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

Optique et photonique — 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 photonics*, Subcommittee SC 9, *Electro-optical systems*.

This third edition cancels and replaces the second edition (ISO 11554:2003), which has been technically revised.

For the purposes of this International Standard, the CEN annex regarding fulfilment of European Council Directives has been removed.

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 document 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.

This International Standard is a Type B standard as stated in ISO 12100-1.

The provisions of this International standard may be supplemented or modified by a Type C standard.

Note that for machines which are covered by the scope of a Type C standard and which have been designed and built according to the provisions of that standard, the provisions of that Type C standard take precedence over the provisions of this Type B standard.

Optics and photonics — 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 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 last edition of the referenced document (including any amendments) applies.

ISO 11145:2006, *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*

International vocabulary of basic and general terms in metrology (VIM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 2nd ed. 1993

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145, in the VIM and the following apply.

3.1
relative intensity noise
RIN
$R(f)$
single-sided spectral density of the power fluctuations normalized to the square of the average power as a function of the frequency f

NOTE 1 The relative intensity noise $R(f)$ or RIN as defined above is explicitly spoken of as the "relative intensity noise spectral density", but usually simply referred to as RIN.

NOTE 2 For further details, see Annex A.

3.2
small signal cut-off frequency
f_c
frequency at which the laser power output modulation drops to half the value obtained at low frequencies when applying small, constant input power modulation and increasing the frequency

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
f	Hz	Frequency
f_c	Hz	Small signal cut-off frequency
$[f_1, f_2]$	Hz	Frequency range for which the relative intensity noise $R(f)$ is given
k	1	Coverage factor for the determination of uncertainty
m	1	Reading
$\bar{m}$	1	Mean value of readings
P	W	Power averaged over the sampling period
$\bar{P}$	W	Mean power, averaged over the measurement period at the operating conditions specified by the manufacturer
ΔP	1	Relative power fluctuation to a 95 % confidence level for the appropriate sampling period [ΔP (1 µs) and/or ΔP (1 ms) and/or ΔP (0,1 s) and/or ΔP (1 s)]
$\bar{Q}$	J	Mean pulse energy
ΔQ	1	Relative pulse energy fluctuation to a 95 % confidence level
$R(f)$	Hz^{-1} or dB/Hz	Relative intensity noise, RIN
$S(t)$	1	Detector signal
s	1	Measured standard deviation
T	s	Pulse repetition period
t	s	Measurement period
U_{rel}	1	Expanded relative uncertainty corresponding to a 95 % confidence level (coverage factor $k = 2$)
$U_{rel}(C)$	1	Expanded relative uncertainty of calibration corresponding to a 95 % confidence level (coverage factor $k = 2$)
τ_F	s	Fall time of laser pulse
$\Delta\tau_H$	1	Relative pulse duration fluctuation with regard to τ_H to a 95 % confidence level
τ_R	s	Rise time of laser pulse
$\Delta\tau_{10}$	1	Relative pulse duration fluctuation with regard to τ_{10} to a 95 % confidence level

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

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* [3]. 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.

NOTE 3 $R(f)$ expressed in dB/Hz equals 10 lg $R(f)$ with $R(f)$ given in Hz^{-1}.

5 Measurement principles

The laser beam is directed on to 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.

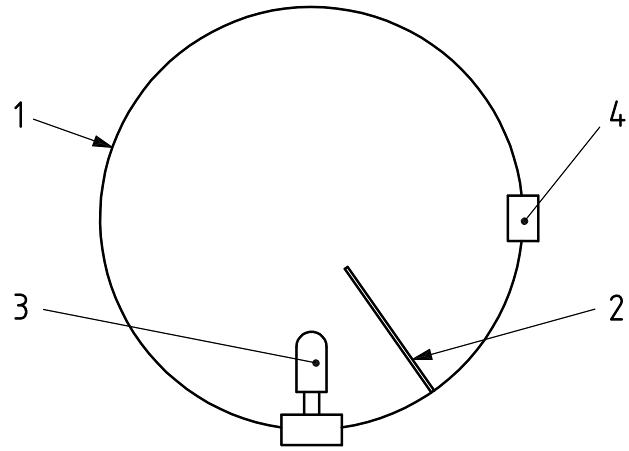
After the initial preparation is completed, make an evaluation to determine if the entire laser beam reaches the detector surface. For this determination, apertures of different diameters can be introduced into the beam path in front of each optical component. Reduce the aperture size until the output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



Key

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

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

6.1.3 RIN measurement

The measuring arrangement for determination of the RIN is shown in Figure 2. The beam propagates through the lens, an attenuator or other lossy medium, and falls on the detector. When adjusting the measuring arrangement, feedback of the output power into the laser shall be minimized to avoid measurement errors.

The RIN, $R(f)$ is 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 detection process.

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

To measure RIN, an electrical splitter sends the dc detector signal produced by a test laser to a meter while the ac electrical noise is amplified and then displayed on an electrical spectrum analyser. RIN depends on numerous quantities, the primary ones being:

— frequency;

— output power;

— temperature;

— modulation frequency;

— time delay and magnitude of optical feedback;

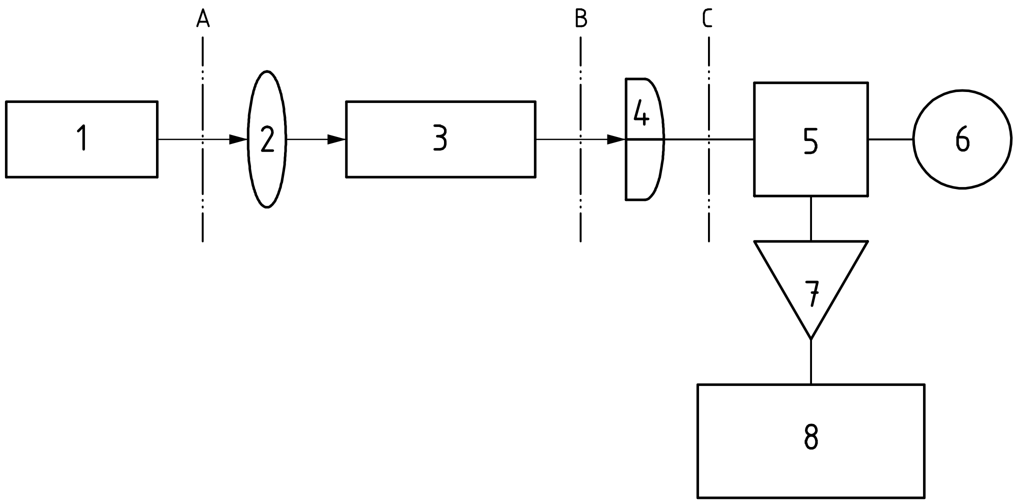
— mode-suppression ratio;

— relaxation oscillation frequency.

Consequently, variations or changes in these quantities should be minimized during the measurement process.

6.1.4 Measurement of small signal cut-off frequency

For determination of the small signal cut-off frequency, f_c, of lasers, the laser is modulated as described in 7.9 and the ac output power measured. Figure 3 shows the basic measurement arrangement for the case of diode lasers. When adjusting the measuring arrangement, feedback of the output power into the laser shall be minimized to avoid measurement errors.



Key

1 laser

2 lens

3 attenuator or other lossy medium

4 detector

5 electrical splitter

6 meter

7 pre-amplifier

8 electrical spectrum analyser

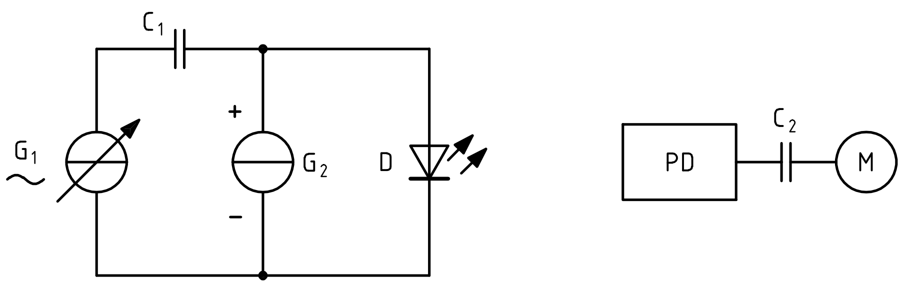
A reference plane that defines RIN

B Poisson RIN increases due to losses

C detector adds shot-noise RIN

NOTE See reference [4].

Figure 2 — Measurement arrangement for RIN determination



Key

D device being measured

PD detector (e.g. photodetector)

M measuring instrument for ac output power

G_1 adjustable frequency ac generator

G_2 dc generator

C_1, C_2 coupling capacitors

Figure 3 — Measurement arrangement for determination of the small signal cut-off frequency of diode lasers