polarized and the other unpolarized.

Note 2 to entry: A laser beam is called "partially linearly polarized" if the degree of linear polarization is greater than 0,1 and smaller than 0,9 and the polarization direction is constant over time.

3.12.7
random polarization
state in which a beam of electromagnetic radiation is composed of two linearly polarized beams of electromagnetic radiation having orthogonal fixed polarization directions and having amplitudes that vary randomly over time with respect to each other

3.13 Power and Energy

3.13.1
average energy density
H_u, H_σ
total energy of a beam divided by its cross-sectional area A_u or A_σ

3.13.2
average power density
E_u, E_σ
total power of a beam divided by its cross-sectional area A_u or A_σ

3.13.3
pulse energy
Q
energy in one pulse

3.13.4
energy density
$H(x_P, y_P, z)$
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 $\delta A \to 0$

Note 1 to entry: Energy density is physically equivalent to radiance exposure. Both have SI units of joules per square meter (J/m^2). Energy density is generally used to describe the distribution of radiation within a beam, whereas radiance exposure is generally used to describe the distribution of radiation incident upon a surface.

Note 2 to entry: See ISO 13694:2018, 3.1.2.1.

3.13.5
continuous wave power
cw power
P
power output of a continuous wave laser

3.13.6
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 $\delta A \rightarrow 0$

Note 1 to entry: Power density is physically equivalent to irradiance. Both have SI units of watts per square meter (W/m^2). Power density is generally used to describe the distribution of radiation within a beam, whereas irradiance is generally used to describe the distribution of radiation incident upon a surface.

Note 2 to entry: See ISO 13694:2018, 3.1.1.1.

3.13.7
pulse power
P_H
ratio of the pulse energy *Q* to the pulse duration τ_H

3.13.8
average power
P_{av}
product of the average pulse energy *Q* and the pulse repetition rate f_p

3.13.9
peak power
P_{pk}
maximum of the power as a function of time for a pulse

3.14 Pulse duration and repetition rate

3.14.1
pulse duration
τ_u
time interval between the moment of *u* % peak power on the leading edge of a pulse and the moment of *u* % peak power on the trailing edge of the pulse

Note 1 to entry: τ_{10} is the time interval between the moments of 10 % peak power on the leading and trailing edges of the pulse.

3.14.2
FWHM pulse duration
full width half maximum pulse duration
τ_H
time interval between the moments of half peak power on the leading and trailing edges of a pulse

3.14.3
pulse repetition rate
f_p
number of laser pulses per second of a repetitively pulsed laser

3.15 Optical resonator

3.15.1
optical resonator
device arranged to direct electromagnetic radiation along a closed path

Note 1 to entry: An optical resonator may be in the form of a linear resonator having a standing wave beam or a ring resonator having a circulating beam.

3.15.2
stable optical resonator
optical resonator with two terminating mirrors, the paths of the paraxial rays of which remain within the resonator for an infinite number of round trips

3.15.3
unstable optical resonator
optical resonator with two terminating mirrors, the paths of the paraxial rays of which escape from the resonator after a finite number of round trips

Note 1 to entry: One axial ray stays in the optical resonator indefinitely.

3.16 Mode

3.16.1
longitudinal mode
eigenfunction of the electromagnetic field distribution within an optical resonator of length L along the direction of propagation of the electromagnetic field

Note 1 to entry: The longitudinal mode number $q = 2n(\lambda)\, L\,/\lambda$, where $n(\lambda)$ is the refractive index of the medium at the wavelength λ , describes the number of half-wavelengths in the optical resonator path length.

3.16.2
transverse mode
eigenfunction of the electromagnetic field distribution within an optical resonator or eigenfunction of the power (energy) density distribution of the laser beam perpendicular to the direction of propagation of the electromagnetic field

Note 1 to entry: For rectangular symmetry, the numbers m and n account for the nodes in the electromagnetic field distribution in the x- and y-directions, respectively, perpendicular to the direction of propagation of the electromagnetic field (Hermite-Gauss modes).

Note 2 to entry: The 01* "doughnut mode" is a linear combination of equal amounts of the rectangular 10 and 01 modes providing a circular symmetry with a node in the centre.

Note 3 to entry: For circular symmetry, p and l account for the radial and azimuthal nodes (Laguerre-Gauss modes).

3.17 Spectral bandwidth

3.17
spectral bandwidth
$\Delta\lambda$, $\Delta\nu$
maximum difference between the wavelengths (optical frequencies) for which the spectral power (energy) density is half of its peak value

3.18 Relative intensity noise

3.18
relative intensity noise
RIN
$R(f)$
ratio of the mean square radiant power fluctuations to the mean square radiant power, normalized to a frequency band of unit width, for a radiant power $P(f)$ as a function of frequency f

$$R(f) = \frac{\langle \Delta P(f)^2 \rangle}{\langle P(f)^2 \rangle} \frac{1}{\Delta f}$$

Note 1 to entry: The relative intensity noise $R(f)$ or RIN as defined above is strictly the "relative intensity noise spectral density", but usually simply referred to as RIN.

3.19 Laser

3.19.1
laser
device having an energized amplifying medium within an optical resonator that generates coherent electromagnetic radiation with wavelengths up to 1 mm by means of amplified stimulated emission

Note 1 to entry: See Figure 1 and Annex A.

Note 2 to entry: The term "laser" is an acronym for "light amplification by stimulated emission of radiation", which is a physical phenomenon for amplifying or generating coherent radiation (laser radiation).

3.19.2
continuous wave laser
cw laser
laser continuously emitting radiation over periods of time greater than or equal to 0,25 s

Note 1 to entry: This definition is consistent with the definition of "continuous wave" in IEC 60825-1 "Safety of laser products – Equipment classification, requirements, and user guide".

3.19.3
pulsed laser
laser which emits radiation in the form of a single pulse or a train of pulses where the duration of a pulse is less than 0,25 s

3.19.4
laser radiation
spatially and temporally coherent electromagnetic radiation with wavelengths up to 1 mm, generated by a laser

3.19.5
laser beam
spatially directed laser radiation

3.19.6
laser device
apparatus including the laser together with essential additional facilities (e.g. cooling supply, power supply and gas supply)

Note 1 to entry: See Figure 1 and Annex A.

3.19.7
laser assembly
laser device together with specific optical, mechanical and/or electrical components for beam guiding and beam shaping

Note 1 to entry: See Figure 1 and Annex A.

3.19.8
laser unit
one or more laser assemblies together with handling units, measurement systems and control systems

Note 1 to entry: See Figure 1 and Annex A.

3.19.9
lifetime
interval (time or number of pulses) over which a laser device or a laser assembly maintains the performance characteristics specified by the manufacturer

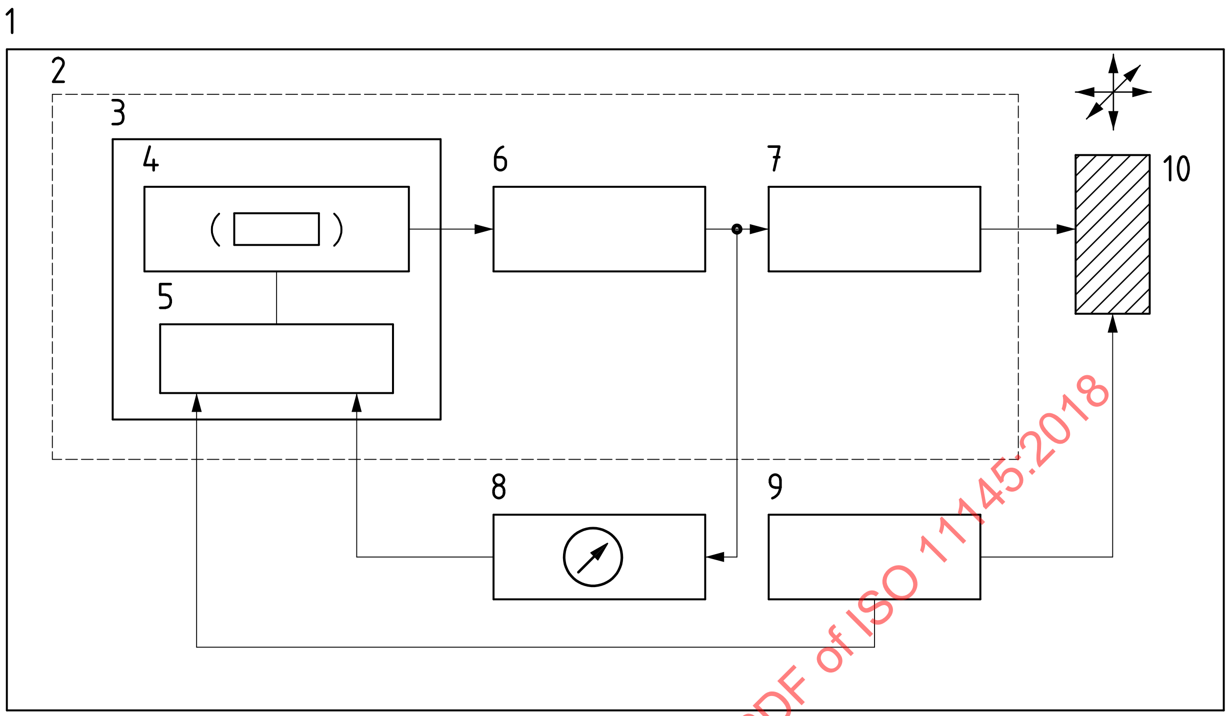
Note 1 to entry: Conditions of use, service and maintenance are specified by the manufacturer.

3.20 Efficiency

3.20.1
laser efficiency
η_L
ratio of the total power (energy) in the laser beam to the total pump power (energy) that is directly supplied to the laser

3.20.2
quantum efficiency
η_Q
ratio of the energy of a single laser photon to the energy of a single pumping photon which causes the population inversion in an optically pumped laser

3.20.3
device efficiency
η_T
ratio of the total power (energy) in the transmitted beam to the total power (energy) directed into a beam-guiding device or a beam-shaping device



Key

1 laser unit
2 laser assembly
3 laser device
4 laser
5 supply (power, cooling, gas)
6 beam-guiding device (mirrors, fibres, lenses)
7 beam-shaping device (telescope, focusing)
8 measurement systems and control systems
9 handling units (robot, workpiece translation and location)
10 workpiece

NOTE 1 This example is taken from materials processing.

NOTE 2 The safety equipment that is usually required is not included here.

NOTE 3 See Annex A.

Figure 1 — Illustration of the terms laser, laser device, laser assembly and laser unit

4 Symbols and units of measurement

Table 1 lists symbols and units which are defined in detail in Clause 3.

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
A_u or A_σ	m^2	Beam cross-sectional area
d_u or d_σ	m	Beam diameter
$d_{x,u}$ or $d_{\sigma x}$	m	Beam width in x-direction
$d_{y,u}$ or $d_{\sigma y}$	m	Beam width in y-direction
$d_{0,u}$ or $d_{\sigma 0}$	m	Beam waist diameter
$d_{\sigma 0} \cdot \Theta_\sigma / 4$	m·rad	Beam parameter product
E_u or E_σ	W/m^2	Average power density
$E(x_P, y_P, z)$	W/m^2	Power density
f_P	Hz	Pulse repetition rate

Table 1 *(continued)*

Symbol	Unit	Term
H_u or H_σ	J/m^2	Average energy density
$H(x_P, y_P, z)$	J/m^2	Energy density
K	1	Beam propagation factor
l_c	m	Coherence length
M^2	1	Beam propagation ratio
p	1	Degree of linear polarization
P	W	cw-power
P_{av}	W	Average power
P_H	W	Pulse power
P_{pk}	W	Peak power
Q	J	Pulse energy
$R(f)$	Hz^{-1} or dB/Hz	Relative intensity noise, RIN
w_u or w_σ	m	Beam radius
$w_{0,u}$ or $w_{\sigma 0}$	m	Beam waist radius
z_R	m	Rayleigh length
$\Delta\vartheta$	rad	Misalignment angle
$\Delta\lambda$	m	Spectral bandwidth in terms of wave-length
$\Delta\nu$	Hz	Spectral bandwidth in terms of optical frequency
$\Delta_x(z')$	m	Beam positional stability in x-direction
$\Delta_y(z')$	m	Beam positional stability in y-direction
Δz_a	m	Astigmatic beam waist separation
Δz_r	1	Relative astigmatic beam waist separation
ε	1	beam ellipticity
η_L	1	Laser efficiency
η_Q	1	Quantum efficiency
η_T	1	Device efficiency
Θ_u or Θ_σ	rad	Divergence angle
$\Theta_{x,u}$ or $\Theta_{\sigma x}$	rad	Divergence angle for x-direction
$\Theta_{y,u}$ or $\Theta_{\sigma y}$	rad	Divergence angle for y-direction
λ	m	Wavelength
τ_H	s	FWHM pulse duration
τ_u	s	Pulse duration
τ_c	s	Coherence time

NOTE R(f) expressed in dB/Hz equals 10 $\log_{10}$ R(f) with R(f) given in Hz^{-1}.

