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Lasers and laser-related equipment — Test methods for laser beam parameters — Polarization

Lasers et équipements associés aux lasers — Méthodes d'essai des paramètres du faisceau laser — Polarisation

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Foreword

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ISO 12005 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems*.

This second edition cancels and replaces the first edition (ISO 12005:1999), which has been technically revised.

Introduction

This International Standard specifies a relatively quick and simple method, requiring minimum equipment, for determining the state of polarization of a laser beam.

This method is for well-polarized laser beams, including those emitted by lasers with a high divergence angle. However, if more completeness in the determination of the polarization status is required, the use of a more sophisticated analysing device is necessary. Although not within the scope of this International Standard, the principle of operation of such devices is given in Annex A, together with a description of the Stokes parameters which are needed in that case.

Lasers and laser-related equipment — Test methods for laser beam parameters — Polarization

1 Scope

This International Standard specifies a method for determining the polarization status and, whenever possible, the degree of polarization of the beam from a continuous wave (cw) laser. It can also be applied to repetitively pulsed lasers, if their electric field vector orientation does not change from pulse to pulse.

This International Standard also specifies the method for determining the direction of the plane of oscillation in the case of linearly polarized (totally or partially) laser beams. It is assumed that the laser radiation is quasi-monochromatic and sufficiently stable for the purpose of the measurement.

The knowledge of the polarization status can be very important for some applications of lasers with a high divergence angle, for instance when the beam of such a laser shall be coupled with polarization dependent devices (e.g. polarization maintaining fibres). This International Standard also specifies a method for the determination of the state of polarization of highly divergent laser beams, as well as for the measurement of beams with large apertures.

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 11145:2001, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols*

IEC 61040:1990, *Power and energy measuring detectors, instruments and equipment for laser radiation*

CIE 59-1984, *Definitions and Nomenclature, Instrument Polarization*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145:2001, IEC 61040:1990, CIE 59-1984 and the following apply.

3.1
polarization
restriction of oscillations of the electric field vector to certain directions

NOTE This is a fundamental phenomenon which can be explained by the concept that electromagnetic radiation is a transverse wave motion, i. e. the vibrations are at right angles to the direction of propagation. It is customary to consider these vibrations as being those of the electric field vector.

3.2
state of polarization
classification of polarization as linear, random, circular, elliptical or unpolarized

3.3
direction of polarization
direction of the electric field vector of an electromagnetic wave

3.4
plane of polarization
plane containing the electric field vector and the direction of propagation of the electromagnetic radiation

3.5
ellipticity
b/a
⟨elliptically polarized radiation⟩ ratio of the minor semiaxis b of the ellipse to the major semiaxis a of the ellipse

NOTE The ellipse is described by the motion of the terminal point of the electric field vector in a transverse plane to the direction of radiation propagation (see Annex A).

3.6
ellipticity angle
ϵ
angle whose tangent is the ellipticity

NOTE The ellipticity angle is constrained to $-45^\circ \leqslant \epsilon \leqslant +45^\circ$. When $\epsilon = \pm 45^\circ$ the polarization is circular and when $\epsilon = 0^\circ$ the polarization is linear (see Annex A).

3.7
azimuth
Φ
angle between the major axis of the instantaneous ellipse and a reference axis perpendicular to the direction of propagation

NOTE See Annex A.

3.8
linear polarizer
optical device whose output is linearly polarized, without regard to the status and degree of polarization of the incident radiation

3.9
extinction ratio
⟨linear polarizer⟩ measure of the quality of the linear polarizer

NOTE If perfectly linearly polarized radiation is incident on a polarizer, then the extinction ratio of the polarizer is given by

$$\text{extinction ratio} = \frac{\tau_{\text{min}}}{\tau_{\text{max}}} \text{ or } \frac{\rho_{\text{min}}}{\rho_{\text{max}}}$$

where

$\tau_{\text{max}}\ (\rho_{\text{max}})$ is the maximum transmittance (reflectance)

$\tau_{\text{min}}\ (\rho_{\text{min}})$ is the minimum transmittance (reflectance)

of power (energy) through (of) the linear polarizer.

3.10
quarter wave plate
optical device which resolves an incident totally polarized beam of radiation into two orthogonally polarized components and introduces a 90° phase shift between them

3.11
stokes parameters
set of four real quantities, which completely describe the polarization state of monochromatic or quasi-monochromatic radiation

NOTE The parameters are, collectively, known as the Stokes vector, a 4 × 1 vector (see Annex A for a complete description and formulae for Stokes parameters).

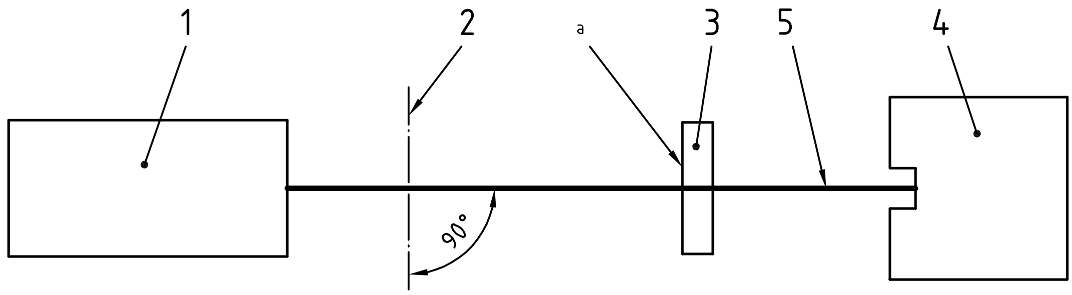
4 Test method for state of polarization

4.1 Principle of measurement

The first test for laser beam polarization determines whether the beam is linearly polarized. This involves recording the maximum and minimum levels of the transmitted radiation while the angular orientation of the linear polarizer is varied, as shown in Figure 1.

If the beam is not linearly polarized (according to the criteria given in 4.5), it is tested for elliptical or circular polarization. For this test the beam is measured after transmission by both a quarter-wave plate and a linear polarizer, as shown in Figure 2.

If not in either of these states, it is only partially polarized or unpolarized.



Key
1 laser
2 reference axis
3 polarizer
4 detector
5 laser beam

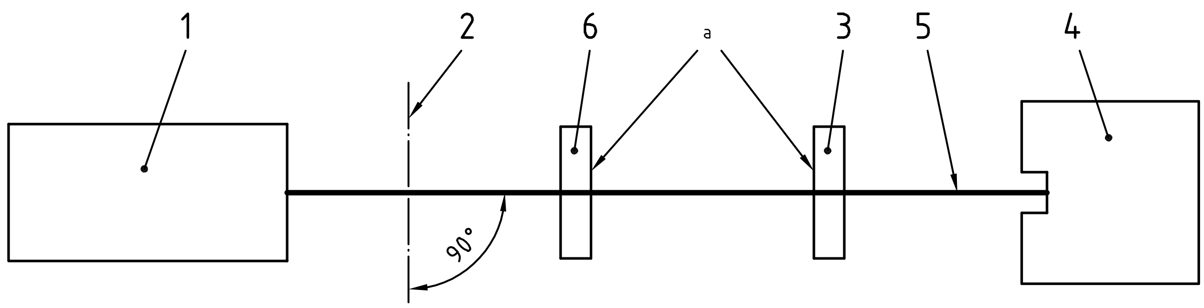
a Rotation 180°

Figure 1 — Schematic arrangement for the test for linear polarization

4.2 Equipment arrangement

4.2.1 General

The experimental set-up is shown in Figures 1 and 2.



Key

1 laser
2 reference axis
3 polarizer
4 detector
5 laser beam
6 quarter-wave plate

[a] Rotation 180°

Figure 2 — Schematic arrangement for the test for elliptical or circular polarization

4.2.2 Special arrangement for the testing of beams with large divergence angles

A highly divergent beam will not be transmitted through all the components of the test arrangements given above. In this case, a collimating assembly shall be inserted between the laser and the first component (reference axis) (see Figure 3). This assembly is made of stigmatic collecting optics (such as a meniscus lens or a group of lenses) corrected for spherical aberration, followed by a telescope with a magnification factor smaller than one, achieving a reduction of the beam radius to a value compatible with the rest of the arrangement.

4.2.3 Special arrangement for the testing of beams with large apertures

Care shall be taken that the detecting system captures the whole beam. If this is not possible, for example for beams with large apertures, the measurement shall be performed using smaller non-overlapping sub-apertures.

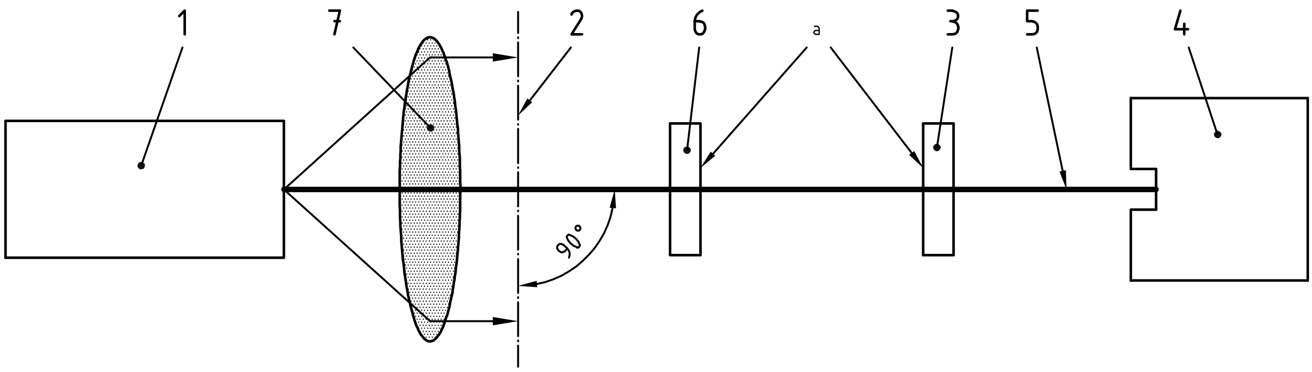
4.3 Components

4.3.1 Radiation detector

The provisions of IEC 61040:1990 apply to the radiation detector; Clauses 3 and 4 are particularly important, with the exception that only relative measurements are necessary. Furthermore, the following points shall be noted.

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

b) Care shall be taken to ascertain the damage thresholds (for irradiance, radiant exposure, power and energy) of the detector surface and of all the optical elements located between the laser and the detector (e.g. polarizer, attenuator) so that it is not exceeded by the incident laser beam.



Key

1 laser
2 reference axis
3 polarizer
4 detector
5 laser beam
6 quarter-wave plate
7 collimating optics

[a] Rotation 180°

Figure 3 — Schematic arrangement for the testing of lasers with highly divergent beams

4.3.2 Linear polarizer

The extinction ratio of the linear polarizer shall be less than $\left[(1/p)-1\right]$/25, where p is the expected degree of polarization, and at most 0,02. The plane of maximum transmission shall be indicated on the mount.

4.3.3 Quarter-wave plate

The quarter-wave plate is selected for the wavelength to be tested, such as to introduce a (λ/4 $\pm$ λ/200) optical path difference between the two resolved orthogonal polarized components. The plane of oscillation of the fast component (lowest refractive index) shall be indicated on the mount.

4.3.4 Optical attenuator

An attenuator is used to reduce the laser power density.

Optical attenuators shall be used when the output laser power or power density exceeds the detector's working (linear) range or the damage threshold. Any wavelength dependence, non-linearity or non-uniformity of the optical attenuator shall be minimized or corrected by the use of a calibration procedure.

4.4 Test procedure

4.4.1 General

Set up the experimental apparatus as specified in 4.2.

Ensure that there is no reflective feedback into the laser by adjusting the angle of the components and their position along the optical path. If attenuating optics are used, test independently to ensure that they have no effect on the polarization.

After the initial preparation is completed, an evaluation to determine if the entire laser beam reaches the detector surface shall be made. Apertures of different diameters can be introduced into the beam path in front of each optical component. Aperture size is reduced until the output signal has been reduced by 5 %. This aperture should have a diameter at least 20 % smaller than the aperture of the optical component.

4.4.2 **Measurement 1** (see Figure 1)

Define and record the orientation of a reference axis perpendicular to the beam axis.

a) Rotate the polarizer to obtain the maximum and minimum readings at the detector.

b) Record these readings and the angular orientation of the polarizer during the maximum and minimum readings of the detector.

c) Calculate the contrast from the beam powers P (energies Q) in two orthogonal directions.

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

The directions x and y are chosen so that the beam power (energy) is attenuated maximally or minimally, respectively, after transmission through the linear polarizer.

d) Repeat the measurement at least 10 times and calculate the average contrast. If it is less than 0,9, proceed with measurement 2.

4.4.3 **Measurement 2** (see Figure 2)

a) Rotate both the quarter-wave plate and the polarizer independently to obtain maximum and minimum readings at the detector. Repeat the procedure to ensure that the absolute maximum and minimum measurements are taken as a function of the angular orientation for both the quarter-wave plate and the polarizer.

b) Record these maximum and minimum readings.

c) Calculate the contrast as defined above for measurement 1 from the measurements obtained.

d) Repeat the measurement at least 10 times and calculate the average contrast.

4.5 Analysis of the results

If the average contrast from the data in measurement 1 is greater than 0,9, then the laser beam is linearly polarized and the degree of linear polarization is equal to the contrast. The azimuth is given by the angular orientation of the polarizer during the maximum reading.

If the average contrast from the data in measurement 1 is between 0,1 and 0,9 and the average contrast from measurement 2 is less than 0,1, then the laser beam is partially linearly polarized. The degree of linear polarization is equal to the contrast from measurement 1.

If the average contrast from the data in measurement 1 is less than 0,1 and the average contrast from measurement 2 is greater than 0,9, then the laser beam is circularly polarized.

If the average contrast from the data in measurement 1 is less than 0,1 and the average contrast from measurement 2 is between 0,1 and 0,9, then the laser beam is partially circularly polarized. The degree of circular polarization is equal to the contrast from measurement 2.

If the average contrast from the data in measurement 1 is between 0,1 and 0,9, and the average contrast from measurement 2 is greater than 0,9, then the laser beam is elliptically polarized. Determination of the azimuth and of the ellipticity of the ellipse can be made with the use of a polarization analysing device which gives access to the four Stokes parameters (see Annex A).

If the average contrast from the data in both measurement 1 and measurement 2 is between 0,1 and 0,9, then the laser beam is partially elliptically polarized. Determination of the azimuth and of the ellipticity of the ellipse can be made with the use of a polarization analysing device which gives access to the four Stokes parameters (see Annex A).

If the average contrast from both measurements is less than 0,1, then the laser beam is measured as unpolarized.

When, in this case, the power fluctuations in the two fixed directions are:

— less than 10 %, the laser shall be classified as unpolarized;

— greater than 10 %, the laser shall be considered to be randomly polarized.

NOTE Some lasers measured as unpolarized may actually be linearly polarized in two fixed orthogonal directions. The amount of energy in each direction may be changing during the time of observation selected by the user for the application.

It is assumed that the radiation has uniform polarization properties over its cross-sectional area. Radiation that exhibits random and spatially unresolvable variations in the state of polarization (and over its aperture or direction behaves as unpolarized to the detector) should be retested, using smaller apertures (as required) to determine the spatially distributed state of polarization (see 4.2.3).

5 Test report

The following information shall be included in the test report.

a) General information:

   1) test has been performed according to ISO 12005:2003;

   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) (or wavelength range) tested at

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

   2) operating mode (cw or pulsed);

   3) laser parameter settings:

      — output power or energy;

      — current or energy input;

      — pulse energy;

      — pulse duration;

      — pulse repetition rate;

   4) mode structure (if known);

   5) environmental conditions.

d) Information concerning testing and evaluation:

   1) detector and sampling system:

      — response time of the detector system;

      — trigger delay of sampling (for pulsed lasers only);

      — measuring time interval (for pulsed lasers only);

   2) beam forming optics and attenuating method (if applicable):

      — type of attenuator;

      — type of beam splitter;

      — type of focusing element;

   3) polarizers used for the test;

   4) orientation of the reference axis;

   5) width of the sub-aperture and resulting measuring angle (if applicable).

e) Test results

   1) Measurement results or readings, in accordance with Table 1;

   2) state of polarization;

   3) degree of polarization (if linear or circular);

   4) azimuth of the polarized component (if linear);

   5) results of the measurements as a function of the angular position of the sub-aperture in respect to the laser beam (if applicable).

Table 1 — Measurement results

	Average contrast		**Angle polarizer**				**Angle quarter-wave plate**			
			γ_{max}		γ_{min}		γ_{max}		γ_{max}	
	mean	s[a]	mean	s[a]	mean	s[a]	mean	s[a]	mean	s[a]
Measurement 1							X	X	X	X
Measurement 2										

[a] s: standard deviation

Annex A
(informative)

Complete description of the polarization status of a monochromatic laser beam

A.1 Stokes vector

The Stokes vector of a laser beam is defined as a set of four real quantities, named S_0 to S_3, each having units of power, and giving a complete description of the state of polarization and power of the beam.

The first parameter S_0 measures the total power of the beam. Therefore $S_0 > 0$.

The most general state of the polarized component, the power of which is S_p, is elliptical. The ratio $p = S_\text{p}/S_0$ is the degree of polarization of the beam.

The complete characterization of this component requires the knowledge of the azimuth angle Φ and the ellipticity angle ϵ, as shown in Figure A.1.

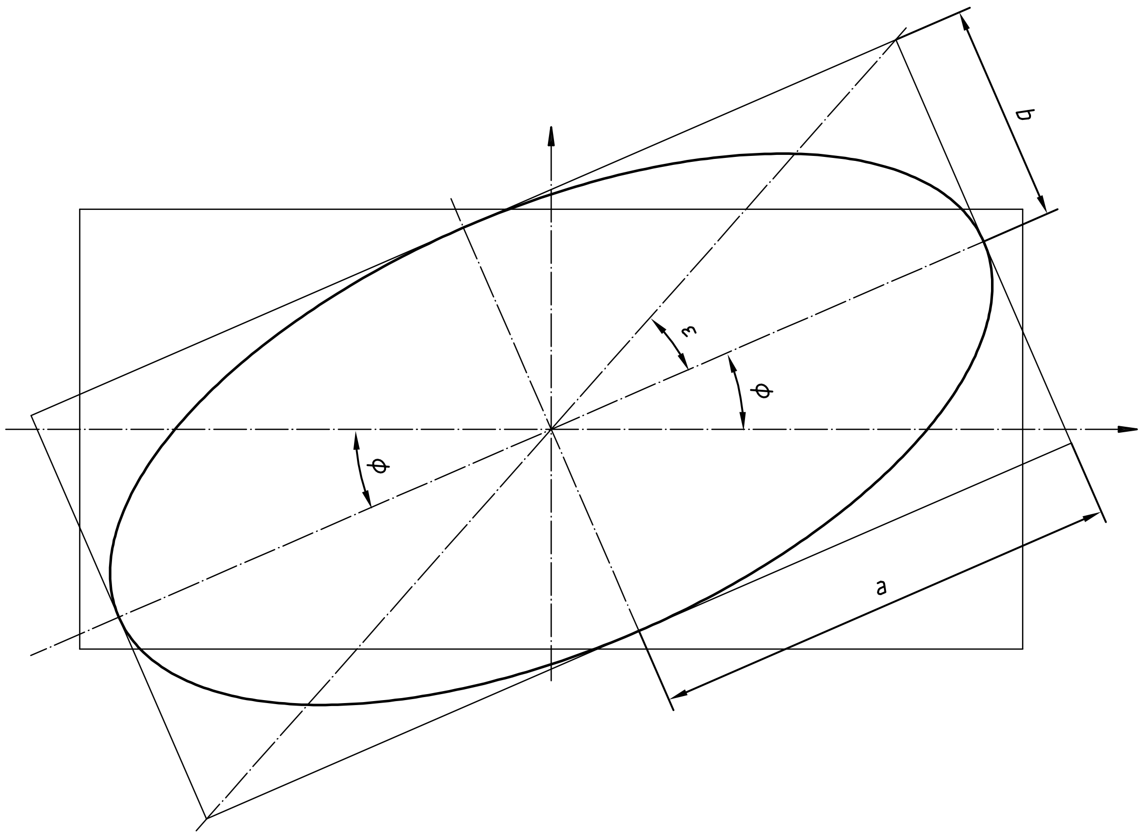


Figure A.1 — Geometrical representation illustrating the significance of the azimuth Φ and ellipticity ϵ angles for an elliptically polarized radiation

If $\epsilon = 0$, the polarization is linear.

If $\epsilon = \pi/4$ (i.e. 45°), the polarization is circular.

The second (S_1), third (S_2) and fourth (S_3) Stokes parameter give an alternative description of the polarized component through:

$$S_1 = S_\mathrm{p}\cos(2\Phi)\cos(2\varepsilon)$$

$$S_2 = S_\mathrm{p}\sin(2\Phi)\cos(2\varepsilon)$$

$$S_3 = S_\mathrm{p}\sin(2\varepsilon)$$

Finally, the Stokes vector can be written as a function of the total beam power, P, the degree of polarization, p, and the azimuth and ellipticity angles Φ and ϵ, namely:

$$S = P[1, p\cos(2\Phi)\cos(2\varepsilon), p\sin(2\Phi)\cos(2\varepsilon), p\sin(2\varepsilon)]$$

Conversely P, p, Φ and ϵ can be determined from the Stokes vector, using the following relations:

$$P = S_0$$

$$p = \left(s_1^2 + s_2^2 + s_3^2\right)^{1/2} / S_0$$

$$\Phi = \frac{1}{2}\tan^{-1}(s_1/s_2)$$

$$\varepsilon = \frac{1}{2}\sin^{-1}\left[s_3 / \left(s_1^2 + s_2^2 + s_3^2\right)^{1/2}\right]$$

A.2 Polarization analysis

As apparent from Clause A.1, the complete description of the polarization status of a laser beam implies the determination of the four Stokes parameters.

This requires at least four independent measurements, in each of which the beam is analysed for a different “polarization content”. Such a requirement is fulfilled for instance by the 4-detector polarimeter[1], [2]. Any device whose principle of measurement is based on this principle is suitable for extracting the four Stokes parameters, and consequently the degree of polarization, the azimuth and ellipticity angles of any laser beam, including the most general situation.

Bibliography

[1] AZZAM, R.M.A. *Optics lett.*, 1985, **10**, p. 309

[2] AZZAM, R.M.A. and LOPEZ, A.G. *Opt. Soc. Am.*, 1989, **A6**, p. 1513

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