INTERNATIONAL STANDARD

# ISO 11146-1

First edition
2005-01-15

# Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios —

## Part 1:
## Stigmatic and simple astigmatic beams



*Lasers et équipements associés aux lasers — Méthodes d'essai des largeurs du faisceau, angles de divergence et facteurs de limite de diffraction —*

*Partie 1: Faisceaux stigmatiques et astigmatiques simples*



Reference number
ISO 11146-1:2005(E)

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Published in Switzerland

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

ISO 11146-1 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

This first edition of ISO 11146-1, together with ISO/TR 11146-3 cancels and replaces ISO 11146:1999, the contents of which have been technically revised and augmented.



ISO 11146 consists of the following parts, under the general title *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios*:

— *Part 1: Stigmatic and simple astigmatic beams*



— *Part 2: General astigmatic beams*

— *Part 3: Intrinsic and geometrical laser beam classification, propagation and details of test methods* (Technical Report)

 

# 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 part of ISO 11146 describes the measurement methods for stigmatic and simple astigmatic beams while Part 2 deals with the measurement procedures for general astigmatic beams. For beams of unknown type the methods of Part 2 shall be applied. 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 an informative Technical Report and describes the procedures for background subtraction and offset correction.

In this part of ISO 11146, 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 part of ISO 11146 are described. These methods are:

— variable aperture method;

— moving knife-edge method;

— moving slit method.



The problem of the dependence of the measuring result on the truncation limits of the integration area has been investigated and evaluated by an international round robin experiment carried out in 1997. The results of this round robin testing were taken into consideration during the preparation of this document.

The International Organization for Standardization (ISO) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning the determination of beam characteristics by measuring along the beam caustic of the transformed beam produced by a lens as described in 5.5.

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

The holder of this patent right (U.S. No. 5,267,012) has assured ISO that he is willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with the ISO. Information may be obtained from:

Coherent Inc.
5100 Patrick Henry Drive
Santa Clara, CA 95056-0980
USA

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. ISO shall not be held responsible for identifying any or all such patent rights.

# Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios —

## Part 1: Stigmatic and simple astigmatic beams

## 1 Scope

This part of ISO 11146 specifies methods for measuring beam widths (diameter), divergence angles and beam propagation ratios of laser beams. This part of ISO 11146 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 should be applied.

## 2 Normative references



The following referenced documents are indispensable for the application 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 optical instruments — 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 optical instruments — Lasers and laser-related equipment — Test methods for laser beam power (energy) density distribution*

IEC 61040:1990, *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, IEC 61040 and the following apply.

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

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

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 For practical application, the infinite integration limits are reduced in a specific manner as given in Clause 7.

**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

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

and



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

and

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

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

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

NOTE 3 The angular brackets are the operator notations as used in ISO 11146-2 and ISO/TR 11146-3.

**3.3**
**principal axes of a power density distribution**
axes of the maximum and minimum beam extent based on the centered second order moments of the power density distribution in a cross section of the beam

NOTE The axes of maximum and minimum extent are always perpendicular to each other.

 

**3.4**
**orientation of a power density distribution**
$\varphi$
angle between the $x$-axis of the laboratory system and that of the principal axis of the power density distribution which is closer to the $x$-axis

NOTE From this definition it follows that $-\pi/4 < \varphi < \pi/4$ for $|\varphi| \neq \pi/4$ ; if $\varphi = \pm\pi/4$ , $\varphi$ is defined as the angle between the $x$-axis and the major principal axis (axis of maximum extent) of the power density distribution.

**3.5**
**beam widths**
$d_{\sigma x}$, $d_{\sigma y}$
extent of a power density distribution in a cross section of the beam at an axial location $z$ along that principal axis which is closer to the $x$- or $y$-axis of the laboratory coordinate system, respectively, based on the centered second order moments of the power density distribution

NOTE 1 If the principal axes make the angle π/4 with the $x$- and $y$-axes of the laboratory coordinate system, then $d_{\sigma x}$ is by convention the larger beam width.

NOTE 2 This definition differs from that given in ISO 11145:2001, subclause 3.5.2, where the beam widths are defined only in the laboratory system, whereas for the purposes of this part of ISO 11146 the beam widths are defined in the principal axes system.

**3.6**
**ellipticity of a power density distribution**
$\varepsilon$
ratio between the minimum and maximum beam widths



**3.7**
**circular power density distribution**
power density distribution having an ellipticity greater than 0,87



**3.8**
**beam diameter**
$d_{\sigma}$
extent of a circular power density distribution, based on the second order moments

**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 or azimuthal orientation as that lens

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

NOTE The principal axes of a power density distribution corresponding to a beam with simple astigmatism are called the principal axes of that beam.

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

NOTE This part of ISO 11146 deals only with stigmatic and simple astigmatic beams. Refer to ISO 11146-2 for general astigmatic beams.

 

**3.12**
**beam waist locations**
$z_{0x}$, $z_{0y}$, $z_0$
positions from $z$ = 0 reference plane where the beam widths or the beam diameter reach their minimum values along the axis of propagation

See Figure 1.

NOTE 1 In the case of general astigmatic beams, which are outside the scope of this part of the standard, this definition does not apply.

NOTE 2 For simple astigmatic beams the waist locations $z_{0x}$ and $z_{0y}$ corresponding to the principal axes, may or may not coincide.

**3.13**
**beam waist widths**
$d_{\sigma x0}$, $d_{\sigma y0}$
beam widths at the beam waist locations of a simple astigmatic beam

NOTE $d_{\sigma x0}$ is the beam width $d_{\sigma x}$ at location $z_{0x}$, $d_{\sigma y0}$ is the beam width $d_{\sigma y}$ at location $z_{0y}$.

**3.14**
**beam waist diameter**
$d_{\sigma 0}$
beam diameter at the beam waist location of a stigmatic beam



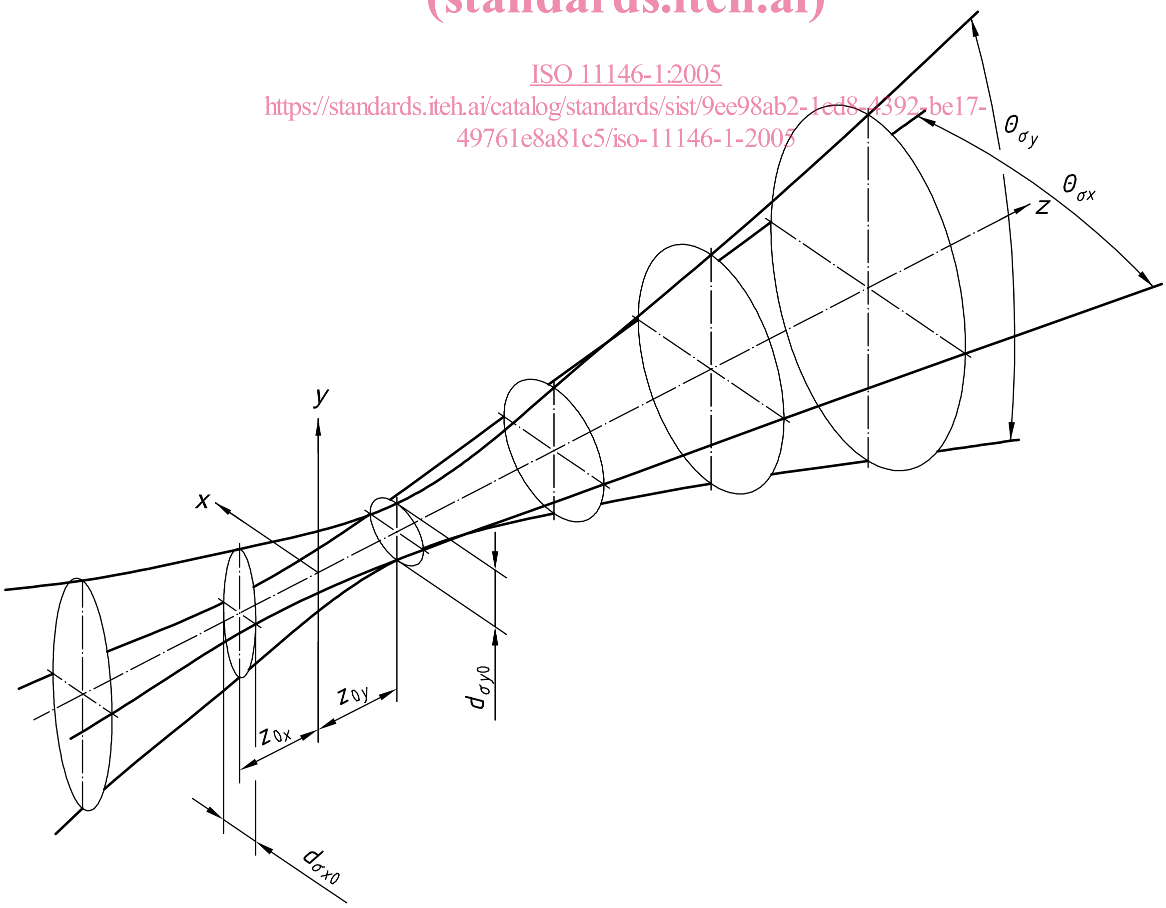


**Figure 1 — Beam propagation parameters of a simple astigmatic beam**

 

**3.15**
**beam divergence angles**
$\Theta_{\sigma x}$, $\Theta_{\sigma y}$, $\Theta_{\sigma}$

measure for the increase of the beam widths or beam diameter with increasing distance from the beam waist locations, 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 The beam divergence is expressed as a full angle.

NOTE 2 This definition differs from that given in ISO 11145:2001, subclause 3.18.2, where the beam divergence angles are defined only in the laboratory system, whereas for the purposes of this part of ISO 11146 the beam divergence angles are defined in the principal axes system.



### 3.16 beam propagation ratios



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



NOTE 2 Beam propagation ratios, as defined in 3.16.1 and 3.16.2, 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.

**3.16.1**
**beam propagation ratios**
$M_x^2$ and $M_y^2$
⟨simple astigmatic beams⟩ ratios of the beam parameter product along the principal axes of the beam of interest to the beam parameter product of a diffraction-limited, perfect Gaussian beam of the same wavelength $\lambda$

$$M_x^2 = \frac{\pi}{\lambda} \frac{d_{\sigma x0} \Theta_{\sigma x}}{4} \tag{9}$$

$$M_y^2 = \frac{\pi}{\lambda} \frac{d_{\sigma y0} \Theta_{\sigma y}}{4} \tag{10}$$

**3.16.2**
**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 $\lambda$

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