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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 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 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 11554 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems.*

Annex ZA of this International Standard is for information only.

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, pulse duration stability and pulse repetition rate stability.

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

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 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* (BIPM, IEC, ISO, OIML).

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 11145 and in the International Vocabulary of Basic and General Terms in Metrology apply.

4 Symbols and units

The symbols and units given 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	W	Medium-term relative power fluctuation (1 min) to a 95 % confidence level
ΔP_{60}	W	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	J	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
$u_{rel,k}$	-	Relative uncertainty of calibration factor to a 95 % confidence level
u_{rel}	-	Relative uncertainty of measurement to a 95 % confidence level
f_D	Hz	Upper cutoff frequency
T	s	Pulse repetition period
τ_R	s	Rise time of laser pulse
$\Delta\tau_H$	-	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

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. Beam-forming and/or -attenuation devices may be used.

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

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 in such a way 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 centers. Care should be exercized to avoid systematic errors.

NOTE 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. 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.

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, 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 1/10 of the value obtained from a measurement with the laser beam reaching the detector.

6.3 Detectors

The provisions of IEC 61040:1990 apply to the radiation detector, clauses 3 and 4 being particularly important. 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.

b) Time-resolving detector

— 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 or the electronic device shall be minimized or corrected by use of a calibration procedure.

— The electrical frequency bandwidth of the detector, including the bandwidth of a succeeding amplifier and associated electronics, shall reproduce the temporal laser pulse shape correctly. The decisive factor for this is the steepest slope. This International Standard cannot be applied to measure pulses faster than the capability of the detection electronics.

The upper cutoff frequency f_D (6 dB decay of the sensitivity) of the detector including the amplifier should at least be three times the reciprocal value of the rise time τ_R of the laser pulse.

$$f_D \geq 3\frac{1}{\tau_R} \tag{1}$$

The lower cutoff frequency shall be zero.

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

6.4 Beam-forming optics

If the cross-section of the beam is greater than the detector area, a suitable optical system shall be used to image the area of the cross-section of the laser beam onto the detector surface.

Optics shall be selected appropriate to wavelength. Absorption/reflection loss shall be measured and accounted for in all measurements. The laser polarization shall be accounted for if polarization-dependent reflections are present.

6.5 Optical attenuators

An attenuator is used to reduce the laser power density at the surface of the detector.

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 polarization and angular dependency, non-linearity or non-uniformity of the optical attenuator shall be minimized or corrected by use of a calibration procedure.

7 Measurements

7.1 General

Unless otherwise stated, carry out the measurements 10 times, with intervening background measurements.

Before beginning the measurements, warm up the laser for at least 1 h (if not otherwise stated by the manufacturer) to achieve thermal equilibrium. Carry out the measurements at the operating conditions specified by the laser manufacturer for the type of laser which is being evaluated.

7.2 Power of cw lasers

Measure the power with a calibrated power meter and, if required, with a calibrated attenuator.

7.3 Power stability of cw lasers

For the determination of medium-term stability, the measurement period is 1 min. The beam is sampled every 1/100 s. The time constant of the detecting system shall be less than or equal to 1/300 s. Synchronization with the incoming electrical ('mains') supply shall be avoided.

For the determination of long-term stability, the measurement period is 1 h. The beam is sampled every 1 s. The time constant of the detecting system shall be less than or equal to 1/3 s.

Record maximum and minimum readings.

7.4 Pulse energy of pulsed lasers

Measure the energy of a single pulse with a calibrated energy meter and, if required, with a calibrated attenuator.

7.5 Energy stability of pulsed lasers

Carry out the measurement described in 7.4 for 100 successive — if possible — pulses. If this is not possible, 100 pulses which do not succeed each other may also be used. State in the test report the procedure employed.

Record maximum and minimum readings.

7.6 Temporal pulse shape, pulse duration, rise time and peak power

Measure the temporal pulse shape with a detector as described in 6.3. For the determination of peak power, measure the pulse energy at the same time in accordance with 7.4.

7.7 Pulse duration stability

Measure the duration of 100 pulses as described in 7.6.

Record maximum and minimum readings.

7.8 Pulse repetition rate

A frequency counter may be used to measure the pulse repetition rate from the detector output signal. Care must be exercised in the triggering method selected to reduce false or double triggering of the counter. This is of particular concern when the laser pulse contains more than one peak. An oscilloscope or transient recorder may be used to view the power versus time waveform output from the detector.

Alternatively, a measurement of the time between two equivalent peaks of successive pulses from the detector output will yield the pulse repetition period T. The pulse repetition rate f_p is evaluated as the reciprocal of the pulse repetition period T.

$$f_p = 1/T \tag{2}$$

8 Evaluation

8.1 General

The standard deviation s from n readings m_i is calculated according to equation (3):

$$s = \sqrt{\frac{\sum_{i=1}^{n}(m_i - \overline{m})^2}{n-1}} \tag{3}$$

with the mean value $\overline{m}$

$$\overline{m} = \frac{\sum_{i=1}^{n} m_i}{n} \tag{4}$$

The relative uncertainty of the calibration factor $u_{rel,k}$ is calculated from the relative uncertainty of the calibration factor of the detector $(u_{rel,k})_D$, the relative uncertainty of the calibration factor of the attenuator $(u_{rel,k})_A$ and the relative uncertainty caused by the electronics as follows:

$$u_{rel,k} = \sqrt{\sum_{i=1}^{n}\left(u_{rel,k}\right)_i^2} \tag{5}$$

where

i is D, A, electronics

$u_{rel,k}$ are determined to a 95 % confidence level.

8.2 Power of cw lasers

Calculate the power $\overline{P}$ as the mean value of 10 single measurements taken in accordance with 7.2. This is required to estimate the variability of the measurement.

Calculate the relative uncertainty u_{rel} of the measurement from the standard deviation s and the relative uncertainty of the calibration factor $u_{rel,k}$

$$u_{rel} = 2\sqrt{\frac{s^2}{\overline{P}^2} + \frac{1}{4}\left(u_{rel,k}\right)^2} \tag{6}$$