भारतीय मानक
Indian Standard

IS 14820 (Part 1) : 2024
ISO 11146-1 : 2021

लेज़र और लेज़र संबंधित उपकरण — लेज़र बीम की चौड़ाई, अपसारण कोणों और बीम प्रेषण अनुपात — परीक्षण पद्धतियाँ

भाग 1 बिन्दुक और साधारण अबिन्दुक बीम

(दूसरा पुनरीक्षण)

Lasers and Laser-Related Equipment — Laser Beam Widths, Divergence Angles and Beam Propagation Ratios — Methods of Test

Part 1 Stigmatic and Simple Astigmatic Beams

(Second Revision)

ICS 31.260

© BIS 2024
© ISO 2021

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

September 2024 **Price Group 9**

Optics and Photonics Sectional Committee, PGD 39

NATIONAL FOREWORD

This Indian Standard (Part 1) (Second Revision) which is identical to ISO 11146 – 1 : 2021 'Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and Beam propagation ratios — Part 1: Stigmatic and Simple Astigmatic Beams' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Optics and Photonics Sectional Committee and approval of the Production and General Engineering Division Council.

This standard was first published as 2000 and was subsequently revised in 2016. The first revision was based on ISO 11146-1 : 2005. This revision has been brought out to align it with the latest version of ISO 11146-1 : 2021. The major changes in this revision are as follows:

a) The terms and definitions have been harmonized with the IS/ISO 11145 : 2018;

b) The 'principal axes' have been defined more thoroughly and named as x' and y'; and

c) The requirements for the integration range for the determination of the second order moments have been relaxed.

This standard has been published in three parts. The other parts in the series are:

Part 2 General astigmatic beams

Part 3 Intrinsic and geometrical laser beam classification, propagation and details of test methods

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated.

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 11145 Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols	IS/ISO 11145 : 2018 Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols (*first revision*)	Identical
ISO 11146-2 Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 2 : General astigmatic beams	IS 14820 (Part 2) : 2024/ISO 11146-2 : 2021 Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios: Part 2 General astigmatic beams (*first revision*)	Identical

(*Continued on third cover*)

Contents

Page

Introduction ..... **iv**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 Coordinate systems **7**

5 Test principles **7**
- 5.1 Applicability 7
- 5.2 Beam widths and beam diameter 7
- 5.3 Beam divergence angles 8
- 5.4 Beam propagation ratios 8
- 5.5 Combined measurement of beam waist locations, beam widths, beam divergence angles and beam propagation ratios 8

6 Measurement arrangement and test equipment **8**
- 6.1 General 8
- 6.2 Preparation 8
- 6.3 Control of environment 9
- 6.4 Detector system 9
- 6.5 Beam-forming optics and optical attenuators 9
- 6.6 Focusing system 10

7 Beam widths and beam diameter measurement **10**
- 7.1 Test procedure 10
- 7.2 Evaluation 10

8 Measurement of divergence angles **12**
- 8.1 Test procedure 12
- 8.2 Evaluation 12

9 Combined determination of beam waist locations, beam widths, divergence angles and beam propagation ratios **12**

10 Test report **14**

Bibliography **17**

Introduction

The propagation properties of every laser beam can be characterized within the method of second order moments by ten independent parameters (see ISO/TR 11146-3). However, due to their higher symmetry most laser beams of practical interest need fewer parameters for a complete description. Most lasers of practical use emit beams which are stigmatic or simple astigmatic because of their resonator design.

This document describes the measurement methods for stigmatic and simple astigmatic beams while ISO 11146-2 deals with the measurement procedures for general astigmatic beams. For beams of unknown type the methods of ISO 11146-2 are applicable. Beam characterization based on the method of second order moments as described in both parts is only valid within the paraxial approximation.

The theoretical description of beam characterization and propagation as well as the classification of laser beams is given in ISO/TR 11146-3, which is a Technical Report and describes the procedures for background subtraction and offset correction.

In this document, the second order moments of the power (energy) density distribution are used for the determination of beam widths. However, there may be problems experienced in the direct measurement of these quantities in the beams from some laser sources. In this case, other indirect methods of the measurement of the second order moments may be used as long as comparable results are achievable.

In ISO/TR 11146-3, three alternative methods for beam width measurement and their correlation with the method used in this document are described. These methods are:

— variable aperture method;

— moving knife-edge method;

— moving slit method.

Indian Standard

LASERS AND LASER-RELATED EQUIPMENT — TEST METHODS FOR LASER BEAM WIDTHS, DIVERGENCE ANGLES AND BEAM PROPAGATION RATIOS

PART 1 STIGMATIC AND SIMPLE ASTIGMATIC BEAMS

(Second Revision)

1 Scope

This document specifies methods for measuring beam widths (diameter), divergence angles and beam propagation ratios of laser beams. This document is only applicable for stigmatic and simple astigmatic beams. If the type of the beam is unknown, and for general astigmatic beams, ISO 11146-2 is applicable.

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 — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 11146-2, *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 2: General astigmatic beams*

ISO 13694, *Optics and photonics — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution*

EN 61040:1992, *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, ISO 13694, EN 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 https://www.iso.org/obp

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

NOTE The x-, y- and z-axes in these definitions refer to the laboratory system as described in Clause 4. Here and throughout this document the term “power density distribution $E(x,y,z)$” refers to continuous wave sources. It might be replaced by “energy density distribution, $H(x,y,z)$” in case of pulsed sources.

3.1
first order moments of a power density distribution
$\bar{x}, \bar{y}$
centroid coordinates of the power density distribution of a cross section of a beam given as

$$\bar{x}(z)=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E\,(x, y, z)\, x \,\mathrm{d}x\, \mathrm{d}y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E\,(x, y, z)\,\mathrm{d}x\, \mathrm{d}y} \tag{1}$$

and

$$\bar{y}(z)=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E\,(x, y, z)\, y \,\mathrm{d}x\, \mathrm{d}y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E\,(x, y, z)\,\mathrm{d}x\, \mathrm{d}y} \tag{2}$$

Note 1 to entry: The first order moments are used for the definition of beam centroid in ISO 11145.

Note 2 to entry: For practical application, the infinite integration limits are reduced in a specific manner as given in Clause 7. The limitation of the integration area here differs from the integration area given in ISO 11145.

3.2
second order moments of a power density distribution
$\sigma_x^2, \sigma_y^2, \sigma_{xy}^2$
normalized weighted integrals over the power density distribution, given as:

$$\sigma_x^2(z)=\langle x^2\rangle=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\left[x-\bar{x}(z)\right]^2 \mathrm{d}x\, \mathrm{d}y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\,\mathrm{d}x\, \mathrm{d}y} \tag{3}$$

and

$$\sigma_y^2(z)=\langle y^2\rangle=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\left[y-\bar{y}(z)\right]^2 \mathrm{d}x\, \mathrm{d}y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\,\mathrm{d}x\, \mathrm{d}y} \tag{4}$$

and

$$\sigma_{xy}^2(z)=\langle xy\rangle=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\left[x-\bar{x}(z)\right]\left[y-\bar{y}(z)\right] \mathrm{d}x\, \mathrm{d}y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x, y, z)\,\mathrm{d}x\, \mathrm{d}y} \tag{5}$$

Note 1 to entry: For practical application, the infinite integration limits are reduced in a specific manner as given in Clause 7.

Note 2 to entry: $\sigma_{xy}^2(z)$ is a symbolic notation, and not a true square. This quantity can take positive, negative or zero value.

Note 3 to entry: The angular brackets are the operator notations as used in ISO 11146-2 and ISO/TR 11146-3.

3.3
principal axes
x’, y’
<power density distribution> axes of the maximum and minimum beam extent based on the second order moments of the power density distribution in a cross section of the beam

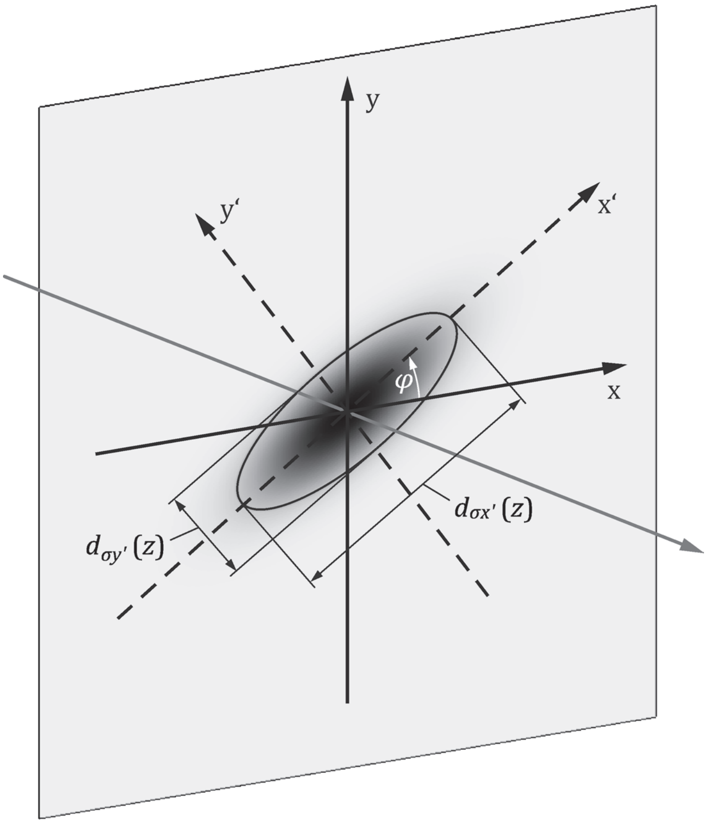


Figure 1 — Beam profile with the laboratory and principle axes coordinate systems

Note 1 to entry: The axes of maximum and minimum extent are always perpendicular to each other.

Note 2 to entry: Unless otherwise stated, in this document x’ is the principal axis which is closer to the x-axis of the laboratory coordinate system, and y’ is the principal axis which is closer to the y-axis of the laboratory coordinate system.

Note 3 to entry: If the principal axes make the angle π/4 with the x- and y-axes of the laboratory coordinate system, then the x’-axis is by convention the direction of maximum extent.

Note 4 to entry: See Figure 1.

3.4
azimuthal orientation
φ
<power density distribution> azimuthal angle between the x-axis of the laboratory system and the principal axis x’

3.5
beam widths
$d_{\sigma x'}(z_{0x'})$, $d_{\sigma y'}(z_{0y'})$
extent of a power density distribution in a cross-section of the beam at an axial location z along the principal axes x' and y', respectively, based on the second order moments of the power density distribution

Note 1 to entry: This definition differs from that given in ISO 11145:2018, 3.5.2, where the beam widths are defined only in the laboratory system, whereas for the purposes of this document the beam widths are defined in the *principal axes* (3.3) system of the beam.

Note 2 to entry: Formulae for calculation of the beam widths from the three second order moments are given in 7.2.

3.6
beam ellipticity
$\varepsilon(z)$
parameter for quantifying the circularity or squareness of a power (energy) density distribution at an axial location z

$$\varepsilon(z)=\frac{\min\left[d_{\sigma x'}(z),\, d_{\sigma y'}(z)\right]}{\max\left[d_{\sigma x'}(z),\, d_{\sigma y'}(z)\right]}$$

Note 1 to entry: It follows that $0<\varepsilon(z)\leq 1$.

Note 2 to entry: If $\varepsilon(z) \geq 0{,}87$, elliptical distributions can be regarded as circular.

Note 3 to entry: In case of a rectangular distribution, ellipticity is often referred to as “aspect ratio”.

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 11145 and ISO 13694.

3.7
circular power density distribution
power density distribution having an ellipticity greater than or equal to 0,87

[SOURCE: ISO 11145:2018, 3.6.4]

3.8
beam diameter
$d_\sigma(z)$
extent of a circular power density distribution in a cross section of the beam at an axial location z, based on the second order moments

Note 1 to entry: Formulae for calculation of the beam diameter from the second order moments are given in 7.2.

3.9
stigmatism
property of a beam having circular power density distributions in any plane under free propagation and showing power density distributions after propagation through a cylindrical lens all having the same *azimuthal orientation* (3.4) as that lens

3.10
simple astigmatism
property of a non-stigmatic beam whose *azimuthal orientation* (3.4) is constant under free propagation, and which retains its original *azimuthal orientation* (3.4) after passing through a cylindrical optical element whose cylindrical axis is parallel to one of the *principal axes* (3.3) of the beam

Note 1 to entry: The *principal axes* (3.3) of a power density distribution corresponding to a beam with *simple astigmatism* (3.10) are called the *principal axes* (3.3) of that beam.

3.11
general astigmatism
property of a beam which is neither stigmatic nor simple astigmatic

Note 1 to entry: This document deals only with stigmatic and simple astigmatic beams. See ISO 11146-2 for general astigmatic beams.

3.12
beam waist locations
$z_{0x'}$, $z_{0y'}$, z_0
<simple astigmatic beams, stigmatic beams> location where the *beam widths* (3.5) or the *beam diameters* (3.8) reach their minimum values along the beam axis

Note 1 to entry: See Figure 2.

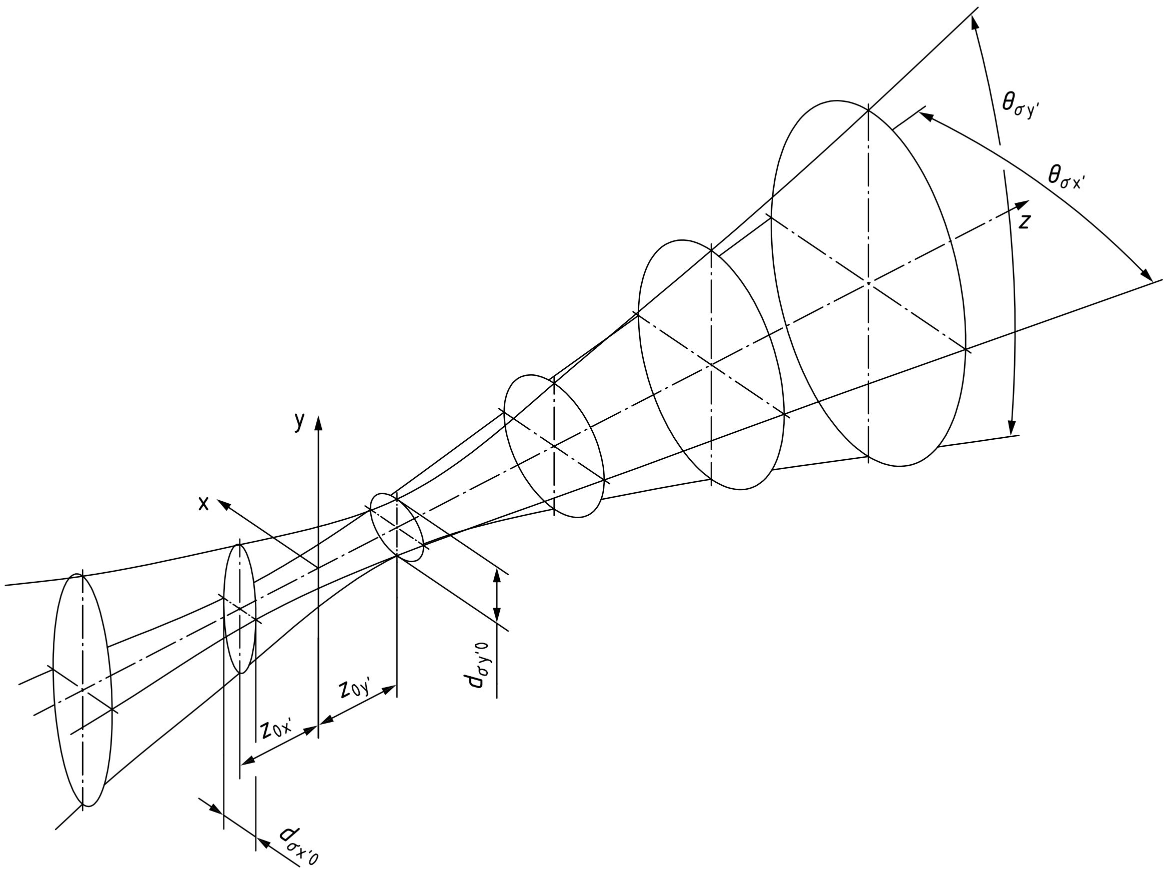


Figure 2 — Beam propagation parameters of a simple astigmatic beam

Note 2 to entry: In the case of general astigmatic beams, which are outside the scope of this document, this definition does not apply, see ISO 11146-2.

Note 3 to entry: For simple astigmatic beams the waist locations $z_{0x'}$ and $z_{0y'}$ corresponding to the *principal axes* (3.3), may or may not coincide.

Note 4 to entry: For simple astigmatic beams, the beam widths are used; for stigmatic beams the beam diameters are used.

3.13
beam waist widths
$d_{\sigma x'0}, d_{\sigma y'0}$
<simple astigmatic beams> beam width $d_{\sigma x'}(z_{0x'})$ and $d_{\sigma y'}(z_{0y'})$, respectively, at the corresponding beam waist locations $z_{0x'}$ or $z_{0y'}$, respectively

3.14
beam waist diameter
$d_{\sigma 0}$
<stigmatic beams> diameter $d_\sigma(z_0)$ of the beam at the location of the beam waist z_0

3.15
beam divergence angles
$\Theta_{\sigma x'}, \Theta_{\sigma y'}, \Theta_\sigma$
measure for the increase of the *beam widths* (3.5) or *beam diameter* (3.8) with increasing distance from the *beam waist locations* (3.12), given by

$$\Theta_{\sigma x'} = \lim_{(z-z_{0x'})\to\infty} \frac{d_{\sigma x'}(z)}{z-z_{0x'}} \tag{6}$$

and

$$\Theta_{\sigma y'} = \lim_{(z-z_{0y'})\to\infty} \frac{d_{\sigma y'}(z)}{z-z_{0y'}} \tag{7}$$

for simple astigmatic beams and

$$\Theta_\sigma = \lim_{(z-z_0)\to\infty} \frac{d_\sigma(z)}{z-z_0} \tag{8}$$

for stigmatic beams

Note 1 to entry: The beam divergence is expressed as a full angle.

Note 2 to entry: This definition differs from that given in ISO 11145:2018, 3.8.2, where the beam divergence angles are defined only in the laboratory system, whereas for the purposes of this document the beam divergence angles are defined in the *principal axes* (3.3) system.

3.16
Rayleigh length
$z_R, z_{Rx'}, z_{Ry'}$
<simple astigmatic beams, stigmatic beams>distance in the direction of propagation from the respective beam waist for which the *beam diameter* (3.8) or the *beam width* (3.5) 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 $z_R = \frac{d_{\sigma 0}}{\Theta_\sigma}$ is valid.

[SOURCE: ISO 11145: 2018, 3.9.1]

3.17
beam propagation ratios

Note 1 to entry: The term "beam propagation ratio" replaces "times-diffraction-limit factor" which was used in ISO 11146:1999.

Note 2 to entry: Beam propagation ratios, as defined in 3.17.1 and 3.17.2, are propagation invariants for stigmatic and simple astigmatic beams, only as long as the optics involved do not change the stigmatic or the simple astigmatic character of the beam.

3.17.1
beam propagation ratios
$M_{x'}^2$ and $M_{y'}^2$

⟨simple astigmatic beams⟩ ratios of the beam parameter product along the *principal axes* (3.3) of the beam of interest to the beam parameter product of a diffraction-limited, perfect Gaussian beam of the same wavelength λ

$$M_{x'}^2 = \frac{\pi}{\lambda} \frac{d_{\sigma x' 0} \Theta_{\sigma x'}}{4} \tag{9}$$

$$M_{y'}^2 = \frac{\pi}{\lambda} \frac{d_{\sigma y' 0} \Theta_{\sigma y'}}{4} \tag{10}$$

3.17.2
beam propagation ratio
M^2

⟨stigmatic beams⟩ ratio of the beam parameter product of the beam of interest to the beam parameter product of a diffraction-limited, perfect Gaussian beam (TEM_{00}) of the same wavelength, λ

$$M^2 = \frac{\pi}{\lambda} \frac{d_{\sigma 0} \Theta_{\sigma}}{4} \tag{11}$$

4 Coordinate systems

The x-, y- and z-axes define the orthogonal space directions in the laboratory axes system and shall be specified by the user. The z-axis shall coincide approximately with the direction of the beam. The x- and y-axes are transverse axes, usually horizontal and vertical, respectively. The origin of the z-axis is in a reference x-y plane defined by the manufacturer, e.g. the front of the laser enclosure.

5 Test principles

5.1 Applicability

The following test principles are only valid for stigmatic and simple astigmatic beams. For general astigmatic beams ISO 11146-2 shall be applied.

5.2 Beam widths and beam diameter

For the determination of beam widths or diameter at location z, the power density distribution of the laser beam shall be measured in the x-y plane at this location z. Suitable background correction shall be applied to the measured data if necessary (see ISO/TR 11146-3). From the measured power density distribution the first order moments and second order moments are calculated. From the second order moments the beam widths, $d_{\sigma x'}(z)$, $d_{\sigma y'}(z)$, the beam ellipticity, $\varepsilon(z)$, and, if appropriate, the beam diameter, $d_{\sigma}(z)$, shall be determined.

5.3 Beam divergence angles

The determination of the divergence angles of the freely propagating beam follows from measurements of the beam widths or the beam diameter in the focal plane of a focusing element.

First, the laser beam shall be transformed by an aberration-free focusing element. For a simple astigmatic beam, the beam widths $d_{\sigma x'f}$ and $d_{\sigma y'f}$ are measured one focal length, *f*, away from the rear principal plane of the focusing element. The corresponding divergence angles $\Theta_{\sigma x'}$ and $\Theta_{\sigma y'}$ are determined using the relationships given in Formulae (12) and (13):

$$\Theta_{\sigma x'} = \frac{d_{\sigma x'f}}{f} \tag{12}$$

and

$$\Theta_{\sigma y'} = \frac{d_{\sigma y'f}}{f} \tag{13}$$

For stigmatic beams, the beam diameter $d_{\sigma f}$ is measured and the divergence angle Θ_σ is determined by using Formula (14):

$$\Theta_\sigma = \frac{d_{\sigma f}}{f} \tag{14}$$

NOTE This procedure provides the divergence angle of the freely propagating beam. The focusing element is introduced to allow the measurement of the divergence angle that the beam has before passing this element.

5.4 Beam propagation ratios

For the determination of the beam propagation ratios $M_{x'}^2$, $M_{y'}^2$ or M^2, it is necessary to determine the beam waist widths $d_{\sigma x'0}$, $d_{\sigma y'0}$ or the waist diameter $d_{\sigma 0}$ and the related beam divergence angles $\Theta_{\sigma x'}$, $\Theta_{\sigma y'}$ or Θ_σ.

5.5 Combined measurement of beam waist locations, beam widths, beam divergence angles and beam propagation ratios

The beam widths data along the propagation axis shall be fitted to a hyperbola as discussed in Clause 9. The beam waist locations, beam waist widths, beam divergence angles and beam propagation ratios are derived from the fit parameters.

6 Measurement arrangement and test equipment

6.1 General

The test is based on the measurement of the cross-sectional power density distribution at a number of axial locations along the beam propagation axis.

6.2 Preparation

The optical axis of the measuring system should be coaxial with the laser beam to be measured. Suitable optical alignment devices are available for this purpose (e.g. aligning lasers or steering mirrors).

The aperture of the optical system should accommodate the entire cross-section of the laser beam. Losses by clipping shall be smaller than 1 % of the total beam power or energy. In order to test this, apertures of different widths can be introduced into the beam path in front of each optical component.

The aperture which reduces the output signal by 5 % should have a diameter less than 0,8 times the aperture of the optical component.

The attenuators or beam-forming optics should be mounted such that the optical axis runs through the geometrical centres. Care shall be taken to avoid systematic errors. Reflections, interference effects, external ambient light, thermal radiation or air draughts are all potential sources of increased uncertainty.

6.3 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 uncertainty of the parameters to be measured is low.

Care should be taken to ensure that the atmospheric environment in high-power laser beam paths does not contain gases or vapours that can absorb the laser radiation and cause thermal distortion in the beam to be measured.

6.4 Detector system

Measurement of the cross-sectional power density distribution requires the use of a detection system with high spatial resolution and high signal-to-noise ratio.

The accuracy of the measurement is directly related to the spatial resolution of the detector system and its signal-to-noise ratio. The latter is important for laser beams with low power densities at larger diameters (e.g. for diffracted parts of the laser beams).

For pixel based detector systems, the spatial resolution should be at least 1/20 of the beam width or beam diameter.

In practice, noise in the wings of the power density distribution $E(x,y,z)$ may readily dominate the second order moment integral. Thus, it is usually necessary to apply background correction procedures. See ISO/TR 11146-3 for further details.

The radiation detector system shall be in accordance with EN 61040:1992, Clauses 3 and 4 in particular. Furthermore, the following points shall be noted.

— Care shall be taken to ascertain the damage thresholds of the detector surface so that they are not exceeded by the laser beam.

— It shall be confirmed, from manufacturers' data or by measurement, that the output quantity of the detector system (e.g. the voltage) is linearly dependent on the input quantity (laser power). Any wavelength dependency, non-linearity or non-uniformity of the detector or the electronic device shall be minimized or corrected by use of a calibration procedure.

— When using a scanning device for determining the power density distribution, care shall be taken to ensure that the laser output is spatially and temporally stable during the whole scanning period.

— When measuring pulsed laser beams, the trigger time delay of sampling as well as the measuring time interval play an important role because the beam parameters may change during the pulse. Therefore, it is necessary to specify these parameters in the test report.

6.5 Beam-forming optics and optical attenuators

If the beam cross-sectional area is greater than the detector area, a suitable optical system shall be used to reduce the beam cross-sectional area on the detector surface. The change in magnification shall be taken into account during the evaluation procedure.

Optics shall be selected appropriate to wavelength.

An attenuator may be required to reduce the laser power density on the surface of the detector.

Optical attenuators shall be used when the laser output-power or power density exceeds the detector's working (linear) range or the damage threshold. Any wavelength, polarization and angular dependency, non-linearity or non-uniformity, including thermal effects 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 density distribution.

6.6 Focusing system

The focusing system shall conform to the requirements relating to the beam-forming optics given in 6.5. The total uncertainty contributed by the focusing system shall be less than 1 % of the beam width.

7 Beam widths and beam diameter measurement

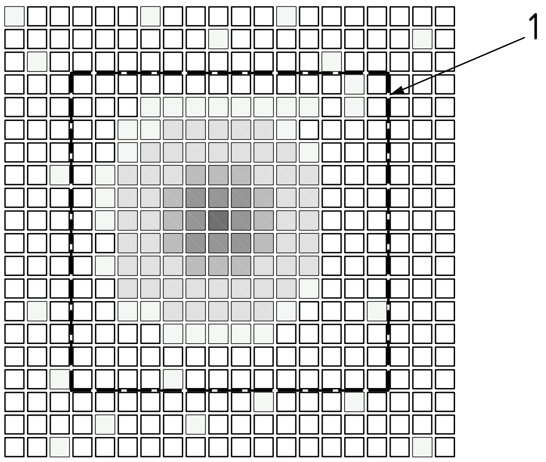
7.1 Test procedure

Before the measurements are started, the laser shall be warmed up to achieve thermal equilibrium. This would be the time stated by the manufacturer or otherwise for at least 1 h. The measurements shall be carried out at the operating conditions specified by the laser manufacturer for the type of laser being evaluated. Multiple measurements may be averaged in order to reduce the statistical error.

7.2 Evaluation

Before evaluating beam widths or beam diameters, background correction procedures shall be applied to the measured distribution (see ISO/TR 11146-3).

The first-order moments and second-order moments are calculated from the measured and corrected distributions. The corresponding integrations are carried out on a subset of the measured data, called the integration area (see Figure 3), because otherwise noise in the data may dominate the integrals. In many cases a proper choice of the integration area is crucial for reliable results. The following procedure relates the size and position of the integration area to the size and position of the measured power density distribution, which are initially unknown. Hence, an iterative procedure follows.



Key

1 outline of integration area

Figure 3 — Detection array with schematic representation of the laser beam and the integration area

All integrations in Formulae (1) to (5) are performed on an integration area which is centered to the beam centroid, defined as the first-order moments, and sized three times the beam widths in the x and y directions. Since the beam centroid coordinates and beam widths are as yet unknown, the procedure starts with an initial guess of the integration area. This initial integration area should approximate the beam extent and position. Using this integration area, initial values for the beam position and size are obtained which are used to recalculate the integration area. From the new integration area new values for the beam position and size are calculated. This procedure shall be repeated until the convergence of the result is obtained.

In particular situations the ideal integration area may differ. In any case, the amplitude of the beam should have fallen below the detection limit within the integration range.

For a simple astigmatic beam the azimuthal orientation of its principal axes φ, can be obtained from the second-order moments of the power density distribution by Formula (15):

$$\varphi(z)=\frac{1}{2}\arctan\left(\frac{2\sigma_{xy}^2}{\sigma_x^2-\sigma_y^2}\right) \tag{15}$$

for $\sigma_x^2 \neq \sigma_y^2$. Otherwise, the azimuthal orientation φ is obtained by Formula (16):

$$\varphi=\mathrm{sgn}(\sigma_{xy}^2)\frac{\pi}{4} \tag{16}$$

where

$$\mathrm{sgn}(\sigma_{xy}^2)=\frac{\sigma_{xy}^2}{\left|\sigma_{xy}^2\right|} \tag{17}$$

The beam widths in the direction of its principal axes are given by Formulae (18) and (19):

$$d_{\sigma x'}(z)=2\sqrt{2}\left\{\left(\sigma_x^2+\sigma_y^2\right)+\gamma\left[\left(\sigma_x^2-\sigma_y^2\right)^2+4\left(\sigma_{xy}^2\right)^2\right]^{\frac{1}{2}}\right\}^{\frac{1}{2}} \tag{18}$$

$$d_{\sigma y'}(z)=2\sqrt{2}\left\{\left(\sigma_x^2+\sigma_y^2\right)-\gamma\left[\left(\sigma_x^2-\sigma_y^2\right)^2+4\left(\sigma_{xy}^2\right)^2\right]^{\frac{1}{2}}\right\}^{\frac{1}{2}} \tag{19}$$

where

$$\gamma=\mathrm{sgn}\left(\sigma_x^2-\sigma_y^2\right)=\frac{\sigma_x^2-\sigma_y^2}{\left|\sigma_x^2-\sigma_y^2\right|} \tag{20}$$

for $\sigma_x^2 \neq \sigma_y^2$. Otherwise the beam widths are given by Formulae (21) and (22):

$$d_{\sigma x'}(z)=2\sqrt{2}(\sigma_x^2+\sigma_y^2+2\left|\sigma_{xy}^2\right|)^{½} \tag{21}$$

$$d_{\sigma y'}(z)=2\sqrt{2}(\sigma_x^2+\sigma_y^2-2\left|\sigma_{xy}^2\right|)^{½} \tag{22}$$

Perform these calculations for each measurement and calculate the mean values and the standard deviations for the beam widths and the azimuthal orientation.

If the beam ellipticity, $\varepsilon(z)$, is larger than 0,87, the beam profile may be considered to be of circular symmetry at that measuring location and the beam diameter can be obtained from Formula (23):

$$d_\sigma(z)=2\sqrt{2}\left(\sigma_x^2+\sigma_y^2\right)^{\frac{1}{2}} \tag{23}$$

8 Measurement of divergence angles

8.1 Test procedure

Locate the focusing element in the beam path in such a way that its optical axis is coaxial with the laser beam to be measured.

Locate the measuring plane of the detector system one focal length, *f*, away from the rear principal plane of the focusing element.

NOTE In general, this location is not identical with the waist location behind the focusing element.

Multiple measurements may be averaged in order to reduce the statistical error.

8.2 Evaluation

Calculate the divergence angle(s) of the unfocused beam according to the formulae given in 5.3 for each measurement and calculate the mean value(s) and the standard deviation(s) for the divergence angle(s).

9 Combined determination of beam waist locations, beam widths, divergence angles and beam propagation ratios

If the beam waist is accessible for direct measurement, the beam waist location, beam widths, divergence angles and beam propagation ratios shall be determined by a hyperbolic fit to different measurements of the beam width along the propagation axis *z*. Hence, measurements at at least 10 different *z* positions shall be taken. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the beam waist, and approximately half of them shall be distributed beyond two Rayleigh lengths from the beam waist. For simple astigmatic beams this procedure shall be applied separately for both principal directions.

A preliminary test for general astigmatism shall be applied to the measured data. For each measured profile, the beam widths $d_{\sigma x'}$ and $d_{\sigma y'}$ and the azimuthal orientation, φ shall be calculated. If the difference in the azimuthal orientation of any two non-circular profiles is greater than 10° the beam shall be considered as general astigmatic and ISO 11146-2 shall be applied.

NOTE 1 Failure of this test is not proof of stigmatism or simple astigmatism. The beam can suffer from hidden general astigmatism, which can be detected by the procedures given in ISO 11146-2.

The hyperbolic fit to the measured diameters, d_σ along the propagation distance, *z*, can be expressed in the following way, as given by Formula (24):

$$d_\sigma(z) = \sqrt{a+bz+cz^2} \tag{24}$$

The coefficients *a*, *b*, *c* (or $a_{x'}$, $a_{y'}$, $b_{x'}$, $b_{y'}$, $c_{x'}$, $c_{y'}$) of the hyperbola(e) shall be determined by appropriate numerical or statistical curve-fitting techniques (see Notes 2 and 3). The values of the beam propagation parameters can be obtained using Formulae (25) to (29):

$$z_0=\frac{-b}{2c} \tag{25}$$

$$d_{\sigma 0} = \frac{1}{2\sqrt{c}} \sqrt{4ac - b^2} \tag{26}$$

$$\Theta_\sigma = \sqrt{c} \tag{27}$$

$$z_R = \frac{1}{2c}\sqrt{4ac - b^2} \tag{28}$$

$$M^2 = \frac{\pi}{8\lambda}\sqrt{4ac - b^2} \tag{29}$$

NOTE 2 If more than one diameter measurement is performed at each z position, it is advisable to weight the data points in an inversely proportional manner to the variance of the data points.

NOTE 3 It is common to perform the fit by minimizing the sum of the squared relative deviations of the diameters.

NOTE 4 Astigmatic waist separation Δz_a , which is also known as astigmatic difference, is given by:

$$\Delta z_a = \left| z_{0x'} - z_{0y'} \right|$$

see ISO 15367-1:2003, 3.3.4.

If the beam waist is not accessible for direct measurement, the same procedure shall be applied to an artificial waist created by using an aberration-free focusing element as defined in 6.6. According to Figure 4, the distances $z_{0,2}$ or $z_{0,2x'}$ and $z_{0,2y'}$ from the artificial waist to the rear principal plane H_2 of the focusing element and the beam widths $d_{\sigma 2}$ or $d_{\sigma 2x'}$ and $d_{\sigma 2y'}$ shall be determined at the artificial waist. From these data, the waist location(s) $z_{0,1}$ or $z_{0,1x'}$ and $z_{0,1y'}$ of the original beam with respect to the front principal plane H_1 of the focusing element, can be calculated using Formula (30):

$$z_{0,1} = V^2 x_2 + f \tag{30}$$

where x_2 (or y_2) is determined using Formula (31)

$$x_2 = z_{0,2} - f \tag{31}$$

and where

$$V = \frac{f}{\sqrt{z_{R2}^2 + x_2^2}} \tag{32}$$

and where

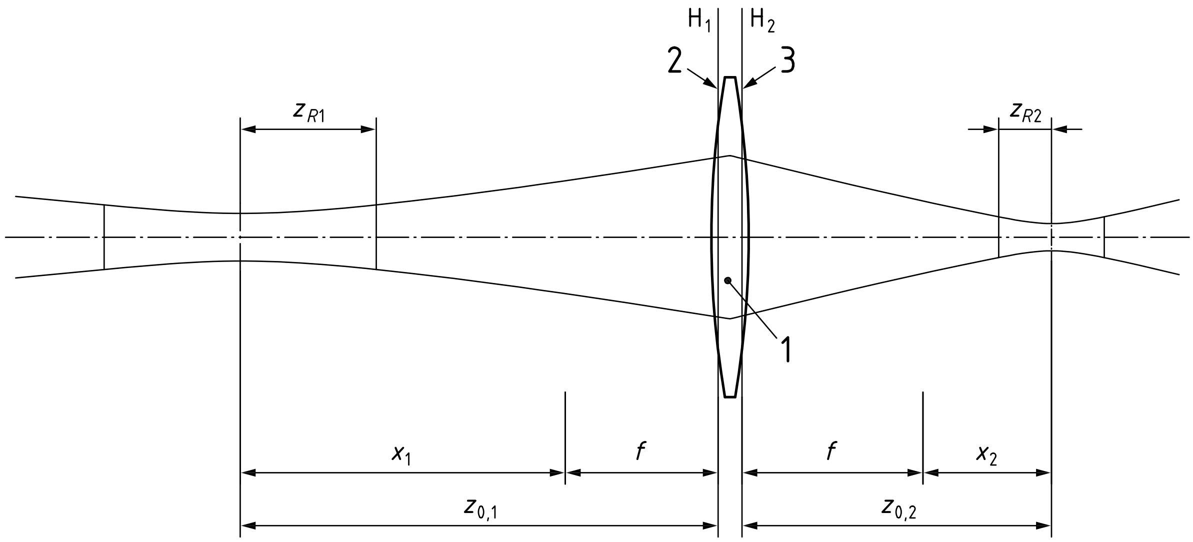
f is the focal length of the lens;

z_{R2} is the Rayleigh length of the artificial beam waist.

The Rayleigh length of the artificial waist z_{R2} can be determined by using Formulae (24) and (28) for the hyperbolic fit procedure.

The beam waist diameter or widths can be calculated in the following way:

$$d_{\sigma 1} = V \cdot d_{\sigma 2} \tag{33}$$



Key

1 focusing element

2 front principal plane H_1

3 rear principal plane H_2

Figure 4 — Scheme for calculation of beam waist location(s)

The Rayleigh length can be calculated in the following way:

$$z_{R1} = V^2 \cdot z_{R2} \tag{34}$$

The beam divergence can be calculated in the following way:

$$\Theta_1 = \frac{\Theta_2}{V} \tag{35}$$

10 Test report

The following information shall be included in the test report:

a) General information:

1) test has been performed in accordance with ISO 11146-1:2021;

2) date of test;

3) name and address of test organization;

4) name of individual performing the test.

b) Information concerning the tested laser:

1) laser type;

2) manufacturer;

3) manufacturer's model designation;

4) serial number.

c) Test conditions:

1) laser wavelength(s) at which tested;

2) temperature in K (diode laser cooling fluid) (only applicable for diode lasers);

3) operating mode (cw or pulsed);

4) laser parameter settings:

i) output power or energy;

ii) current or energy input;

iii) pulse energy;

iv) pulse duration;

v) pulse repetition rate;

5) polarization;

6) environmental conditions.

d) Information concerning testing and evaluation:

1) device used for the measurement of power distributions

2) detector and sampling system:

i) response time of the detector system,

ii) trigger delay of sampling (for pulsed lasers only),

iii) measuring time interval (for pulsed lasers only);

3) beam forming optics and attenuating method:

i) type of attenuator,

ii) type of beam splitter,

iii) type of focusing element;

4) other optical components and devices used for the test (polarizer, monochromator, etc.);

5) other relevant parameters or characteristics of the test which shall be chosen (aperture setting, reference plane, reference axis, laboratory system).

e) Test results:

1) beam widths or beam diameter and azimuthal orientation (in accordance with Clause 7);

Location z ____

	Mean value	**Standard deviation**
Beam diameter d_σ		
Beam width $d_{\sigma x'}$		
Beam width $d_{\sigma y'}$		
Azimuthal orientation φ		

2) Beam divergence angles (in accordance with Clause 8);

Focusing element used ____

Focal length ____

	Mean value	Standard deviation
Beam divergence angle Θ_σ		
Beam divergence angle $\Theta_{\sigma x'}$		
Beam divergence angle $\Theta_{\sigma y'}$		

3) Beam propagation parameters derived from hyperbolic fit (in accordance with Clause 9).

	Value	Estimated uncertainty
Beam waist location z_0		
Beam waist location $z_{0x'}$		
Beam waist location $z_{0y'}$		
Beam waist diameter d_0		
Beam waist width $d_{0x'}$		
Beam waist width $d_{0y'}$		
Azimuthal orientation φ		
Rayleigh length z_R		
Rayleigh length $z_{Rx'}$		
Rayleigh length $z_{Ry'}$		
Beam divergence angle Θ_σ		
Beam divergence angle $\Theta_{\sigma x'}$		
Beam divergence angle $\Theta_{\sigma y'}$		
Beam propagation ratio M^2		
Beam propagation ratio $M_{x'}^2$		
Beam propagation ratio $M_{y'}^2$		

Bibliography

[1] ISO/TR 11146-3, *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 3: Intrinsic and geometrical laser beam classification, propagation and details of test methods*

[2] ISO 15367-1, *Lasers and laser-related equipment — Test methods for determination of the shape of a laser beam wavefront — Part 1: Terminology and fundamental aspects*

This Page has been Intentionally left blank

(*Continued from second cover*)

The Committee has reviewed the provisions of the following International Standards referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard.

International Standard	*Title*
ISO 13694	Optics and photonics — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution
EN 61040 : 1992	Power and energy measuring detectors, instruments and equipment for laser radiation

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any form without the prior permission in writing of BIS. This does not preclude the free use, in the course of implementing the standard, of necessary details, such as symbols and sizes, type or grade designations. Enquiries relating to copyright be addressed to the Head (Publication & Sales), BIS.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the website-www.bis.gov.in or www.standardsbis.in.

This Indian Standard has been developed from Doc No.: PGD 39 (22111).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: 601/A, Konnectus Tower -1, 6th Floor, DMRC Building, Bhavbhuti Marg, New Delhi 110002	2323 7617
Eastern	: 8th Floor, Plot No 7/7 & 7/8, CP Block, Sector V, Salt Lake, Kolkata, West Bengal 700091	2367 0012 2320 9474
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg, Chandigarh 160019	265 9930
Southern	: C.I.T. Campus, IV Cross Road, Taramani, Chennai 600113	2254 1442 2254 1216
Western	: 5th Floor/MTNL CETTM, Technology Street, Hiranandani Gardens, Powai Mumbai 400076	25700030 25702715

Branches : AHMEDABAD, BENGALURU, BHOPAL, BHUBANESHWAR, CHANDIGARH, CHENNAI, COIMBATORE, DEHRADUN, DELHI, FARIDABAD, GHAZIABAD, GUWAHATI, HARYANA (CHANDIGARH), HUBLI, HYDERABAD, JAIPUR, JAMMU, JAMSHEDPUR, KOCHI, KOLKATA, LUCKNOW, MADURAI, MUMBAI, NAGPUR, NOIDA, PARWANOO, PATNA, PUNE, RAIPUR, RAJKOT, SURAT, VIJAYAWADA.

Published by BIS, New Delhi