INTERNATIONAL STANDARD

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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 des faisceaux laser — Polarisation

Reference number
ISO 12005:1999(E)

Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

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

Annex A of this International Standard is for information only.

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Introduction

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

This method is suitable for most of the current needs with well-polarized laser beams. However, if more completeness in the determination of the polarization status is needed, the use of a more sophisticated analysing device is necessary. Although not in 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 defines a method for determining the polarization status and, whenever possible, the degree of polarization of the beam from a 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 defines the method for determining the direction of the plane of vibration in the case of linearly polarized (totally or partially) laser beams. Unless otherwise stated, it is assumed that the laser radiation is quasi-monochromatic and sufficiently stable for the purpose of the measurement.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 11145:1994, *Optics and optical instrument — 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 International Standard, the terms and definitions given in ISO 11145, IEC 61040 and CIE 59 and the following apply.

3.1
polarization
restriction of electromagnetic wave motion 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 vibration
direction of the electric field vector of an electromagnetic wave

3.4
plane of vibration
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 $-45° \leqslant \varepsilon \leqslant +45°$. When $\varepsilon = \pm 45°$ the polarization is circular, and when $\varepsilon = 0°$ the polarization is linear (see annex A).

3.7
azimuth
$\boldsymbol{\Phi}$
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 state 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:

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

where

τ_{max} (ρ_{max}) is the maximum transmittance (reflectance) and

τ_{min} (ρ_{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

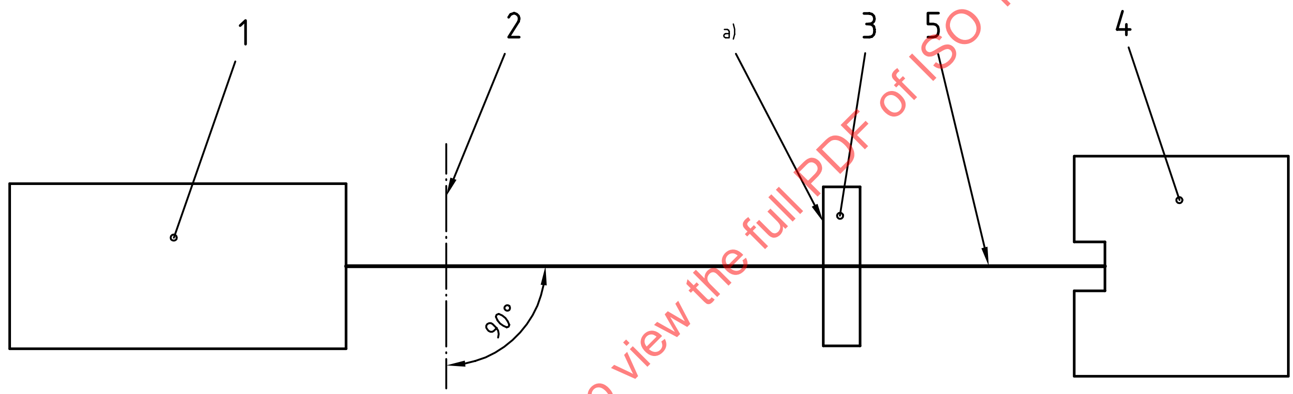
The first test for laser beam polarization determines whether the beam is linearly polarized. This involves recording the maximum and minimum levels of the transmitted radiation while the angular orientation of the linear polarizer is varied. See Figure 1.

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. See Figure 2.

If not in any of these states, the laser beam is only partially polarized or unpolarized.

4.2 Equipment arrangement

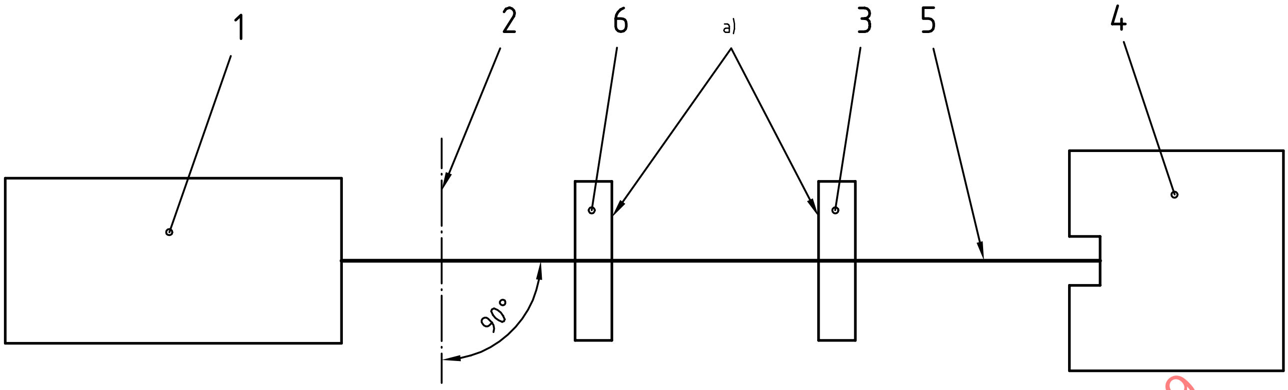
See Figures 1 and 2 for the experimental set-up.



Key

1 Laser
2 Reference axis
3 Polarizer
4 Detector
5 Laser beam
a) Rotation 180°

Figure 1 — Schematic arrangement of the test for linear polarization



Key
1 Laser
2 Reference axis
3 Polarizer
4 Detector
5 Laser beam
6 Quarter-wave plate
a) Rotation 180°

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

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.

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.

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.

4.3.2 Linear polarizer

The extinction ratio of the linear polarizer shall be less than $[(1/p)-1]/25$, 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 ($\lambda/4 \pm \lambda/200$) optical path difference between the two resolved orthogonal polarized components. The plane of vibration 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 laser output-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 illustrated in 4.2.

Ensure 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 they have no effect on the polarization.

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 x and y directions 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 classified 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** according to this International Standard;

— 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.

5 Test report

5.1 General and test conditions

The following general information shall be included in the test report.

a) Manufacturer's model designation of the laser;

b) laser medium, wavelength or wavelength range tested at, mode structure (if known), and power level;

c) laser parameter settings;

d) orientation of the reference axis;

e) response time of the detector system;

f) date of test;

g) name of test organization;

h) name of individual performing the test.

5.2 Test results

The following test results shall be included in the test report.

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

Table 1

	Average contrast		Angle polarizer				Angle quarter-wave plate			
			γ_{max}		γ_{min}		γ_{max}		γ_{min}	
	mean	$s^{1)}$	mean	$s^{1)}$	mean	$s^{1)}$	mean	$s^{1)}$	mean	$s^{1)}$
Measurement 1							X	X	X	X
Measurement 2										
1) s: standard deviation										

b) state of polarization;

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

d) azimuth of the polarizer component (if linear).

Annex A
(informative)

Complete description of the polarization state 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, termed 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, whose power is S_p, is elliptical. The ratio $p = S_p/S_0$ 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.

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

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

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

$$S_1 = S_p \cos(2\Phi) \cos(2\varepsilon)$$

$$S_2 = S_p \sin(2\Phi) \cos(2\varepsilon)$$

$$S_3 = S_p \sin(2\varepsilon)$$

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:

$$P = S_0$$

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

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

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