BS ISO 14997:2011

BSI Standards Publication

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

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## National foreword

This British Standard is the UK implementation of ISO 14997:2011. It supersedes BS ISO 14997:2003, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CPW/172/1, Optics and Photonics - Fundamental Standards.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**ISO 14997**

Second edition
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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*

Reference number
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# Foreword

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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 photonics*, Subcommittee SC 1, *Fundamental standards*.

This second edition cancels and replaces the first edition (ISO 14997:2003), which has undergone minor revision to adapt ISO 14997:2011 to ISO 10110-7:2008; the main changes are the deletion of one of the two test methods and the addition of a new Annex E.

## Introduction

This International Standard was developed in response to worldwide demand for test methods for surface imperfections that are objective and permit fast assessment of component quality. Existing standards have been assessed (see Reference [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 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 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 can have suffered obvious damage and will be reworked or regarded as unacceptable. This can leave some components which, although slightly damaged, may 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 International Standard describes how these methods are implemented.

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 either is 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.

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 photonics — Test methods for surface imperfections of optical elements

## 1 Scope

This International Standard establishes the physical principles and practical means for the implementation of methods for measuring surface imperfections. This method evaluates the surface area obscured or affected by the imperfections.

The method is 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, *Optics and photonics — 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 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

**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.

**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

**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 (see Reference [9]) under workshop conditions. The parametric method described in Clause 5 overcomes this problem by equating imperfection severity with the obscuration of the incident beam in comparison with an absorbing artefact of known size. 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. Preferred values for grade numbers are given in Annex E. 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.

## 5 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.

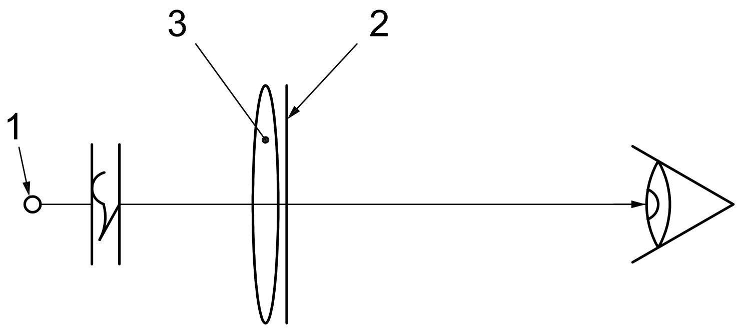
 

The affected areas of imperfections with dimensions greater than 10 µm on transmitting or reflecting substrates can be determined with the aid of a scale comparison plate, such as that described in Annex B. A simple magnifier or low power microscope may be used for this purpose.

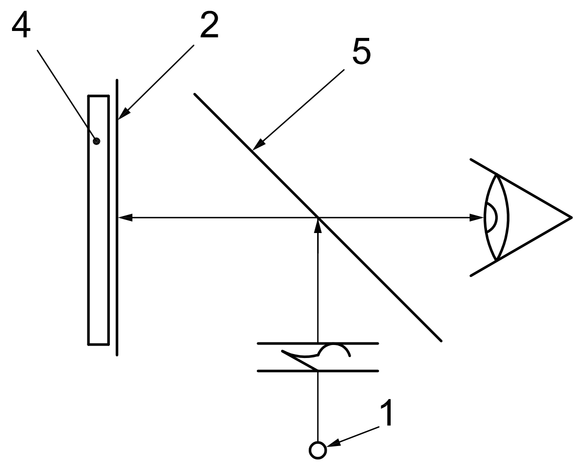
For imperfections equal to or smaller than 10 µm, Figure 1 a) shows a schematic arrangement illustrating the simplest configuration required for the measurement of LEW and SED when viewing in transmission. Light from a distant source on the left illuminates the component. A comparison plate is placed 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.

In the event that there is no specification for long imperfections, all scratches are measured and accumulated by area with general imperfections.

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 1 b).




**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 measurement**

## 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.

## 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) International Standard 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 the 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;

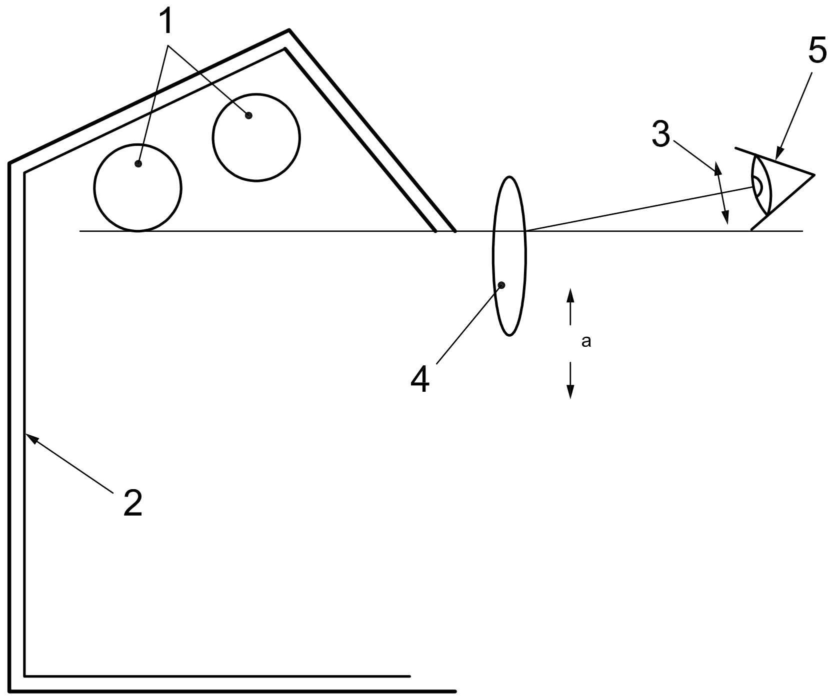
   9) uncertainty of measurement of effective surface area;

   10) decision taken.

# Annex A
(informative)

## Component inspection

Figure A.1 gives the typical arrangement for the component inspection for the test method.




**Key**

1 twin fluorescent tubes

2 matt black finish

3 magnifier

4 component under test

5 viewing position

[a] Rotation and displacement of component.

**Figure A.1 — Typical arrangement for the routine inspection of optical elements for imperfections seen in transmission**

# Annex B
(informative)

## Recommended dimensions of artefacts on a scale comparison plate

Table B.1 gives recommended dimensions for circular and scratch-like artefacts, which may be used as a means for size comparison during the inspection of optical elements.

For the size comparison of defects on transmissive surfaces, artefacts consisting of non-transmitting material or glass are useful.

For the size comparison of defects on reflection surfaces, non-reflecting artefacts on a surface which is otherwise reflecting may be useful.

In both cases, it is recommended that the scale comparison plates be made by depositing chrome onto glass by evaporation.

Larger or smaller artefacts may also be useful for certain applications.

**Table B.1 — Recommended dimensions of artefacts for size comparison**

| Plate number | Grade number | Diameter of circular "defect"<br>µm | Dimension of "scratch"<br>µm × µm |
|---|---|---|---|
| **Plate No. 1** | 0,004 | 4,5 | 1 × 16 |
| | 0,006 | 7 | 1,6 × 25 |
| | 0,010 | 11 | 2,5 × 40 |
| | 0,016 | 18 | 4,0 × 63 |
| | 0,025 | 28 | 6,3 × 100 |
| | 0,040 | 45 | 10 × 160 |
| **Plate No. 2** | 0,040 | 45 | 10 × 160 |
| | 0,060 | 70 | 16 × 225 |
| | 0,100 | 110 | 25 × 400 |
| | 0,160 | 180 | 40 × 630 |
| | 0,250 | 280 | 63 × 1 000 |
| | 0,400 | 450 | 100 × 1 600 |

# Annex C
(informative)

# Description of the instrument used for measuring imperfections below 0,01 mm: microscope image comparator

## C.1 Principle of operation

When an imperfection is fully developed with dimensions larger than 0,01 mm, its area of obscuration can be obtained from its measured surface dimensions using a microscope with a micrometer eyepiece or by comparison with a graticule having lines of varying width and spots of varying diameter.

Since a high proportion of naturally occurring small imperfections transmit as well as scatter, their dimensions cannot be directly related to their obscuration of light. It is, however, possible to quantify the obscuration of an imperfection by comparing the peak contrast of its image, formed by a small aperture lens under bright-field conditions, with that of an opaque line or spot of known size. In this way, the amount of light removed from a beam by an imperfection, by the process of scatter, is equated to the amount of light removed by an absorbing artefact of known dimensions. Here, only the direct or undiffracted light is collected and the same low aperture lens is used to image both the imperfection and the comparison artefact. Since the instrument required to make the measurement of imperfection severity is in the form of a comparator, the following description can be regarded as informative. A more detailed description of a microscope image comparator, its operation in support of a standard and currently used thresholds for imperfections are reviewed in Reference [10].

## C.2 Schematic representation of a comparator

Figure C.1 shows a schematic representation of a microscope image comparator capable of measuring LEW and SED values of most imperfections likely to be met in practice on transmitting or reflecting surfaces. Isolated defects within material can also be measured to a precision significantly better than can usually be achieved by eye.

Light from a tungsten lamp, S, is focused by the condenser lens, $L_1$, onto the pinhole, P. After passage through the polarizer, $Z_1$, the light from P, which is at the focus of $L_2$, passes as a parallel beam into the polarizing beamsplitter, B. The beam passing straight through B is transmitted by the quarterwave plate, $Q_1$, before falling at normal incidence on to the plate, R, which carries a transparent reference slit in a reflecting substrate. The light reflected by R can now be imaged, after a return passage through $Q_1$ and B by lens $L_3$ onto the TV camera after transmission by the analyser, $Z_2$, and by the spatial frequency filter, F, placed in the back focal plane of $L_3$. This spatial frequency filter takes the form of a pinhole of diameter sufficiently small to remove the fine structure from the image. The parallel beam from $L_2$ reflected by B into the test channel is transmitted by the quarterwave plate, $Q_2$, and illuminates the test specimen, T, at normal incidence. As in the reference channel, the light reflected by T can now also be imaged, after a return passage through $Q_2$ and B, by $L_3$ onto the TV camera. The plates $Q_1$ and $Q_2$ are rotated in turn in a setting-up operation to maximize the intensity of the beams from T and R on the TV camera. As the light falling on T and R is circularly polarized and at normal incidence, the amount of light reflected is found to be independent of the rotation of the imperfection.

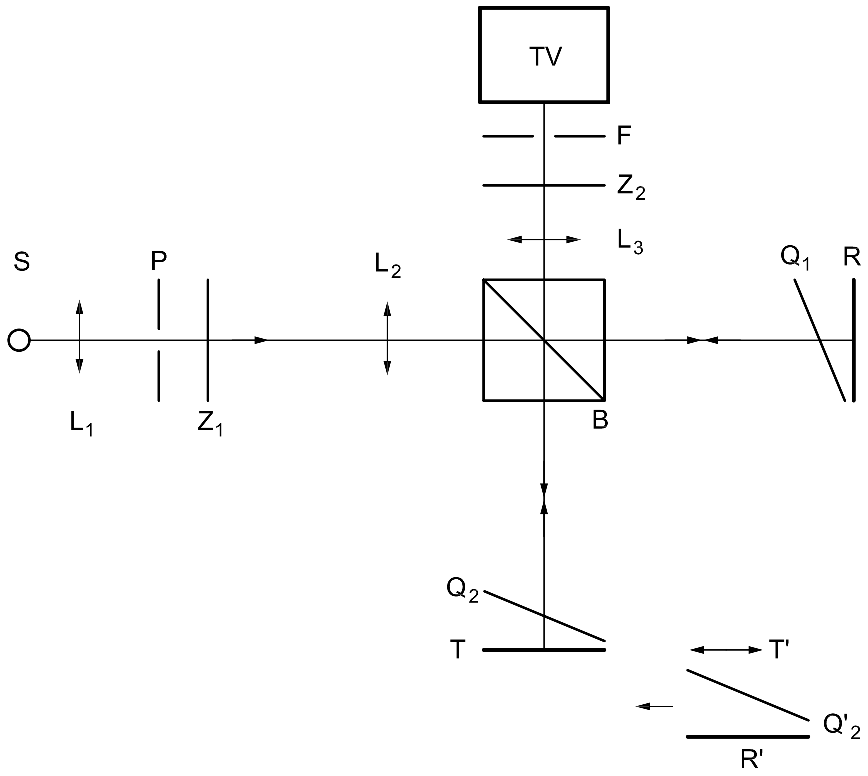



**Figure C.1 — Microscope image comparator**

## C.3 Method of operation

A scratch on T and a slit on R are positioned so that their images are both in focus side-by-side on the TV, and then the contrast of their images, seen as dark lines in a bright field, will be related to the amount of light they have removed from their illumination beams. The instrument is used by spinning $Z_2$ so as to expose both beams alternately to the TV and adjusting the angular setting of $Z_1$ to reduce the flicker of the background of the test and reference images to zero. The polarizer, $Z_2$, can now be brought to rest and carefully adjusted in angle to the setting $\Phi$ where the test and reference images are of equal contrast. It can be shown (see Reference [9]) that $\tan^2\Phi$ is then equal to the ratio of the amounts of light removed by the test and reference imperfections. Since, for convenience, the reference imperfection is chosen to be sufficiently wide to create an image of maximum or unit contrast, this value is a measure of the visibility of the imperfection under test. By replacing T with a calibration plate having lines of known width and spots of known diameter, the scale $\Phi$ can be calibrated in LEW and SED values. The instrument is then ready to quantify any imperfection in terms of its effective obscuration.

When the imperfection is on a transmitting substrate or appears as a bubble within the material, the illuminating beam has to be returned by some form of retroreflector, such as a beaded screen as shown in the three unit assembly which replaces T and $Q_2$, see bottom right corner of Figure C.1. In this case, the plate $Q'_2$ is placed between the component T', shown as a lens and the retroreflector, R'.

It should be noted that the severity of an imperfection seen in externally reflected light will usually be greater than when viewed in transmission, due to an effective increase of the wavefront depth profile. In transmitting mode, the instrument is calibrated with a plate having opaque lines on a transmitting substrate and, in reflecting mode, the plate carries transmitting slits on a reflecting substrate.

The following design values have been found to be convenient but, because the instrument is only used as a comparator, tolerances are generous and not given:

— Focal length of $L_1$ = 25 mm Diameter of P = 1 mm

— Diameter of F = 1 mm Focal length of $L_2$ = 50 mm

— Focal length of $L_3$ = 50 mm Total magnification = 50

For rapid routine inspection, some organizations use scratch plates covering the range of imperfections of particular interest. These plates can be calibrated in terms of the LEW and SED values of the imperfections they carry by means of the microscope image comparator which, in turn, has been calibrated by the use of certified line and spot standards. Table C.1 shows, for example, the approximate relationship between the MIL Standards employed in the USA, their contrast under bright-field viewing, their LEW values and the equivalent angular setting of the analyser. The spread in analyser settings reflects variability in standard scratches and setting errors.

**Table C.1 — Relationship between contrast and LEW of MIL standards and equivalent angular setting of the analyser**

| MIL standard | Contrast | LEW<br>µm | Analyser setting<br>degrees (°) |
|---|---|---|---|
| 10 | 0,05 | 0,25 | 10 — 12 |
| 20 | 0,10 | 0,63 | 17 — 19 |
| 40 | 0,20 | 1,60 | 24 — 26 |
| 60 | 0,40 | 4,00 | 31 — 33 |

It should be noted that, as the instrument doubles as a low power microscope, the dimensions of fully-developed imperfections and edge chips can also be measured. Measurement of imperfections on steeply curved mirrors require the use of a power compensating lens placed close to the sample under test.

# Annex D
(informative)

## Imperfection quality control

A typical sequence of events for imperfection quality control is shown in Figure D.1. A conventional side illumination dark-field inspection box, as shown in Figure A.1, can be used at level 2 to decide if an item from component production at level 1 is clearly “accept” or “reject”, in which case it passes directly to level 8, or if it is doubtful, in which case it passes to level 3. All imperfections of interest will be seen at level 2. The location of all imperfections will be known at level 3 and the observer, with the aid of information provided on the drawing, will know the classification of imperfections specified. The drawing indication for the number, $N$, of allowed general surface imperfections of maximum permitted grade $A$ is 5/$N \times A$, where $A$ is equal to the square root of the effective surface area of a single maximum allowed imperfection, expressed in mm.

This indication can be subdivided, if desired, into permissible levels of imperfections classified as coatings, long scratches (longer than 2 mm) and edge chips bearing the prefixes C, L and E. The number of coating and long scratch imperfections of maximum permitted grade $A'$ and $A''$ are indicated as $N'$ and $N''$. For long scratches, $A''$ refers to the maximum allowed width of a scratch, in mm, whilst the grade $A'''$ for edge chips is its maximum allowable extent of any number of chips from the edge of the polished surface, in mm.

The required dimensions of every imperfection are now to be measured at level 4 and their grade numbers calculated. This involves measuring the widths and/or lengths of a variety of different imperfections, some of which could be sub-micrometre in size. Experience has shown that dimensions greater than 0,01 mm can be measured using a magnifier or low power microscope in which the size of an image of the imperfection is compared with that of lines and dots of known dimensions on a comparator plate. Such a plate is described in Annex B. Imperfections below 0,01 mm may not be well resolved by an optical microscope and so the beam obscuration these cause can best be measured by comparing the amount of light they remove with absorbing artefacts of known size with the aid of a microscope image comparator as described in Annex C.

At level 5, imperfections with grades less than 0,16$A$ and 0,3$A''$ can be ignored, unless the drawing specifies otherwise and, if there are no others, the component can be accepted. Clusters of imperfections are a cause for rejection at level 6 when more than 20 % of the allowed number is found in any 5 % of the test region. If the total number of allowed imperfections is less than 10, then 2 or more within a 5 % area would be defined as an unacceptable cluster.

Level 7 provides the last opportunity to reclaim a component, provided the measured grade is less than the permissible value quoted on the drawing. Even if rejected, a proportion of components may, at level 8, be returned for reworking.

Inspection, as indicated in Figure D.1, may be carried out along one of three routes specified in the indication for surface imperfections (and coating blemishes, long scratches and/or edge chips, if given) and separated from them by a semicolon, as follows.

— Route 1, typically for mass-produced optics, stops at level 2.

— Route 2, typically for precision visual optics, at the top of level 4 employs subjective comparison of imperfections with lines and dots of known dimensions.

— Route 3, typically for precision optics including lasers and/or optical sensors at the lower part of level 4, employs objective measurement of imperfections, as described in Annex C.

NOTE Route 3 achieves the highest measurement accuracy, for example, where system performance is critical or for the solution of disputes.

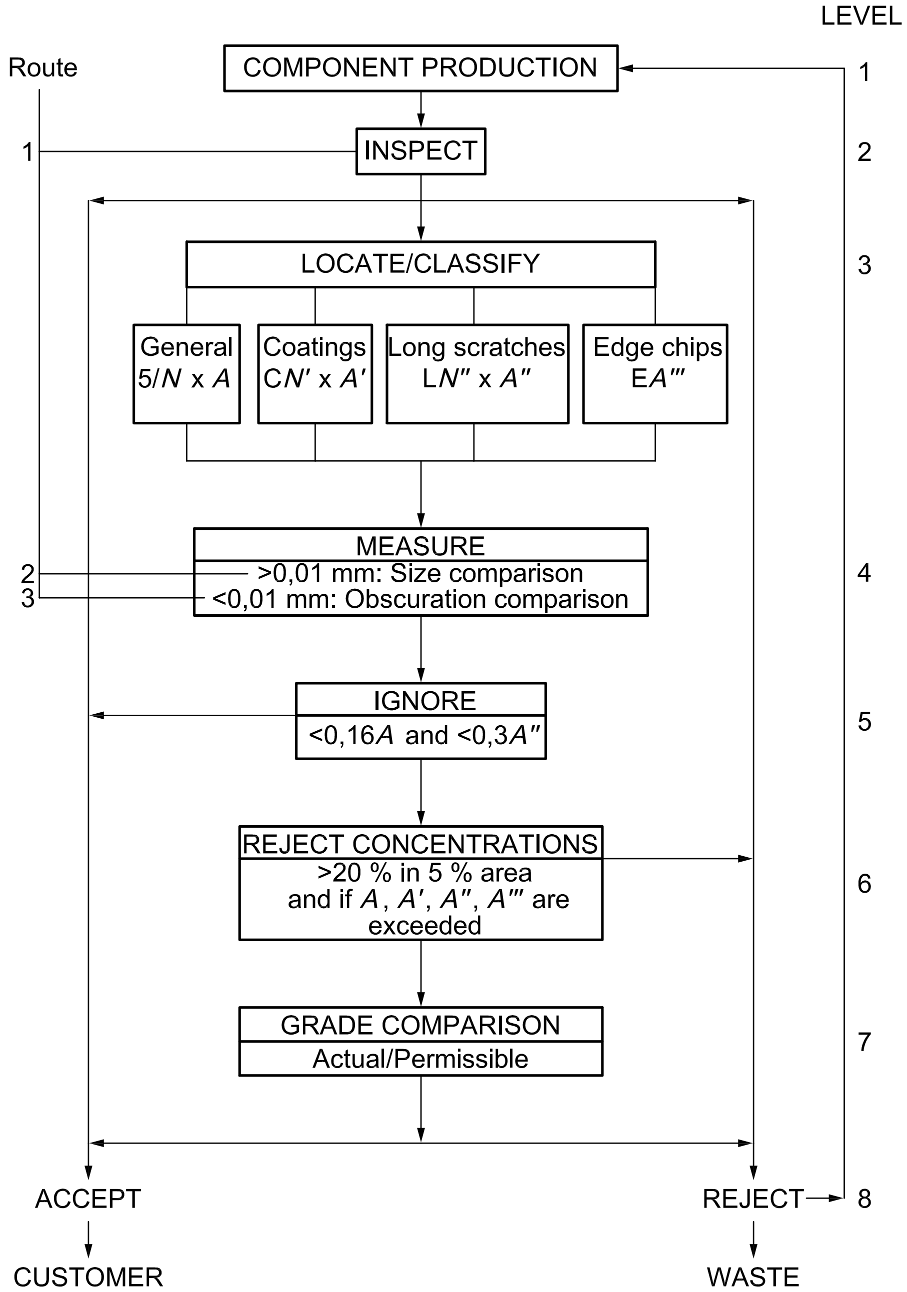



**Figure D.1 — Imperfection quality control**

# Annex E
(normative)

## Preferred values of grade numbers and subdivision factors

The preferred range of values for grade number $A$ is given in the first column of Table E.1. Columns two to four show the connection between grade numbers and their multiplication factors. The table indicates, for example, that six surface imperfections of grade number 0,25 have the same area as one imperfection of grade number 0,63.

**Table E.1 — Preferred size designation and factors for sub-division for surface imperfections**

| | **Multiplication factors** | | | |
|---|---|---|---|---|
| | 1 (preferred values) | 2,5 | 6,3 | 16 |
| **Grade number** $A$, mm | 0,006 | — | — | — |
| | 0,010 | 0,006 | — | — |
| | 0,016 | 0,010 | 0,006 | — |
| | 0,025 | 0,016 | 0,010 | 0,006 |
| | 0,040 | 0,025 | 0,016 | 0,010 |
| | 0,063 | 0,040 | 0,025 | 0,016 |
| | 0,10 | 0,063 | 0,040 | 0,025 |
| | 0,16 | 0,10 | 0,063 | 0,040 |
| | 0,25 | 0,16 | 0,10 | 0,063 |
| | 0,40 | 0,25 | 0,16 | 0,10 |
| | 0,63 | 0,40 | 0,25 | 0,16 |
| | 1,0 | 0,63 | 0,40 | 0,25 |
| | 1,6 | 1,0 | 0,63 | 0,40 |
| | 2,5 | 1,6 | 1,0 | 0,63 |
| | 4,0 | 2,5 | 1,6 | 1,0 |

EXAMPLE

If the indication is 5/2 × 0,25 (i.e. 2 surface imperfections of grade number 0,25), then 2 × 2,5 ≈ 5 surface imperfections of grade number 0,16, or 2 × 6,3 ≈ 12 surface imperfections of grade number 0,1, or 2 × 16 ≈ 32 surface imperfections of grade number 0,063 are permissible. Alternatively, any corresponding combination of the above is permissible provided that the total projected area of all surface imperfections with a grade number greater than 0,16 × 0,25 = 0,04 does not exceed $2 \times 0{,}25^2$ mm$^2$ = 0,125 mm$^2$.

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2) To be published. (Revision of ISO 11254-1:2000 and ISO 11254-2:2001)

3) To be published. (Revision of ISO 11254-3:2006)

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