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Optics and photonics — Test methods for surface imperfections of optical elements — Part 2: Machine vision

Optique et photonique — ~~Élément central~~Méthodes d'essai applicables aux imperfections de surface des éléments optiques — Partie 2: Visionique

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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~~www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see ~~www.iso.org/patents~~www.iso.org/patents).

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For an explanation of 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 ~~www.iso.org/iso/foreword.html~~www.iso.org/iso/foreword.html.

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

A list of all parts in the ISO 14997 series can be found on the ISO website.

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at ~~www.iso.org/members.html~~www.iso.org/members.html.

This corrected version of ISO/TR 14997-2:2022 incorporates the following corrections:

— editorial corrections added in Introduction, Clause 2, 3.4, Figure 1 and Annex A;

— ISO 9802:2022 was added in Bibliography, the cross-references and the Bibliography were renumbered.

Introduction

This document was developed to account for the increased use of machine vision for surface quality inspections. The visual assessment of grades of surface imperfections of optical elements and systems is described in ISO 10110-7, and ISO 14997-1[1]. The latter gives methods to obtain subjective results using the human eye, reference comparison standards, and in some cases optical magnification tools.

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Utilizing machine vision opens the door for the objective evaluation of imperfections as well as electronic data storage of detailed and precise test reports along with statistical data handling. It offers an opportunity for better repeatability of the characterisation of surfaces and a potential method of arbitration in supplier ~~/~~ /customer discussions about surface imperfections.

Inspection results of optics obtained by manual inspection and from already existing machine vision systems have shown good correlation. Minor deviations arise, but are largely due to the differences of subjective and objective evaluation.

Of particular concern can be long scratches such as sleeks. Such imperfections often are more visible when tilting and rotating the sample to the optimum position which, in machine vision devices, is often accomplished by covering an amount of incident illumination angles, which are limited due to practical reasons.

[1] ISO 14997-1 is at the time of publication of this document published as ISO 14997:2017. The change in numbering of the International Standard is intended at the next revision of ISO 14997.

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Optics and photonics — Test methods for surface imperfections of optical elements — Part 2: Machine vision

1 Scope

This document provides guidance for the use of machine vision to objectively assess grades of surface imperfections as defined on a drawing using ISO 10110-7 with equivalent results as those obtained by applying the inspector-based methods described in ISO 14997-1.

This document also gives guidelines on how to setup a machine vision device regarding fidelity, repeatability and reproducibility, based on the dark field detection principles of ISO 14997-1.

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.

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

~~<std>ISO 14997-1, *Optics and photonics - Test methods for surface imperfections of optical elements*</std>~~

ISO 14997-1, *Optics and photonics — Test methods for surface imperfections of optical elements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10110-7 and ISO 14997-1 and the following apply.

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

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

— IEC Electropedia: available at ~~https://www.electropedia.org/~~https://www.electropedia.org/

3.1
machine vision
application of computer vision to machine, robot, process or quality control

Note 1 to entry: This definition is also applicable for use in optical elements and components.

[SOURCE ISO 2382:2015, 2123788, modified — Notes to entry omitted and new Note 1 to entry added.]

3.2
machine vision grading
application of a machine vision system and a computer algorithm to determine the grades of imperfections

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Note 1 to entry: Machine vision grading reports the grade of a particular scratch or dig, which has usually been presented to the machine vision system by an operator.

3.3
machine vision inspection
application of automation hardware and software with a machine vision system to determine if a component or surface passes or fails a given surface imperfection specification

Note 1 to entry: In machine vision inspection, the machine vision grading is performed on all the detected imperfections on the surface to evaluate the surface against all of its requirements, i.e. maximum imperfection grade, accumulation of all imperfections and concentrations of imperfections.

3.4
sleek
polishing (hairline) scratch without visible conchoidal fracturing of the edges

[SOURCE: ISO 9802:~~1996~~2022, 3.6.2.1.4]

4 Symbols

Please see symbols of ISO 14997-1:2017, Clause 4 and the following:

IMV_D dimensional inspection using machine vision

IMV_V visibility inspection using machine vision

5 Considerations for machine vision systems applied to surface imperfection inspection of optics

5.1 Evaluation limits

ISO 14997-1 specifies the required evaluation limits for manual visual inspection, taking into account the human evaluation method and the limits of normal visual resolution. In machine vision assessment of imperfections, a typical inspection device consists of a camera, magnification optics, an illumination system and a computer-based evaluation algorithm. One key difference between machine vision and visual inspection is that visual inspectors are advised by ISO 14997-1 to filter irrelevant defects by adapting the illumination. Machine vision systems can use the same illumination independent of the surface specification and filter irrelevant defects when processing the data with a suitable algorithm.

NOTE Some calculations can be deceptively difficult for a system performing machine vision inspection. For example, the concentration requirements of ISO 10110-7:2017 4.2.4 and 4.3.3 require an extensive decision algorithm to evaluate all the possible combinations of imperfections that are present to determine if a concentration has occurred.

5.2 Sample preparation

According to ISO 14997-1 a test sample needs to be cleaned well enough to allow inspection to the required level. Adhered particles tend to be indistinguishable from digs and pits in the glass and therefore need to be counted as imperfections as well (see ISO 10110-7). If the operator is uncertain about the cleanliness of the sample, it is often best to re-clean the sample after inspection and test it again.

5.3 Illumination configuration

The test method is often a dark field configuration, to be sensitive to scattered light. It can be either a reflective light configuration or a transmitted light configuration. Best contrast is often achieved in dark field, close to the specular reflection. It is important to make sure the illumination conditions are sufficient for the testing system to be sensitive enough to observe all relevant imperfections as described in ISO 10110-7 and ISO 14997-1, including adhered particles.

Most of the imperfections have a well distributed angle dependency for scattered light. In many cases, long imperfections like scratches and sleeks will have a directional bias to the peak scattering direction; typically, in a rotation of 90° with respect to the long axis of the scratch. Moreover, they can produce a small cone of light with a small opening angle. Visual inspectors will tilt and rotate the sample until they reach best visibility and continue with the evaluation. In machine vision, this approach can be impractical and time consuming. In most machine vision inspection systems, a single camera is observing the element under only one angle, e.g. parallel to the optical axis or orthogonal to the surface. The lack of different camera viewing angles can be compensated partly by using an illumination system that covers a large angular spectrum.

Best results are usually achieved when the illumination system covers a wide range of azimuth (around the test piece) and polar (between the plane of the test piece and the system optical axis) angles. This can be achieved, for example, by using a passively illuminated dome or a direct ring or dome-like illumination with individual sources (typically LEDs) that are packed closely together. Illumination uniformity is important, both in azimuthal and polar angles. Best illumination is continuous or close to continuous in azimuthal range. Larger gaps in the azimuthal range increase the probability that scratches and sleeks are not continuously visible in the images. The range of polar angles is often maximized, within the practical constraints of a darkfield configuration and the application. For most imperfections, most light is scattered by only small angles, so that scattered light intensity is highest close to the direction of specular reflection. Larger polar angles tend to add to background illumination, but only a small fraction of the light ends up being scattered into the camera. Manufacturers of machine vision systems used in surface imperfection inspection can assist the user in determining the functionality of the system in their specific application by specifying the azimuthal and angular ranges covered by their device.

NOTE For curved elements, the ideal polar angle for illumination will vary across the surface, as it depends on the slope of the surface.

6 Dimensional inspection using machine vision (IMV_D)

NOTE For visual dimensional inspection (IV_D, IS_D and IM_D), see ISO 14997-1.

6.1 Dimensional resolution and accuracy considerations

For dimensional grade assessment of optical surface imperfections, the task of the inspection is to classify imperfections into grades according to the Renard R5 series described in ISO 3, e.g. 0,1; 0,063; 0,04; 0,025; 0,016; 0,01, etc. For (long) scratches, where these have been specified in the drawing, the grade number corresponds to the width of the scratch. General (and coating) imperfections such as digs are classified according to the square root of their area. The task of the inspection is to differentiate between imperfections of grade 0,25*A* and 0,16*A*, where *A* is the specified grade number, because of the accumulation and concentration rules for general and coating imperfections. ISO 10110-7:2017, 4.2.3, states that imperfections of "grade number of 0,16*A* or smaller shall not be counted", while larger imperfections are accumulated to compute the effective imperfection area. Long scratches are ignored if their grade is 0,25*A* or less.

The machine vision system for dimensional inspection typically uses a high-resolution image and image processing algorithms to determine the width and/or area of imperfections. The imperfections are then assigned grade numbers from the Renard R5 series.

The resolution of the machine vision system is dependent on

— the optical resolution of the magnification optics,

— the pixel pitch of the camera sensor, and

— the algorithm used to process the image data.

NOTE 1 The design of the illumination system could influence the resolution, e.g. when the aperture of a bright field light source is smaller than the aperture of the imaging lens.

ISO 10110-7:2017, 4.2.3 states that "A larger number of surface imperfections (including coating imperfections) with a smaller grade number is permitted, if the sum of their areas does not exceed the maximum total area." It goes on to say "When determining the number of permissible surface imperfections or localized imperfections in optical assemblies, those with a grade number of 0,16*A* or smaller shall not be counted". Consequently, to evaluate the surface for the accumulation and concentration requirements the resolution of the system needs to be at least 0,16*A*, where *A* is the specified grade number.

NOTE 2 This is a much stronger expectation than asking that imperfections can be detected down to grade 0,16*A*. Typical machine vision systems with good signal-to-noise ratios can detect isolated objects well below their resolution.

The machine vision grading for each imperfection is subject to both random (statistical) and systematic errors. Key quantities are the system's fidelity (proximity of results to the true value) and precision (repeatability and reproducibility) for determining the correct grade of an imperfection. However, the effect of fidelity and precision of an imperfection's width/area *measurement* on its *classification* into a specific grade depends upon how close the given imperfection's actual width/area is with respect to the limiting values of the grade size range. If the actual width or square root of the area is exactly equal to a grade number, the classification will be correct only 50 % of the time, assuming a Gaussian distribution of measurement results.

Under the assumption that the measurement results of the machine vision system for a given imperfection follow a Gaussian probability distribution, the probability of assigning the correct grade *A* to the imperfection can be approximated as

$$p \approx 1 - 0{,}8 \times \sigma / (A - 0{,}63A)$$

where

σ is the standard deviation of the Gaussian distribution, i.e. the precision of the system, and

$(A - 0{,}63A)$ is the size of the interval of grade number *A* (see Annex A for a derivation).

EXAMPLE The probability of misclassifying an imperfection with grade number *A* with a machine vision system with a precision equal to 0,1*A* is approximately 22 %.

6.2 Brightness and sensitivity

ISO 14997-1 prescribes an illumination brightness that is required to be used with visual inspection. For machine vision grading, the detection limit will not only depend on the brightness of illumination, but also on the characteristics of the camera (gain and dark noise floor) and the image processing algorithms that are employed.

If the illumination is too bright, light scattered by larger and/or highly scattering imperfections will saturate the image sensor; if the illumination is too weak, smaller and/or weakly scattering imperfections do not stand out from the noise floor. The illumination needs to be as bright as necessary to make the smallest relevant defects stand out from the noise floor. If larger imperfections tend to saturate under these conditions, it is important that a careful calibration of the system is performed across the full relevant width and area range, so that very bright large imperfections do not appear enlarged to the processing algorithms.

