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Optics and optical instruments — Test methods for surface imperfections of optical elements

Optique et instruments d'optique — Méthodes d'essai applicables aux imperfections de surface des éléments optiques

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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 14997 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 1, *Fundamental standards*.

Introduction

This International Standard was developed in response to worldwide demand for test methods for surface imperfections which are objective and permit fast assessment of component quality. Existing standards have been assessed [9] and found to be too variable in use to satisfy the current requirements of industry. Surface imperfections, such as digs and scratches, arise from localized damage during or after manufacture. They may be visible as a result of the light they scatter, giving rise to a false impression of poor quality. Alternatively, this light may appear as unwanted veiling glare (stray radiation) in an image plane, or it may lead to a degradation in signal quality at an image sensor. Imperfections can also provide centres of stress, eventually leading to failure of components exposed to high laser radiation power/energy densities.

Since modern methods of surface examination are capable of atomic resolution, no surface is likely to be found totally free of localized imperfections. Most surfaces produced are satisfactory for their intended purpose, but a small proportion may have suffered obvious damage and shall be reworked or regarded as unacceptable. This can leave some components which, although slightly damaged, may, when tested, still be acceptable depending on the level of acceptability of surface imperfections requested by the customer and specified on drawings in accordance with either of the two methods specified in ISO 10110-7. This International Standard describes how these methods are implemented.

In Method I, the obscuration of imperfections larger than 10 µm can be judged visually by comparison of areas with artefacts of known size on a comparison plate. The obscuration caused by imperfections equal to or less than 10 µm across and yet still visible under dark-field illumination is either too small for accurate area measurement or may transmit as well as scatter radiation. These need to be quantified by comparison of their radiometric obscuration with totally absorbing artefacts of known size. Every imperfection detected is measured and considered for summation to produce a level of grade for each surface.

In Method II, all imperfections, independently of their width, length or number or whether on or between the surfaces of a component, are observed simultaneously and the component is quickly rejected if one imperfection exceeds a pre-set level of visibility under controlled conditions of illumination and viewing.

It should be noted that other light scattering defects, which also need to be measured, can arise as digs distributed over the surface of an incompletely polished surface, and as bubbles and as striae within an optical material. The measurement of laser damage thresholds also requires sensitive means for quantifying the level of radiation scattered by damage in its early stages.

Optics and optical instruments — Test methods for surface imperfections of optical elements

1 Scope

This International Standard establishes the physical principles and practical means for the implementation of two methods, specified in ISO 10110-7, for measuring surface imperfections. These methods are: Method I, the surface area obscured or affected by the defects, and, Method II, the visibility of the imperfections.

Both methods are suitable for prototype, small scale or large scale production of a wide variety of optical components. Imperfection appearance or functional tolerances related to a particular component can be determined by agreement between supplier and customer.

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 11145:2001, *Optics and optical instruments — 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 10110-7 and ISO 11145 and the following apply.

3.1
fully-developed imperfection
imperfection which scatters all radiation incident upon it

3.2
partially-developed imperfection
imperfection which transmits as well as scatters radiation incident upon it

3.3
line-equivalent width
LEW
width of a fully-developed scratch or absorbing line which obscures the same amount of radiation as a partially-developed scratch

NOTE The LEW of a fully-developed scratch equals its geometrical width.

3.4
spot-equivalent diameter
SED
diameter of a fully-developed dig or absorbing spot which obscures the same amount of radiation as a partially-developed dig

NOTE The SED of a fully-developed dig equals its geometrical diameter, but its grade number is the square root of its area.

3.5
imperfection threshold
total magnitude of imperfections on a surface quoted as a numerical term above which the component may be rejected for a particular application

NOTE This value applies to Method I.

3.6
bright-field imperfection contrast
ratio of the difference between the background maximum and minimum intensities across an imperfection image to the sum of these values

NOTE This value depends on whether the imperfection is viewed in transmission or reflection and on whether it is viewed directly or through the component; it applies to Method I.

3.7
obscuration comparison
process of measuring the severity of an imperfection by comparing its peak contrast under bright-field conditions with that of an obscuring artefact of known size

NOTE This value applies to Method I.

3.8
visual contrast threshold
smallest ratio of the brightness of an object to its background which can be seen by a particular observer

4 Physical principles

Precise metrology of small surface imperfections, which may be clearly visible under dark-field illumination, has proved to be very difficult [9] under workshop conditions. The parametric methods described below overcome this problem by equating imperfection severity with either the obscuration of the incident beam in comparison with an absorbing artefact of known size or its visibility employing a calibrated observer eye under controlled conditions of illumination and viewing.

In Method I, the obscuration of each imperfection of doubtful severity identified during inspection is measured separately. A dig is usually fully developed and is quantified by measuring its encircled diameter and then calculating its area and grade number in accordance with ISO 10110-7. The length and width of a scratch with dimensions greater than 10 µm are measured with the aid of a comparison plate or low power measuring microscope. Scratches equal to or less than 10 µm in width are measured from their LEW values. If different values are found for actual width and LEW or the actual diameter of a dig and its SED, for these two approaches the smaller number which allows for transmission of a partially-developed imperfection shall be used when calculating the grade number.

NOTE Choice of the smaller value is likely to reduce over-specification and lead to increased yields and lower costs.

Method II depends on imperfection visibility as viewed by a calibrated eye under controlled conditions of illumination and viewing. Since the contrast threshold of the eye decreases progressively with background luminance, this parameter can be fixed for different observers by each one adjusting the background luminance when viewing a standard defect under conditions of limiting detection. Any number of imperfections below an acceptance level of severity are then rendered invisible for certain classes of component by the use of particular levels of sample illumination. The component is rejected if any imperfection is visible.

The method chosen by the designer when specifying imperfection tolerances will be governed by the application and the need for objective measurement of all imperfections (Method I) or the desire for a fast overall assessment of component quality (Method II). Due to radiometric differences between the two methods, the quality assessments to which they give rise cannot be compared.

5 Method I: Measurement of obscured or affected area

5.1 General

Optical components shall first be cleaned and inspected, preferably in low angle scattered light by strong side-illumination under dark-field conditions, to select the usually small proportion of doubtful components with imperfections which require measurement. A typical arrangement for the routine inspection of optical elements for imperfections seen in transmission is shown in Annex A. A mirror can be inspected by placing it close to the back wall of the box and tilted so as to avoid reflected light entering the eye.

The affected areas of imperfections with dimensions greater than 10 µm on transmitting or reflecting substrates can be determined with the aid of a scale comparison plate, such as that described in Annex B. A simple magnifier or low power microscope may be used for this purpose.

For imperfections equal to or smaller than 10 µm, Figure 1a shows a schematic arrangement illustrating the simplest configuration required for the measurement of LEW and SED when viewing in transmission. Light from a distant source on the left illuminates the component. A comparison plate is placed close to the component so that the eye can form a match between the contrast of the imperfection under bright-field conditions and that of a line of known width on the plate or a spot of known diameter when quantifying a dig.

Imperfections on a reflecting substrate shall be viewed through a beam splitter to provide normally incident illumination of the mirror. The same comparison plate operating again in transmission is used as shown schematically in Figure 1b).

5.2 Requirements

The requirements for the measurement of LEW and SED for imperfections of size equal to or less than 10 µm are summarized below.

a) The imperfection on the component under test and the comparator plate shall be illuminated and imaged under the same conditions.

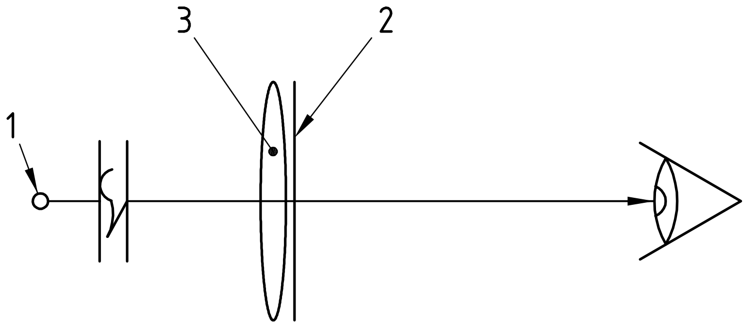
b) The illumination shall be substantially parallel and avoid speckle in the image plane.

c) The imaging system shall have a low numerical aperture — typically 0,01 — chosen to remove fine structure from the imperfection image, but to leave sufficient radiation to enable comparison of the peak contrasts of the imperfection and artefact images.

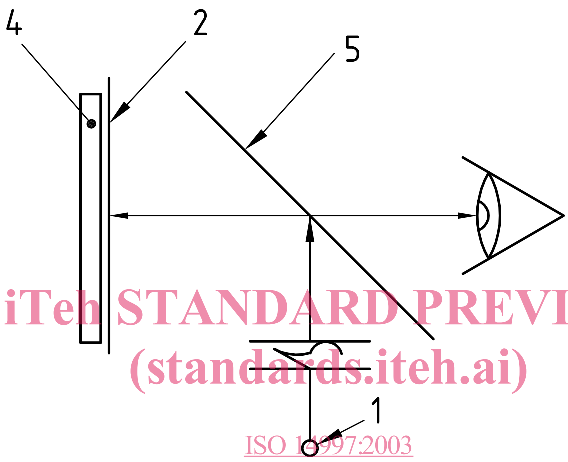
d) The image may be viewed directly, but remote viewing by television is preferred.

A variety of different designs of image comparator may be used to fulfil the above requirements, but the preferred arrangement with a precision and sensitivity which exceeds that possible with unaided vision is a microscope image comparator described in Annex C. If the LEW of a scratch varies along its length, its peak value shall be taken when calculating its grade number.

The length of scratches required to calculate their grade number and the extent of edge chips from the physical edge of the surface should be measured with the aid of the comparison plate or by low power microscope.



a) Viewing in transmission



b) Viewing in reflection

Key

1 source
2 comparison plate
3 test component
4 test mirror
5 beam splitter

Figure 1 — Schematic arrangement for Method I measurement

5.3 Calibration

The measurement of LEW and SED requires the use of a reference dig and scratch calibration plate which may be of the form of that described in Annex B, extended to sub-micrometre values, if required. When testing in transmission, this shall have opaque lines and spots on a transparent substrate. Testing in reflection, when using the microscope image comparator, requires the negative of this plate with transparent slits and spots of the same size on a reflecting substrate. The uncertainty of measurement of these artefacts shall be 5 % of the measured dimension.

5.4 Procedure

The precise procedure for optical component inspection and measurement will vary between companies, depending on past experience and customer needs. The approach described in Annex D is based largely on existing practice.

5.5 Test report

If a test report is requested on the drawing, the following information shall be provided for each face of component tested.

a) General information:

1) name and address of workshop;

2) name of the inspector;

3) date of the measurement;

4) ISO document and/or test specification numbers.

b) Sample information:

1) component drawing number;

2) specifications relating to storage, cleaning and production date;

3) transmitting/reflecting component;

4) component diameter;

5) description of orientation and face marking;

6) operational mode: conformity/quality grade.

c) Test specification:

1) description of test equipment;

2) f/ratio of imaging lens or state if unaided eye is used for assessment;

3) number of imperfections of maximum size allowed and their grade numbers for general and specific types of imperfection;

4) maximum allowable extent of a chip from the physical edge of the surface.

d) Results:

1) map showing positions and description of all types of imperfections in relation to the face examined and their orientation within the effective aperture;

2) the number and SED values of digs above the minimum grade and the number and surface area of coating blemishes;

3) the number, the length and the LEW values of scratches less than 2 mm long, with LEW values above the minimum grade;

4) the number, the length and the LEW values of scratches greater than 2 mm long, with LEW values above the minimum grade;

5) the grade number of edge chips;

6) the total number of imperfections;

7) the effective surface area obscured by imperfections;

8) assessment of imperfection concentrations;

9) uncertainty of measurement of effective surface area;

10) decision taken.