INTERNATIONAL STANDARD

ISO
11554

Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power, energy and temporal characteristics

Optique et instruments d'optique — Lasers et équipements associés aux lasers — Méthodes d'essai de la puissance et de l'énergie des faisceaux lasers et de leurs caractéristiques temporelles

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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.

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

ISO 11554 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 11554:1998), which has been technically revised.

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Introduction

The measurement of laser power (energy for pulsed lasers) is a common type of measurement performed by laser manufacturers and users. Power (energy) measurements are needed for laser safety classification, stability specifications, maximum laser output specifications, damage avoidance, specific application requirements, etc. This International Standard provides guidance on performing laser power (energy) measurements as applied to stability characterization. The stability criteria are described for various temporal regions (e.g. short-term, medium-term and long-term) and provide methods to quantify these specifications. This International Standard also covers pulse measurements where detector response speed can be critically important when analysing pulse shape or peak power of short pulses. To standardize reporting of power (energy) measurement results, a report template is also included.

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Optics and optical instruments — Lasers and laser-related equipment — Test methods for laser beam power, energy and temporal characteristics

1 Scope

This International Standard specifies test methods for determining the power and energy of continuous-wave and pulsed laser beams, as well as their temporal characteristics of pulse shape, pulse duration and pulse repetition rate. Test and evaluation methods are also given for the power stability of cw-lasers, energy stability of pulsed lasers and pulse duration stability.

The test methods given in this International Standard are to be used for the testing and characterization of lasers.

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*

VIM, *International Vocabulary of Basic and General Terms in Metrology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145, in the VIM, *International Vocabulary of Basic and General Terms in Metrology*, as well as the following apply.

3.1
relative intensity noise
RIN
mean square of the optical power fluctuations, $\langle \Delta P^2 \rangle$, over the system bandwidth, normalized to P_0^2, the square of the average power $P_0 = \langle P \rangle$

NOTE 1   The spectral relative intensity noise, $R(\omega)$, is the single-sided spectral density of the power fluctuations normalized to P_0^2.

NOTE 2   For further details, see Annex A.

4 Symbols and units of measurement

The symbols and units specified in ISO 11145 and in Table 1 are used in this International Standard.

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
ΔP_1	—	Medium-term relative power fluctuation (1 min) to a 95 % confidence level
ΔP_{60}	—	Long-term relative power fluctuation (60 min) to a 95 % confidence level
P_1, P_{60}	W	Power averaged over 0,01 s for t_1 and over 1 s for t_{60}
$\overline{P_1}, \overline{P_{60}}$	W	Mean power, averaged over 1 min and 60 min, respectively, at the operating conditions specified by the manufacturer
ΔQ	—	Relative pulse energy fluctuation to a 95 % confidence level
t_1	s	Medium-term interval (1 min)
t_{60}	s	Long-term interval (60 min)
s	—	Measured standard deviation
$u_{\mathrm{rel,k}}$	—	Expanded relative uncertainty of calibration factor ($k = 2$) corresponding to a 95 % confidence level
u_{rel}	—	Expanded relative uncertainty of measurement ($k = 2$) corresponding to a 95 % confidence level
T	s	Pulse repetition period
τ_{R}	s	Rise time of laser pulse
$\Delta \tau_{\mathrm{H}}$	—	Relative pulse duration fluctuation with regard to τ_{H} to a 95 % confidence level
$\Delta \tau_{10}$	—	Relative pulse duration fluctuation with regard to τ_{10} to a 95 % confidence level
m	—	Reading
$\overline{m}$	—	Mean value of readings
$U(t)$	—	Detector signal
$R(\omega)$	dB/Hz or Hz^{-1}	Spectral relative intensity noise (spectral noise power density)
RIN	dB	Relative intensity noise

NOTE 1   For further details regarding 95 % confidence level, see ISO 2602.

NOTE 2   The expanded uncertainty is obtained by multiplying the standard uncertainty by a coverage factor $k = 2$. It is determined according to the *Guide to the Expression of Uncertainty in Measurement* [2]. In general, with this coverage factor, the value of the measurand lies with a probability of approximately 95 % within the interval defined by the expanded uncertainty.

5 Measurement principles

The laser beam is directed onto the detector surface to produce a signal with amplitude proportional to the power or energy of the laser. The amplitude versus time is measured. Radiation emitted by sources with large divergence angles is collected by an integrating sphere. Beam forming and attenuation devices may be used when appropriate.

The evaluation method depends on the parameter to be determined and is described in Clause 8.

6 Measurement configuration, test equipment and auxiliary devices

6.1 Preparation

6.1.1 Sources with small divergence angles

The laser beam and the optical axis of the measuring system shall be coaxial. Select the diameter (cross-section) of the optical system such that it accommodates the entire cross-section of the laser beam and so that clipping or diffraction loss is smaller than 10 % of the intended measurement uncertainty.

Arrange an optical axis so that it is coaxial with the laser beam to be measured. Suitable optical alignment devices are available for this purpose (e.g. aligning lasers or steering mirrors). Mount the attenuators or beam-forming optics such that the optical axis runs through the geometrical centres. Care should be exercised to avoid systematic errors.

NOTE 1   Reflections, external ambient light, thermal radiation and air currents are all potential sources of errors.

After the initial preparation is completed, make an evaluation to determine if the entire laser beam reaches the detector surface. For this determination, apertures of different diameters can be introduced into the beam path in front of each optical component. Reduce the aperture size 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. For divergent beams, the aperture should be placed immediately in front of the detector to assure total beam capture.

NOTE 2   Remove these apertures before performing the power (energy) measurements described in Clause 7.

6.1.2 Sources with large divergence angles

The radiation emitted by sources with large divergence angles shall be collected by an integrating sphere. The collected radiation is subjected to multiple reflections from the wall of the integrating sphere; this leads to a uniform irradiance of the surface proportional to the collected flux. A detector located in the wall of the sphere measures this irradiance. An opaque screen shields the detector from the direct radiation of the device being measured. The emitting device is positioned at or near the entrance of the integrating sphere, so that no direct radiation will reach the detector.
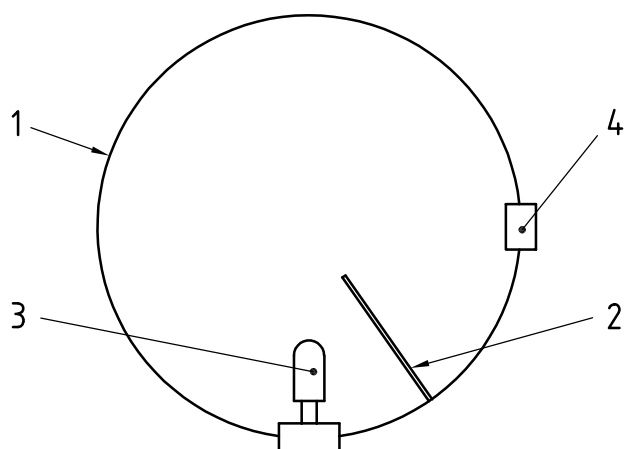
Figure 1 shows an integrating sphere measurement configuration for a small emitting source positioned inside the integrating sphere. Large-sized sources should, of course, be positioned outside the sphere but close enough to the input aperture so that all emitted radiation enters the sphere.

6.1.3 Measurement of the RIN spectrum

As shown in Figure 2, the beam propagates through the lens, an attenuator or other lossy medium and falls on the photodetector. The RIN $R(\omega)$ is to be determined at reference plane A, before any losses. The Poisson component of the RIN is increased at plane B due to losses and again at plane C due to inefficiency in the photodetection process.

NOTE   For an explanation of the different components of RIN, see Annex A.

To measure RIN, an electrical splitter sends the dc photocurrent produced in a detector by a test laser to a current meter while the ac electrical noise is amplified and then displayed on an electrical spectrum analyzer. RIN depends on numerous quantities, the primary ones being: frequency, output power, temperature, modulation frequency, time delay and magnitude of optical feedback, mode-suppression ratio and relaxation oscillation frequency. Consequently, variations or changes in these quantities should be minimized during the measurement process.
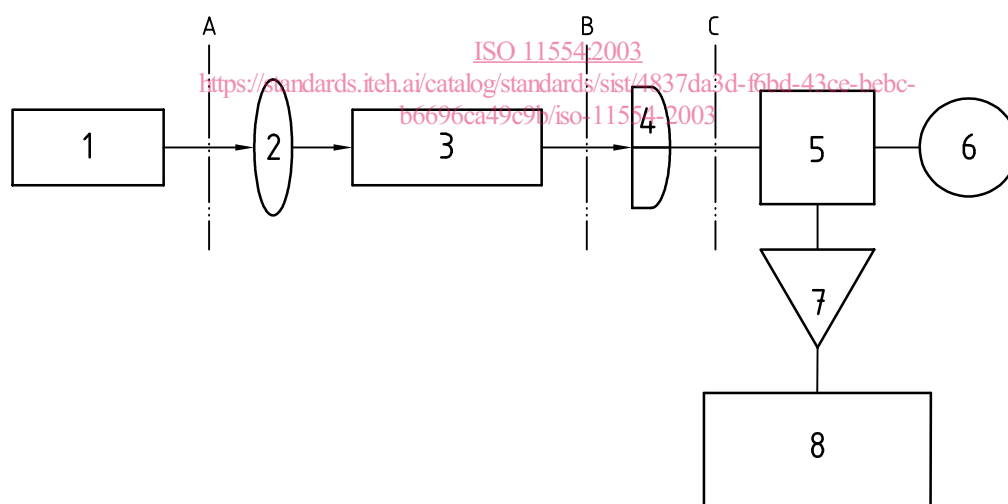
Key

1   integrating sphere
2   diffusing opaque screen
3   device being measured
4   calibrated detector

Figure 1 — Schematic arrangement for the measurement of highly divergent sources

Key

1   laser
2   lens
3   attenuator or other lossy medium
4   photodetector
5   electrical splitter
6   current meter
7   pre-amplifier
8   electrical spectrum analyzer

Figure 2 — Measurement arrangement for determination of the RIN spectrum

6.2 Control of environmental impacts

Take suitable precautions, such as mechanical and acoustical isolation of the test set-up, shielding from extraneous radiation, temperature stabilization of the laboratory and choice of low-noise amplifiers to ensure that the contribution to the total error is less than 10 % of the intended uncertainty. Check by performing a background measurement such as described in Clause 7, but with the laser beam blocked from the detector (e.g. by a beam stop in the laser resonator or close to the laser output). The value for the standard deviation (laser beam blocked) obtained by an evaluation as described in Clause 8 shall be smaller than one tenth of the value obtained from a measurement with the laser beam reaching the detector.

6.3 Detectors

The radiation detector shall be in accordance with IEC 61040:1990, in particular with Clauses 3 and 4. Furthermore, the following points shall be noted.

a) Calibrated power/energy meter:

— 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;

— for measuring beams with large divergence, an integrating sphere detector should be used to assure collection of all the emitted radiation. The direct measurement (i.e. using a planar-surface detector without an integrating sphere) can only be used when it has been determined that the sensitivity of the detector is uniform and independent on incident angles to within $5°$ and the entire beam reaches the photosensitive surface of the photodetector;

— detectors used for all quantitative measurements shall be calibrated with traceability back to relevant national standards.

b) Integrating sphere (used together with a calibrated power/energy meter when measuring sources with large divergence angles sources):

— the sphere surface shall be large compared to the device being measured, the screen and the apertures;

— the area of the sphere openings shall be small compared to the overall surface area of the sphere;

— the inner surface of the sphere and screen shall have a diffusing coating with a high uniform reflectance (0,9 minimum);

— the total losses through the sphere ports shall be less than 5 %;

— the sphere and detector assembly shall be calibrated with traceability back to relevant national standards;

— change in peak-emission wavelength and flux due to power dissipation shall be taken into account.

c) Time resolving detector:

— it shall be confirmed, from the 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 any associated electronic devices shall be minimized or corrected by use of a calibration procedure;

— the electrical frequency bandwidth of the detector, including the bandwidth of all associated electronics, shall reproduce the temporal laser pulse shape correctly. This International Standard cannot be applied to measure pulses faster than the capability of the detection system.

When measuring pulse shape characteristics (e.g. peak power, pulse width, etc.), the risetime of the detector (including the amplifier and other associated electronics) being used shall be less than one tenth of the risetime of the pulses to be measured.

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