INTERNATIONAL STANDARD

ISO 11254-3

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Lasers and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces —

Part 3:
Assurance of laser power (energy) handling capabilities

Lasers et équipements associés aux lasers — Détermination du seuil d'endommagement provoqué par laser sur les surfaces optiques —

Partie 3: Vérification de la capacité à supporter la puissance (l'énergie) laser

Reference number
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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 11254-3 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

ISO 11254 consists of the following parts, under the general title *Lasers and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces*:

— *Part 1: 1-on-1 test*

— *Part 2: S-on-1 test*

— *Part 3: Assurance of laser power (energy) handling capabilities*

Introduction

Optical components can be damaged by laser irradiation of sufficiently high energy or power density. At any specified laser irradiation level the probability of laser damage is usually higher for the surface of a component than for its bulk. Thus the limiting value of an optical component is usually given by the damage threshold of its surface.

This document provides a test procedure for obtaining consistent measurement results, which may be used for acceptance tests or may be compared between different testing laboratories.

This testing procedure is applicable to all combinations of different laser wavelength and pulse length durations. Comparison of laser damage threshold data may be misleading unless the measurements have been taken at identical wavelengths and pulse lengths.

Lasers and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces —

Part 3: Assurance of laser power (energy) handling capabilities

SAFETY PRECAUTIONS — Some laser and optical components are made of materials which are toxic if vaporized (e.g. ZnSe, GaAs, CdTe, ThF_4, chalcogenides, Be, Cr, Ni). Due care shall be taken not to damage these materials without taking suitable safety precautions.

1 Scope

This part of ISO 11254 describes a test procedure for assurance of power density (energy density) handling capability of optical surfaces, both coated and uncoated.

This part of ISO 11254 specifies this procedure by providing two test methods for assurance of the power density (energy density) handling capability of optical surfaces.

The first method provides a rigorous test that fulfils requirements at a specified confidence level in the knowledge of potential defects.

The second method provides a simple test for an empirically derived test level, allowing an inexpensive test.

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 10110-7:1996, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 7: Surface imperfection tolerances*

ISO 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

3 Terms and definitions

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

3.1
surface damage
any permanent laser radiation-induced change of the surface characteristics of the specimen, which can be observed by an inspection technique described in this part of ISO 11254

3.2
1-on-1 test
test programme that uses one shot of laser radiation on each unexposed site on the specimen surface

3.3
S-on-1 test
test programme that uses S shots on each unexposed site on the specimen surface

3.4
target plane
plane tangential to the surface of the specimen at the point of intersection of the test laser beam propagation axis with the surface of the specimen

3.5
effective pulse duration
τ_{eff}
ratio of total pulse energy to peak pulse power

3.6
assurance level
ϕ
energy density/power density/linear power density of the laser radiation incident on the optical surface at which the component is tested

3.7
assurance area
A_ϕ
area over which the value of the energy density H(x,y,z) is equal to or greater than the assurance level, ϕ

3.8
confidence level
γ
complement of the probability of successful completion of the assurance test

3.9
effective beam diameter
twice the square root of the assurance spot area divided by pi (π)

See Table 1 for symbols and units.

$$d_{\phi,\text{ eff}} = 2\sqrt{\frac{P}{\pi E_{\text{max}}}} \tag{1}$$

3.10
flat-top beam
beam that has a broad area of nearly constant peak intensity (or fluence)

4 Symbols and units of measurement

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
λ	nm	wavelength
α	rad	angle of incidence
p	1	degree of polarization
τ_{H}	ns, µs, ms, s	pulse duration
τ_{eff}	ns, µs, s	effective pulse duration
Q	J	pulse energy
P_{pk}	W	peak pulse power
P	W	power
H_{max}	J/cm^2	maximum energy density
E_{max}	W/cm^2	maximum power density
F_{max}	W/cm	maximum linear power density
d_{sep}	mm	separation of test sites
γ	1	confidence level
R	1	risk of false assurance
f_{test}	1	fraction of test area to be exposed
N_{d}	1	number of damage initiation sites
ϕ	J/cm^2, W/cm^2, W/cm	assurance level
A_{ϕ}	cm^2	assurance area
A_{test}	cm^2	area to be tested
N_{TS}	1	number of sites in tested area to be interrogated
Ω_{x}	1	horizontal overlap
Ω_{y}	1	vertical overlap

5 Sampling

This part of ISO 11254 provides a procedure that will give a high level of confidence to the power density (energy density) handling capability of the component tested.

It may be used in a wide variety of applications, including: non-destructive inspection, witness sampling, lot sampling and sub-aperture inspection. The level of confidence that the component does not contain a defect with a lower damage threshold than the acceptable irradiation strength, increases with the percentage fraction of the area tested. These confidence levels are discussed in Annexes B and C.

Discussion between the testing house and the user/component manufacturer shall be held to define the confidence level required and number of shots per site (1-on-1 or S-on-1 testing) and the pulse repetition frequency at which the tests are taken.

This will define such parameters as the acceptable irradiation spot area, A_{ϕ}, the spot site separation, d_{sep}, and the total number of sites, N_{TS}, to be irradiated.

6 Test method

6.1 Principle

This test irradiates sampled test sites on the specimen surface at an agreed or specified irradiation strength, irradiating in sequence, a fraction of the specimen area and verifying that no damage is observable. Enough samples (test sites) of the optical surface under test shall be irradiated so that a given confidence level can be established. See Figure 1.

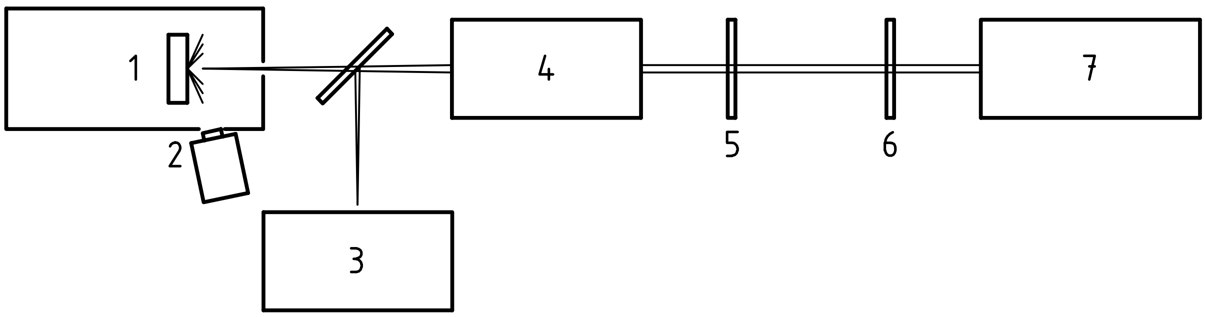
Since the observation of any damage during a test constitutes failure, this test can be non-destructive for acceptable parts.

Microscopic examination of the testing site before and after irradiation is used to detect damage.

This procedure is applicable to testing with all laser systems. The polarization state is set with an appropriate waveplate.

The fluence handling ability of an optical surface under irradiation by short pulsed lasers is usually expressed in units of energy density (joules per square centimetre).

The power handling ability of an optical surface under irradiation by quasi-continuous wave (cw) or cw-lasers is usually expressed in units of linear power density (watts per centimetre). Power density refers to the average power per unit area during the irradiation time. The proper units and physical parameter for scaling results for quasi-cw and cw-lasers is the linear power density expressed in watts per centimetre.



Key

1 sample in compartment
2 online damage detector
3 beam diagnostic
4 focusing system
5 waveplate
6 variable attenuator
7 laser system

Figure 1 — Basic approach to laser damage testing

6.2 Apparatus

6.2.1 Laser system

A laser system delivering laser radiation with a reproducible near flat-top spatial profile is required. The temporal profile of the pulses is monitored during the measurement. For the different laser groups, the maximum permissible variations of the pulse parameters are compiled in Table 2. Stability criteria for the beam parameters, and therefore the incident energy density of the laser, shall be determined and documented in an error budget and included with the test report as shown in Annex A.

References for the production of a flat-top beam and laser damage scaling are contained in the Bibliography.

Table 2 — Maximum variation of laser system parameters and corresponding percentage variation of the assurance pulse power density

Laser type	Pulse energy Q	Average power P_{av}	Pulse duration τ_H	Assurance area A_ϕ	Power density E_{max}
pulsed	± 5	–	± 10	± 10	± 15
cw	—	± 5	—	± 6	± 20
NOTE Variations are tabulated in percent.					

6.2.2 Variable attenuator and beam delivery system

The laser output shall be attenuated to the required level with an external variable attenuator free of drifts in transmissivity and imaging properties.

The beam delivery system and the attenuator shall not affect the properties of the laser beam in a manner inconsistent with the tolerances given in 6.2.1. The polarization state of the laser beam shall not be altered by the beam delivery system.

6.2.3 Focusing system

The focusing system shall deliver a flat top energy distribution along a section of the beam. The beam shall have a central peak region where the local fluence or power density for pulsed lasers or linear power density for cw lasers varies less than the values given in Table 3.

Table 3 — Maximum variations in central peak regions

Laser type	Maximum variation (peak to valley) over the central peak region expressed as a percentage of the maximum value
pulsed	± 11 %
cw	± 14 %

Coherence effects in specimens with parallel surfaces may affect the measurement. These effects shall be eliminated by appropriate techniques such as wedging or tilting of the specimen. The application of a highly converging beam is a method for removing coherence effects in the specimen.

6.2.4 Specimen holder

The test station shall be equipped with a manipulator for a precise placement of the test sites on the specimen with precision sufficient for the specimen size.

6.2.5 Damage detection

A microscope technique shall be used to inspect the surface before and after the test. The inspection shall be made with an incident light microscope having Nomarski-type differential interference contrast. A magnification in the range from 100 × to 150 × shall be used. For routine inspection and objective measurement of laser damage, an image analyser may be attached to the microscope.

An appropriate online damage detection system may be installed to evaluate the state of the surface under test. For online detection, any appropriate technique may be used. Techniques suited to this purpose are online microscopic techniques in conjunction with image analysers, photoacoustic and photothermal detection, and scatter measurements using a separate laser or radiation from the damaging laser. A typical set-up for an online scatter measurement system is described in ISO 11254-2.

6.2.6 Beam diagnostics

6.2.6.1 Total pulse energy and power

The diagnostic package shall be equipped with a calibrated detector to measure the pulse energy or beam power delivered to the target plane. This instrument shall be traceable to a national standard with an absolute uncertainty of ± 5 % or better.

6.2.6.2 Temporal profile

The diagnostic package shall include suitable instrumentation for analysing the temporal profile of the laser to determine the pulse duration.

6.2.6.3 Spatial profile

The spatial profile shall be analysed in the target plane or an equivalent plane. The diagnostic package shall be equipped with instrumentation to measure the two dimensional spatial profile with a spatial resolution to the requirements stated in Table 2.

6.3 Preparation of test specimens

Wavelength, angle of incidence and degree of polarization of the laser radiation used in the test shall be in accordance with the specifications by the manufacturer for normal use. If ranges are given for the values of these parameters, an arbitrary combination of wavelength, angle of incidence and polarization within these ranges may be used.

Storage, cleaning and preparation of the specimens shall be according to the specifications provided by the manufacturer for normal use.

In the absence of manufacturer specified instructions, the following procedure shall be used.

The specimen shall be stored at less than 50 % RH for 24 h prior to testing. The specimen shall be handled by the non-optical surfaces only. Before testing, a microscopic evaluation of surface quality and cleanliness in accordance with ISO 10110-7 shall be made using a Nomarski/darkfield microscope at 150 × magnification or higher.

If contaminants are seen on the specimen, the surface shall be cleaned. The cleaning procedure shall be documented. If the contaminants are not removable they shall be documented by photographic and/or electronic means before testing. The test site shall be inspected for dust particles during irradiation. The test environment shall be clean filtered air of less than 50 % RH and shall be documented.

The testing-sites shall be arranged in a well defined and reproducible arrangement. The test grid shall be referred to fixed reference points on the specimen.

6.4 Test procedures

6.4.1 General

In tests that sample the ability of an optic to withstand laser irradiation, it is possible to define two types of test.

The first, a Type 1 test, allows the determination of a confidence level that permits no more than a certain number of defects to exist within a tested area. The Type 1 test is discussed in 6.4.2.

The second, a Type 2 test, is designed, usually empirically, to be used on a specific optic for a specific use. Such tests are used to provide a cost effective screen in a high rate industrial environment. It should be noted that such empirically derived tests were the first widely used laser damage tests applied to production systems. The criteria that shall be specified to define a Type 2 test are given in 6.4.3.

6.4.2 Type 1 procedure

a) According to the application select the assurance level, ϕ, the confidence level, γ, and the number of defects N_d per sample (usually the responsibility of the user).

b) Use Figure 2 to determine the fraction of the area to be tested, A_{test}, that shall be exposed, f_{test}.

c) Determine (via measurement) A_ϕ from irradiating beam power density or energy density profile in the target plane.

d) Determine the number of interrogations, N_{TS} that shall be made to expose f_{test} of the surface under test. $N_{TS} = (A_{test} \times f_{test})/A_\phi$.

e) Determine the spacing d_{sep} between the test sites for hexagonal close packed arrays and for square arrays

$$d_{sep} = \sqrt{\frac{2A_{test}}{N_{TS}\sqrt{3}}} \text{ for hexagonal close packed arrays}$$

$$\sqrt{\frac{A_{test}}{N_{TS}}} \text{ for square arrays} \tag{2}$$

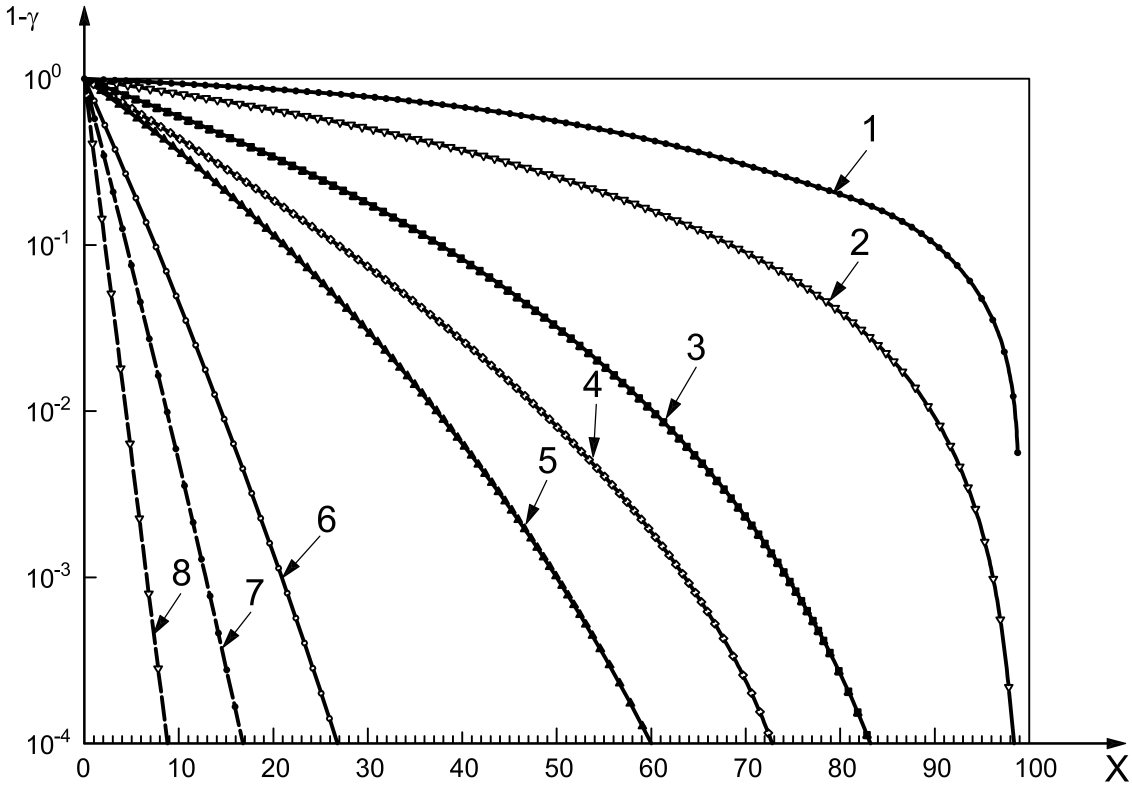
f) Calculate the overlap, Ω_x

$$\Omega_x = \frac{\iint H(x,y) \cdot H(x - d_{sep}, y)\, dxdy}{\iint H(x,y)^2 dxdy} \tag{3}$$

In all cases it may not be possible to perform an unconditioned assurance test, i.e. Ω_x or $\Omega_y \ll 1$. Also note, if H(x,y) is significantly non-symmetric it is necessary to calculate Ω_y.

$$\Omega_y = \frac{\iint H(x,y) \cdot H(x, y - d_{sep})\, dxdy}{\iint H(x,y)^2 dxdy} \tag{4}$$

g) Irradiate the optical surface under test step by step for N_{TS} test sites. Each test site shall be separated in a hexagonal closed packed array of lattice constant d_{sep}. For S-on-1 tests, each test site shall be irradiated to the required number of pulses according to its application. If there is damage at any site the part is a failure and disposed of as such. If the part under test survives (no damage at any site), then it is passed for the test parameters as listed.



NOTE The derivation of the curve above, called the operating characteristic (OC) curve, is based on a defect dominated damage mechanism. The details of the derivation of the OC curve are given in Annex C.

Key

X percentage of area tested

1 1 defect
2 2 defects
3 5 defects
4 7 defects
5 10 defects
6 30 defects
7 50 defects
8 100 defects

Figure 2 — Operating characteristic curve

6.4.3 Type 2 procedure

In order to specify a Type 2 test the following parameters shall be specified and controlled:

a) assurance level, ϕ;

b) area of assurance level, A_ϕ;

c) number of spots tested;

d) shots exposed per spot;

e) pulse repetition frequency if an S-on-1 test;

f) separation of test sites, d_{sep}.

If the specifying contractor does not specify these parameters, then the testing laboratory shall use the maximum spot area at which they can produce enough irradiation strength for an assurance. The testing laboratory shall also propose an irradiation pattern without spot overlap and the test rationale (e.g. ten rows of ten discrete spots over the centre of the area to be tested).

An example of a defined Type 2 test is given in the latter portion of Annex B.

NOTE A Type 2 test has been shown to have a high degree of utility in industrial (large scale) applications.

7 Accuracy

The calibration error budget shall be prepared in order to determine the overall measurement accuracy. Variations in the total energy or beam power, spatial profile, and temporal profile shall be included in the error budget. An example is given in Table 4.

Table 4 — Typical error budget for a pulsed laser system

Random variations	
Pulse-to-pulse energy stability	± 3 %
Pulse-to-pulse spatial profile stability	± 5 %
Pulse-to-pulse temporal profile stability	± 5 %
Systematic variations	
Calorimeter calibration	± 3 %
Calorimeter-energy monitor correlation	± 2 %
Overall energy density measurement reproducibility	± 5,8 %
Overall energy density measurement uncertainty	± 6,8 %
Overall power density measurement reproducibility	± 7,7 %
Overall power density measurement uncertainty	± 8,5 %

8 Test report

The following information shall be included in the test report.

a) General information

1) that the test has been performed according to ISO 11254-3:2006;

2) date of test;

3) name and address of test organization;

4) accreditation (if relevant);

5) name of individual performing the test;

6) customer/client.

b) Information concerning the test sample

1) type of test sample;

2) manufacturer of test sample;

3) part ID, date of production;

4) specifications by the manufacturer concerning storage, cleaning, etc.;

5) specifications by the manufacturer for normal use.

c) **Information concerning the test facility**

1) beam source;

— type of beam source;

— manufacturer;

— manufacturer's model designation;

— serial number;

2) description of other relevant test equipment.

d) **Test conditions**

1) wavelength tested at;

2) operating mode: cw/pulsed;

3) source parameter settings:

— assurance test area;

— current or energy input;

— pulse energy;

— pulse duration;

— pulse repetition rate;

4) mode structure (in case a laser source is used);

5) polarization;

6) environmental conditions;

7) cleaning;

8) method of mounting of optical component.

e) **Information concerning testing and evaluation**

1) test method used;

2) 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);

3) beam forming optics and attenuating method;

   - type of attenuator;
   - type of beam splitter;
   - type of focusing element;

4) other optical components and devices used for the test (polarizer, monochromator, etc.);

5) surface quality/imperfections/contamination;

6) other relevant parameters or characteristics of the test which shall be chosen (aperture setting, orientation of the test sample with respect to the beam, reference plane, reference axis, laboratory system).

f) Error budget

g) Test results

1) disposition of the part, pass or fail;

2) if a failure, then a photomicrograph should be included showing the damaged site.

A test report containing the test specifications and the test results shall be written and supplied to the customer. An example is given in Annex A.

Annex A
(informative)

Test report example

Testing organization

Organization name:	Tres Gatos Laser Testing Corporation, Santa Monica CA USA
Name of tester and date of test	Ben L. Gato / 06/07/2000

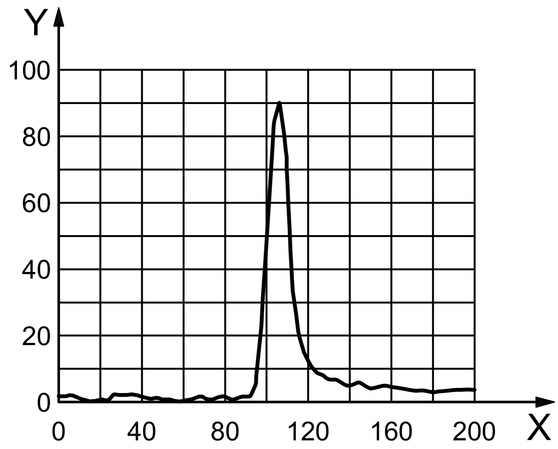
Specimen

Type of specimen:	Original part, HR at 193 nm on CaF_2
Manufacturer:	Blinding Light Optical, Salem, Mass.
Storage, cleaning:	Normal laboratory conditions
Specification:	High reflective mirror, $R > 99{,}5\ \%$ at 193 nm, 0 rad angle of incidence, standard coating for normal use in excimer lasers
Part identification, date of production:	BLO, 2001/10/05
Serial number of part:	BLO, 3328-5570-193

Test specification

Laser parameter:

Wavelength	193 nm
Incidence angle	0 rad
Polarization state	unpolarized
Pulse repetition frequency	200 s^{-1}
Effective beam radius in target plane	3,3 mm
Pulse duration	13,0 ns
Effective pulse duration	12,5 ns

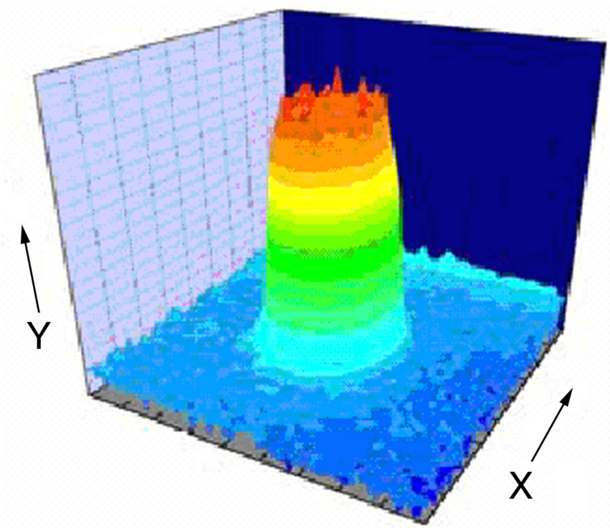


Key

X time in nanoseconds

Y power (arbitrary units)

Figure A.1 — Temporal profile



Key

X Y-position in millimetres

Y fluence

Figure A.2 — Spatial distribution of energy

Error budget:

a) Random variations:

Pulse-to-pulse energy stability	± 7 %
Pulse-to-pulse spatial profile stability	± 3 %
Pulse-to-pulse temporal profile stability	± 10 %

b) Systematic variations:

Energy monitor calibration	± 8 %
Overall energy density measurement reproducibility	± 8 %
Overall energy density measurement uncertainty	± 10 %

Test procedure:

Test type	Type 1
Assurance level	6,5 mJ/cm^2
Confidence level	97 %
Defect density per part	5
Area to be tested	4,9 cm^2
Conditioned test: Y or N	No
Pulse repetition frequency	200 Hz
Number of shots per site	100 000
Number of shots per specimen	800 000
Arrangement of test sites	hexagonal close packed (see Figure A.3)
Distance between sites	6,7 mm
Number of specimens tested	1
Total number of sites for the test	8
Damage detection	post inspection, Nomarski microscope
Storage of the specimen	manufacturer box, PE, normal room conditions
Test environment	clean filtered air
Cleaning	manual cleaning with lens paper, isopropanole, acetone
Test disposition	Pass

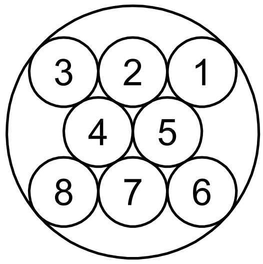


Figure A.3 — Arrangement of test sites

Annex B
(informative)

Usage notes

B.1 General

This appendix traces the use of this part of ISO 11254 from a typical drawing note, to the test of the optic in question and the resultant test report.

A typical drawing note for assurance might appear as written below:

Coated optical surface to be certified at 10 J/cm^2 per ISO 11254-3, to 95 % confidence that there are no more than 2 damage initiation sites over the clear aperture. The clear aperture for this part has an area of 10 cm^2.

B.2 Type 1 test

Design of the test — the parameters of the assurance are given in the drawing note as shown in the italicised text given in B.1.

Step 1: Determine the fraction of the clear aperture, f_{test}, that shall be interrogated at the test level of 10 J/cm^2 to certify to a 95 % level of confidence that there are no more than two damage initiation sites. To determine f_{test}, Figure 2 in 6.4 is consulted. Using Figure 2, make the following construction. Draw a horizontal line (A) with the value 0,05, this value being the complement of the confidence (which can also be called the risk), continue this line until it intersects the curve corresponding to N_{d} = 2, point P. Then construct the perpendicular line (B) to (A) through P. The intersection of (B) with the horizontal axis is the fraction of the surface area that shall be interrogated, namely 0,77 or 77 %.

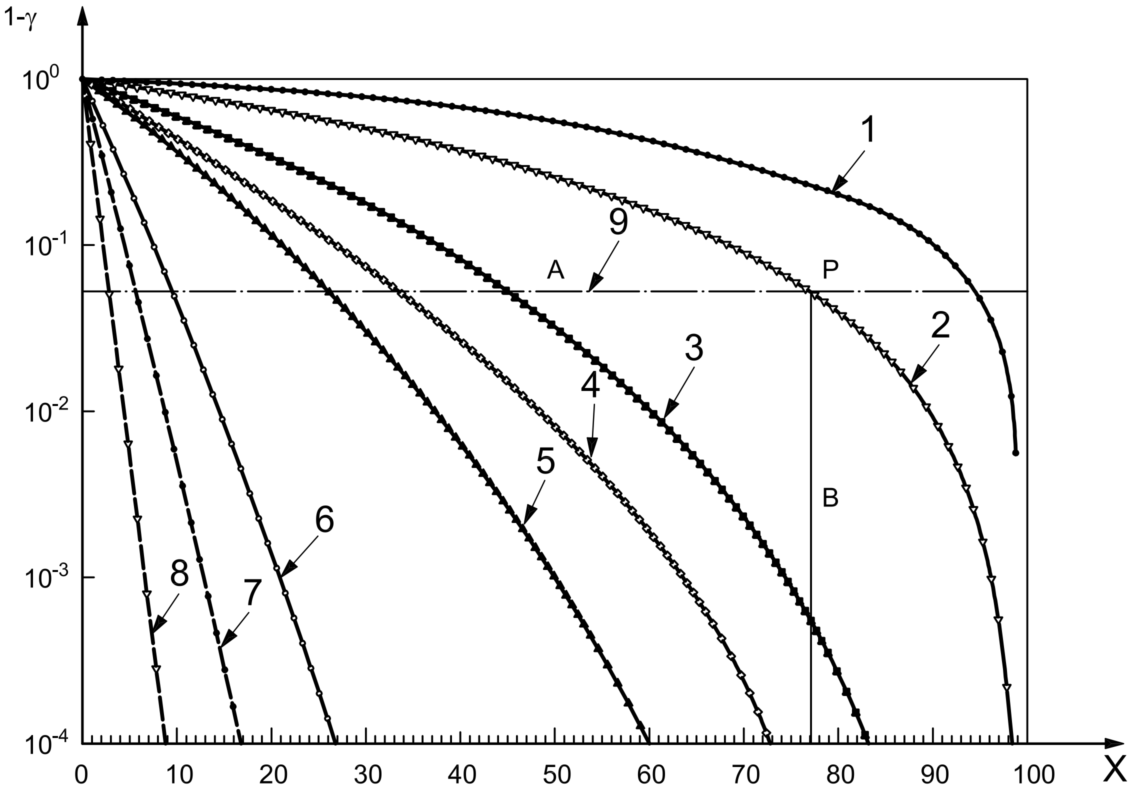
Step 2: Determine the area of the laser test spot that is at or above 10 J/cm^2, A_{10}. The determination of A_{10} requires knowledge of the spatial fluence profile H(y,z). For the purposes of this example it is assumed that spatial fluence profile is an ideal “top-hat” distribution of radius 1 mm. Specifically,

$$H(\text{y,z}) = \begin{array}{ll} H_0 & \text{if } \sqrt{\text{y}^2 + \text{z}^2} \leqslant 1\,\text{mm} \\ 0 & \text{if } \sqrt{\text{y}^2 + \text{z}^2} > 1\,\text{mm} \end{array} \tag{B.1}$$

For this fluence distribution, A_{10} is π mm^2 or 0,031 cm^2.

Step 3: The next step is the calculation of the number of interrogation sites, N_{TS}, required to expose 77 % of the clear aperture to 10 J/cm^2.

$$N_{\text{TS}} = \frac{A_{\text{CA}} f_{\text{test}}}{A_{10}} = 249 \tag{B.2}$$



Key

X percentage of the area tested

1 1 defect

2 2 defects

3 5 defects

4 7 defects

5 10 defects

6 30 defects

7 50 defects

8 100 defects

9 95 % confidence [0,05 % Pr (S)]

Figure B.1 — Fraction of surface required to be tested for a confidence level of γ, for various values of N_d

Step 4: Determination of the spacing between the interrogation sites is determined next. The most efficient arrangement of a two-dimensional lattice is the hexagonal closed packed array, in which each site has six neighbours each of which is equidistant. If the separation of the test sites is denoted d_{sep}:

$$d_{sep} = \sqrt{\frac{2A_{test}}{N_{TS}\sqrt{3}}} \text{ for hexagonal close packed arrays}$$

$$\sqrt{\frac{A_{test}}{N_{TS}}} \text{ for square arrays} \qquad \text{(B.3)}$$

Step 5: Solving for d_{sep} in the present case gives a centre to centre separation of 1,9 mm, for a hexagonal close packed array.

Step 6: In the present case there is no overlap as d_{sep} is greater than the spot diameter, thus $\Omega = 0$.

Step 7: Exposure of the sample is the final step in the procedure. The sample is interrogated 249 times with a separation of 1,9 mm between sites and each site is monitored for damage. If all sites are exposed without observance of damage, the part is certified.

B.3 Type 2 test

In the case of a Type 2 test, the following parameters are decided upon:

a) assurance level, ϕ;

b) interrogation area, A_ϕ;

c) number of interrogations, N_{TS};

d) number of shots per interrogation site, S;

e) pulse repetition frequency if $S > 1$;

f) separation of interrogations sites, d_{sep}.

For the purposes of this example, consider the test design for a hypothetical 5 cm × 5 cm window.

This part of ISO 11254 gives the process and parameters that shall be specified to achieve a repeatable result. This part of ISO 11254 does not give guidance on the values of the parameters for a Type 2 test; this is the responsibility of the user, manufacturer or testing organization.

For the 5 cm × 5 cm window the user has defined:

a) assurance level, ϕ = 10 J/cm^2;

b) interrogation area, A_ϕ = 15 mm^2;

c) number of interrogations, N_{TS} = 5;

d) number of shots per interrogation site, S = 200;

e) pulse repetition frequency, 20 Hz;

f) separation of interrogations sites, maximum possible.

In the case of this hypothetical test, the window being tested is exposed initially at site 1 to 200 shots, see Figure B.2. If no damage is observed, then the laser is repositioned to site 2, where again 200 shots are applied. This process continues until either site 5 has received its 200 shots or damage is observed.

Dimensions in millimetres

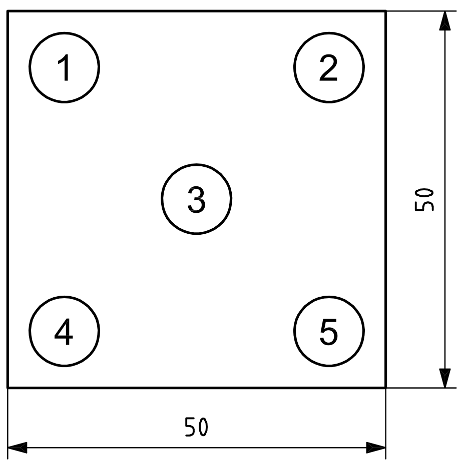


Figure B.2 — Typical Type 2 test spot layout

Annex C
(informative)

Details of the derivation of the operating characteristic curve

This annex provides the details of the derivation of the operating characteristic curve relating the probability of a successful test to the fraction of the test area interrogated and parameterized by the number of damage sites, N_d.

The derivation begins with the derivation of the probability of damage on the first shot, denoted $\Pr(D_1)$, which is given by

$$\Pr(D_1) = 1 - e^{\frac{-A_\phi N_d}{A_{test}}} \tag{C.1}$$

The probability of survival (no damage) on the first shot, denoted, $\Pr(ND_1)$ is the complement of $\Pr(D_1)$ namely

$$\Pr(ND_1) = e^{\frac{-A_\phi N_d}{A_{test}}} \tag{C.2}$$

The probability of survival on the second shot, is the product of the probabilities of survival on the first and then second shots. The value of $\Pr(ND_2)$ is given by

$$\Pr(ND_2) = e^{\frac{-A_\phi N_d}{A_{test} - A_\phi}} \tag{C.3}$$

The reason for the decrement by A_ϕ is that there are no defects in the first spot interrogated, therefore the N_d defects shall be in the remaining fraction of the A_{test}. So the probability of survival to the second shot, $\Pr(S_2)$ is

$$\Pr(S_2) = \Pr(ND_1)\Pr(ND_2) = e^{\frac{-A_\phi N_d}{A_{test}}} \times e^{\frac{-A_\phi N_d}{A_{test} - A_\phi}} \tag{C.4}$$

From (C.4) it is clear that the value of $\Pr(S_n)$, the probability of survival on the nth interrogation is

$$\Pr(S_n) = e^{\frac{-A_\phi N_d}{A_{test}}} \times e^{\frac{-A_\phi N_d}{A_{test} - A_\phi}} \ldots e^{\frac{-A_\phi N_d}{A_{test} - (n-1)A_\phi}} \tag{C.5}$$

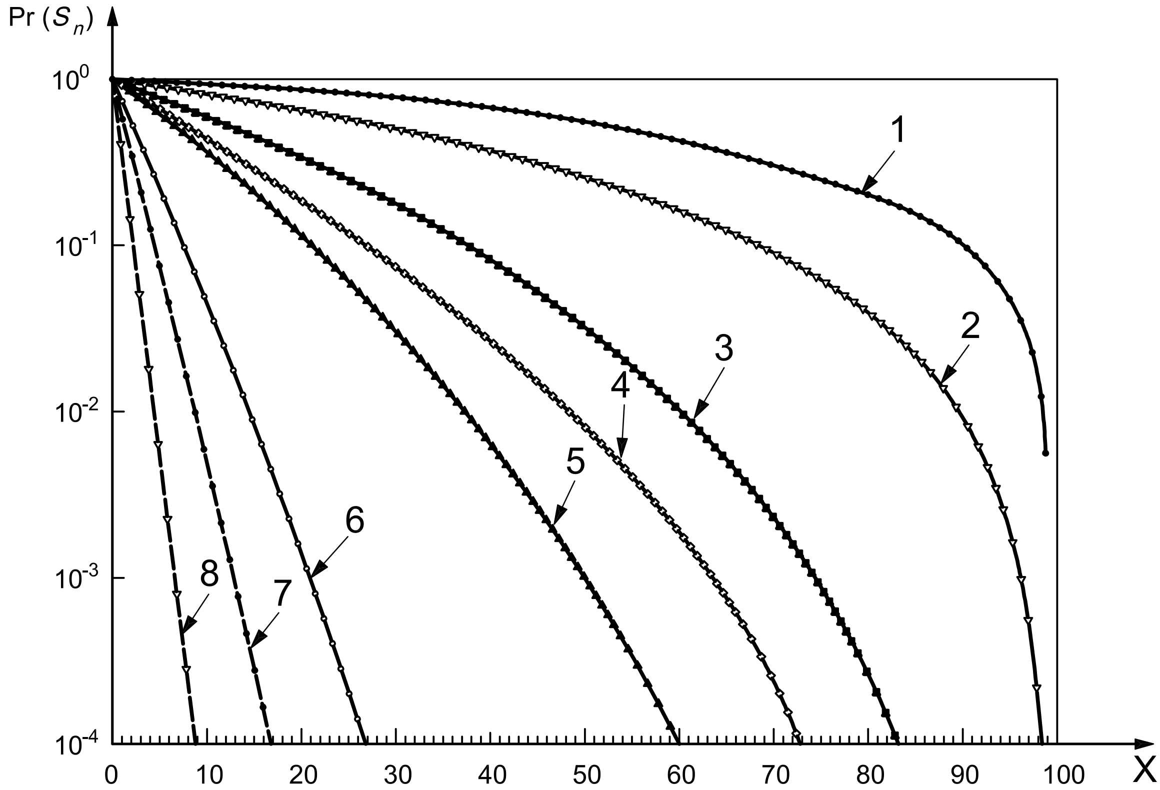
Next, the expression in (C.5) may be non-dimensionalized by factoring out A_{test} from the exponent, namely

$$\Pr(S_n) = e^{-\frac{A_{\phi d}}{A_{test}} Nd} \times e^{\frac{-\frac{A_\phi}{A_{test}} N_d}{1 - \frac{A_\phi}{A_{test}}}} \ldots e^{\frac{-\frac{A_\phi}{A_{test}} N_d}{1 - (n-1)\frac{A_\phi}{A_{test}}}} \tag{C.6}$$

Let $u = \frac{A_\phi}{A_{\text{test}}}$, it is clear that u is the laser spot area expressed in units of the area to be tested and it is also seen that u is the reciprocal of the number of interrogations needed to expose A_{test}. So, the quantity $(n–1)u$ is the fraction of the total area to be tested that has been interrogated (up to the nth interrogation). So (C.6) can be written as

$$\Pr\left(S_n\right) = e^{-uN_{\text{d}}} e^{\frac{-uN_{\text{d}}}{1-u}} \dots e^{\frac{-uN_{\text{d}}}{1-(n-1)u}} \quad \text{(C.7)}$$

A plot of (C.7) is given in Figure C.1.



Key

X percentage of the area tested

1 1 defect

2 2 defects

3 5 defects

4 7 defects

5 10 defects

6 30 defects

7 50 defects

8 100 defects

Figure C.1 — Operating characteristic curve

Figure C.1 shows that $\Pr(S_n)$ will vary strongly with the number of defects and the fraction of the assurance area interrogated. Further, $\Pr(S_n)$ decreases monotonically with increasing area tested. Thus, survival is interpreted as a determination that fewer than N_{d} defects are in the assurance area. But, there is a finite probability that the optic under test will fail early, or have more than N_{d} defects and not fail. The smaller this complimentary probability is made, the more certain, that in the area of assurance, the number of defects does not exceed N_{d}. Therefore, $1–\gamma$ is taken to be the confidence in the validity of the outcome of the assurance test.

For example, if very little of the area is interrogated, the part is expected to survive except at the highest defect densities. So there is low confidence in a small area test determining the maximum number of defects in the area of assurance, and the value of $1-\gamma$ is small. Conversely, if a large fraction of the area is interrogated, discrimination can be made even between N_d values of 1 and 2. In this regime, $1-\gamma$ is large and there is high confidence that there are less than N_d defects in the assurance area. This leads to the assignment of the name confidence to $1-\gamma$.

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