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

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

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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This third edition cancels and replaces the second edition (ISO 14997:2011), which has been technically revised to adapt ISO 14997 to the new version of ISO 10110-7.

The main change compared to the previous edition is as follows:

— the addition of language required to accommodate visibility inspection.

Introduction

Standard practice in the optics industry since the 1950s has been to visually inspect optical surfaces for small, localized imperfections and determine if they are acceptable.

This document was developed in response to worldwide demand for the standardization of test methods for surface imperfections. Surface imperfections, such as digs and scratches, arise from localized damage during or after manufacture. They can be visible as a result of the light they scatter, giving rise to a false impression of poor quality. Alternatively, this light can appear as unwanted veiling glare (stray radiation) in an image plane, or it can lead to 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. In most cases, however, surface imperfections are representative of the quality of workmanship and do not have any impact whatsoever on the performance of the component in question.

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 can have suffered obvious damage and will be reworked or regarded as unacceptable. This can leave some components that, although slightly damaged, can still be found acceptable, when tested, depending on the level of acceptability of surface imperfections requested by the customer and specified on drawings in ISO 10110-7. This document describes how these methods are implemented.

In some cases, it is necessary to measure or estimate the size of the imperfections on an optical surface. In other cases, however, it is necessary or desirable to assess their brightness or appearance, and not their size. In these cases, visual inspection is preferred over dimensional measurements.

This document describes the human evaluation of surface imperfections for the dimensional and visibility methods. New developments open the route to machine vision approaches which are more objective and exhibit an increased reproducibility, less conflict and an optimized production closer to the allowed specification, lowering cost[10],[11]. Some of these machine vision-based approaches may be able to validate the surface imperfection specifications of ISO 10110-7. It is incumbent upon the manufacturers and users of objective measurement equipment to demonstrate compatibility with the methods described herein and to report their results consistent with the notation described in ISO 10110-7.

It should be noted that other light scattering imperfections, 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 photonics — Test methods for surface imperfections of optical elements

1 Scope

This document specifies the physical principles and practical means for the implementation of methods for evaluating surface imperfections.

For imperfections specified using the visibility method, two inspection methods are described. The first is visual evaluation of the surface without any comparison standard (IV_V). The second is a visibility assessment of a surface imperfection when compared to an artefact of known brightness (IS_V).

For imperfections specified using the dimensional method, three methods are described. The first is visual evaluation of the surface without any comparison standard (IV_D). The second is a dimensional assessment of a surface imperfection when compared to an artefact of known size (IS_D). The third is the dimensional measurement of a surface imperfection using magnification and either a comparison artefact of known size or a reticle or ruler (IM_D).

Instruments exist that allow objective measurement of brightness (digital scatterometry) or size (digital microscopy). While these instruments can be used for evaluation of surface imperfections, they are beyond the scope of this document.

This document applies to optical surfaces of components or assemblies such as doublets or triplets.

This document can be applied to optical plastic components; however, attention is drawn to the fact that impact damage to plastic materials often looks very different from that on harder materials as it does not always result in the removal of material but instead can displace material, causing ripples in the surface. Consequently, visual comparisons of scratch and dig damage to plastic with those on glass or crystalline materials can give very different results.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 9211-1, *Optics and photonics — Optical coatings — Part 1: Definitions*

ISO 10110-7, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 7: Surface imperfections*

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 10110-7, ISO 9211-1 and ISO 11145 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
brightness comparison standard
plate, paddle, or window with one or more artefacts of known brightness grade

3.2
dimensional comparison standard
plate, paddle, or window with one or more patterned artefacts (chrome on glass, ink on film, iron oxide on glass, etched glass, focused ion beam milling (FIB) on glass substrate, etc.) of a specified size grade

4 Symbols

IV_V visual inspection of visibility

IS_V subjective comparison inspection of visibility

IV_D visual inspection of dimensions

IS_D subjective comparison inspection of dimensions

IM_D inspection with magnification of dimensions

5 Inspection methods and levels

Surface imperfections may be specified and graded using the notations provided in ISO 10110-7 in terms of visibility or size. Surface imperfections may be evaluated visually with or without magnification, or objectively using equipment designed for the purpose. Table 1 shows the evaluation arrangements by inspection level for visibility of surface imperfections. Table 2 shows the evaluation arrangements by inspection level for dimensional specifications of surface imperfections.

Table 1 — Evaluation methods for the visibility based specification of surface imperfections

Inspection level	Evaluation arrangement	Comparison standard
Visual evaluation (Level IV_V)	Any arrangement is allowed per 7.1	None required
Visibility comparison inspection (Level IS_V)	Any Annex A arrangement per 7.2	Brightness comparison standard indicated on the drawing

If no inspection level is indicated on the drawing, the default inspection level for visibility based specifications is IS_V.

Table 2 — Evaluation methods for the dimensional based specification of surface imperfections

Inspection level	Evaluation arrangement	Comparison standard
Visual evaluation (Level IV_D)	Any arrangement is allowed per 8.1	None required
Dimensional comparison inspection (Level IS_D)	Figure A.3 arrangement per 8.2	Dimensional comparison standard per Annex B
Dimensional comparison inspection with magnification (Level IM_D)	Loupe or stereo microscope per 8.3	Dimensional comparison standard per Annex B

The number of allowed smaller imperfections with equivalent area of the specified grade can be found in Annex C.

The angular resolution of the human eye is about 1 arcminute[9]; therefore, an unstressed human inspector can reasonably estimate the size of imperfections larger than 0,1 grade under the arrangement described in Annex A. Assuming long imperfections can be resolved to approximately one-fourth of this value, a scratch of width 0,025 mm can be estimated under the same conditions. Since in accordance

with ISO 10110-7, imperfections shall be accumulated down to 0,16× the specification (or 0,25× for long imperfection), the default inspection method for specifications of 5/1 × 0,63; C1 × 0,63; L1 × 0,1 or larger shall be IS_D. For smaller specifications, the default inspection level is IM_D.

When using the IM_D method, the magnification and device resolution shall correlate with the required specification.

EXAMPLE 1 For testing 5/1 × 0,04, the smallest imperfection size to test is 0,006 3 mm and therefore the magnification should be >16×.

Fractioned imperfections with gaps smaller than the resolution required for the measurement shall be treated as a single imperfection. Imperfections with gaps larger than the resolution required for the measurement shall be treated as separate imperfections.

EXAMPLE 2 For testing 5/1 × 0,04, the smallest imperfection size to test is 0,006 3 mm. Imperfections with gaps larger than this shall be treated as separate imperfections.

If two or more optical elements are to be cemented (or optically contacted), the surface imperfection tolerances and inspection levels given for the individual elements apply also for the surfaces of the optical subassembly, i.e. after cementing (or optically contacting), unless otherwise specified.

6 General information regarding visual inspection

Optical components shall first be cleaned and inspected, preferably in low angle scattered light by strong side-illumination under dark field conditions. Most optical components will be either obviously acceptable or obviously unacceptable. For these components, no further evaluation is necessary. There is usually a small proportion of doubtful components with imperfections that require careful evaluation.

7 Evaluation methods for the visibility based specification of surface imperfections

7.1 Visual evaluation (IV_V)

7.1.1 General

The inspector shall assess the brightness grade of the imperfection. If necessary, the inspector shall refer to the brightness comparison standard referenced on the drawing.

The length of scratches, when required, and the extent of edge chips from the physical edge of the surface should be estimated visually.

7.1.2 Typical visual evaluation method

7.1.2.1 Viewing station

This inspection method is typically performed with a high-intensity, goose-neck fibre light source in a dark area, with a matte-black background material. No specific viewing station is required; however, the inspector may choose the best conditions for the inspection.

7.1.2.2 Inspection technique

The element shall be rotated and/or tilted and the fibre light manoeuvred to provide the maximum visibility of the imperfections on the surface when viewed against the black background. Imperfection grades are visually judged based on the experience of the inspector. To ensure maximum visibility of the imperfection, imperfections are observed in dark field, i.e. by light scattered from the reflecting

surface, viewed against a black background. This method may be used for inspection of any uncoated, coated or reflective optic.

7.2 Visibility comparison inspection (IS_V)

7.2.1 General

The brightness of individual imperfections may be determined using a visibility comparison evaluation. Any of the three setups described in Annex A may be used, along with the appropriate brightness comparison standard that is indicated on the drawing.

Imperfections are visually judged using a side-by-side comparison of the comparison standard and the element under inspection. The element and comparison standard shall be rotated and/or tilted to ensure maximum visibility of the imperfection.

The brightness of the imperfection shall be compared to each of the artefacts of the comparison standard to determine which is the closest. The grade of the imperfection is the grade of the closest but more visible comparison standard artefact. For example, if the imperfection is close to the 10 grade scratch artefact, but is brighter, it is considered a grade 20 scratch.

When required, the length of scratches and the extent of edge chips from the physical edge of the surface shall be measured with the aid of the comparison standard plate or ruler. A loupe or low-power microscope may be used for this purpose, regardless of the specification type or inspection level.

7.2.2 Typical transmitted light visibility comparison method

7.2.2.1 Viewing station

This inspection method requires a matte-black background material and a lamp with a ground or opal glass diffuser mounted vertically above the matte-black background. The illuminance shall be at least 350 lx and not more than 1 250 lx. A schematic of such a setup is shown in Figure A.1.

7.2.2.2 Inspection technique

The element being inspected and the brightness comparison standard shall be held so that they are approximately perpendicular to the edge of the diffuser described above and viewed against the matte-black background. Imperfections are observed in dark field, i.e. by light scattered from the surface while viewing them at approximately 90° to the path of the beam.

7.2.3 Alternative transmitted light visibility comparison method

7.2.3.1 Viewing station

This inspection method requires a lamp positioned approximately 75 mm from a ground or opal glass diffuser. Approximately half the area of the glass diffuser shall be masked by two or more opaque, horizontal or vertical black bars located in front of and in contact with the diffuser. The illuminance shall be at least 150 lx and no more than 360 lx. A schematic of such a setup is shown in Figure A.2.

7.2.3.2 Inspection technique

The element being inspected and the brightness comparison standard shall be held in front of the diffuser. The element and comparison standard are viewed using the black bars as background. Imperfections are observed in dark field, i.e. against the black bars while being illuminated at a near normal incidence.

7.2.4 Reflective light visibility comparison method

7.2.4.1 Viewing station

This inspection method requires a matte-black background material and an overhead lamp. The illuminance shall be at least 1 000 lx and not more than 2 800 lx. A schematic of such a setup is shown in Figure A.3.

7.2.4.2 Inspection technique

The element being inspected and the brightness comparison standard shall be held so that they are approximately coplanar beneath the inspection lamp described above and viewed against the matte-black background. Imperfections are observed in dark field, i.e. by light scattered from the reflecting surface, viewed against the black background. This method may be used for inspection of any uncoated, coated or reflective optic.

When inspecting reflective parts using this method, care should be taken to protect against glare to the inspector's eye.

8 Evaluation methods for the dimensional based specification of surface imperfections

8.1 Visual evaluation (IV_D)

8.1.1 General

The inspector shall assess the size grade of the imperfection. If necessary, the inspector shall refer to a dimensional comparison standard such as that described in Annex B.

The extent of edge chips from the physical edge of the surface should be estimated visually.

8.1.2 Typical visual evaluation method

8.1.2.1 Viewing station

This inspection method is typically performed with a high-intensity, goose-neck fibre light source in a dark area, with a matte-black background material. No specific viewing station is required; however, the inspector may choose the best conditions for the inspection.

8.1.2.2 Inspection technique

The element shall be rotated and/or tilted and the fibre light is manoeuvred to provide the maximum visibility of the imperfections on the surface when viewed against the black background. Imperfection grades are visually judged based on the experience of the inspector. Imperfections are observed in dark field, i.e. by light scattered from the reflecting surface, viewed against the black background. This method may be used for inspection of any uncoated, coated or reflective optic.

8.2 Dimensional comparison inspection (IS_D)

8.2.1 General

Visual evaluation can be used on transmitting or reflecting substrates to determine grades greater than 0,1 or widths greater than 0,025 mm. The reflected light setup shown in Figure A.3 shall be used, along with the appropriate dimensional comparison standard described in Annex B.