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Optics and optical instruments — Preparation of drawings for optical elements and systems —

Part 5:
Surface form tolerances

Optique et instruments d'optique — Indications sur les dessins pour éléments et systèmes optiques —

Partie 5: Tolérances de forme de surface

Reference number
ISO 10110-5:1996(E)

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.

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.

International Standard ISO 10110-5 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 1, *Fundamental standards*.

ISO 10110 consists of the following parts, under the general title *Optics and optical instruments — Preparation of drawings for optical elements and systems*:

- *Part 1: General*
- *Part 2: Material imperfections — Stress birefringence*
- *Part 3: Material imperfections — Bubbles and inclusions*
- *Part 4: Material imperfections — Inhomogeneity and striae*
- *Part 5: Surface form tolerances*
- *Part 6: Centring tolerances*
- *Part 7: Surface imperfection tolerances*
- *Part 8: Surface texture*
- *Part 9: Surface treatment and coating*

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- *Part 10: Table representing data of a lens element*
- *Part 11: Non-toleranced data*
- *Part 12: Aspheric surfaces*
- *Part 13: Laser irradiation damage threshold*

Annexes A, B, C and D of this part of ISO 10110 are for information only.

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Optics and optical instruments — Preparation of drawings for optical elements and systems —

Part 5:
Surface form tolerances

1 Scope

ISO 10110 specifies the presentation of design and functional requirements for optical elements and systems in technical drawings used for manufacturing and inspection.

This part of ISO 10110 specifies rules for indicating the tolerance for surface form.

NOTE 1 The terminology of interferometry is used for the specification of tolerances, and in particular, for the units in which the tolerances are to be specified; however, this does not stipulate that only interferometric methods may be used for the actual testing of optical parts. Other, non-interferometric methods may be used if the results are converted to the units specified here.

This part of ISO 10110 applies to surfaces of both spherical and aspheric form.

NOTE 2 ISO 10110-12 allows the surface form tolerance for aspheric surfaces to be specified without reference to this part of ISO 10110.

Annexes A and B describe methods for determining the types of surface form deviation. Annex C addresses the physical significance of the rms measures of surface form deviations.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 10110. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 10110 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 10110-1:1996, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 1: General.*

ISO 10110-10:1996, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 10: Table representing data of a lens element.*

3 Definitions

For the purposes of this part of ISO 10110, the following definitions apply.

3.1 surface form deviation: Distance between the optical surface under test and the nominal theoretical surface, measured perpendicular to the theoretical surface, which is nominally parallel to the surface under test.

NOTE 3 For testing purposes, the desired theoretical surface may be represented by a test glass, interferometric reference surface, or other measuring device of sufficient accuracy.

3.2 peak-to-valley (PV) difference (between two surfaces)**:** Maximum distance minus the minimum distance between the surfaces.

NOTE 4 If one of the surfaces is a theoretical surface, it is possible that the surfaces cross, in which case the minimum distance between the surfaces is a negative number; the sign must be taken into account in computing the PV difference.

3.3 unit of fringe spacings: Surface form deviation equal to one-half the light wavelength.

NOTES

5 When a surface is tested interferometrically, a surface form deviation of one-half the wavelength of light causes an interference pattern in which the intensity varies from one bright fringe to the next, or from one dark fringe to the next- that is, one "fringe spacing" is visible. For the purpose of this part of ISO 10110, the words "fringe spacings" do not refer to the transverse distance between fringes, but to the fact that the number of fringe spacings visible in the interference pattern corresponds to the number of half-wavelengths of surface form deviation.

6 See subclause 6.2 regarding the light wavelength.

3.4 total surface deviation function: Theoretical surface defined by the difference between the actual surface and the desired theoretical surface. [See figure 1 a).]

3.5 approximating spherical surface: Spherical surface for which the root-mean-square (rms) difference to the total surface deviation function is a minimum. [See figure 1 b).]

NOTE 7 See clause 5 in the case of non-circular test areas.

3.6 sagitta error: Peak-to-valley difference between the approximating spherical surface and a plane.

NOTE 8 Sagitta error results from the test surface having a radius of curvature different from the specified radius.

3.7 irregularity function: Theoretical surface defined by the difference between the total surface deviation function and the approximating spherical surface. [See figure 1 c).]

3.8 irregularity: Peak-to-valley difference between the irregularity function and the plane which best approximates it.

NOTE 9 For nominally spherical surfaces, the irregularity represents the departure of the surface from sphericity. For aspheric surfaces, the irregularity represents the aspheric part of the total surface deviation function.

3.9 approximating aspheric surface: The rotationally symmetric surface for which the rms difference to the irregularity function is a minimum. [See figure 1 d).]

NOTE 10 See clause 5 in the case of non-circular test areas.

3.10 rotationally symmetric irregularity: Peak-to-valley difference between the approximating spherical surface and the plane which best approximates it.

NOTE 11 The rotationally symmetric irregularity is the rotationally symmetric part of the irregularity defined in subclause 3.8. Its value cannot exceed that of the irregularity.

3.11 total rms deviation, RMSt: Root-mean-square difference between the optical surface under test and the desired theoretical surface, without subtraction of any surface form deviation types.

3.12 rms irregularity, RMSi: Root-mean-square value of the irregularity function defined in 3.7.

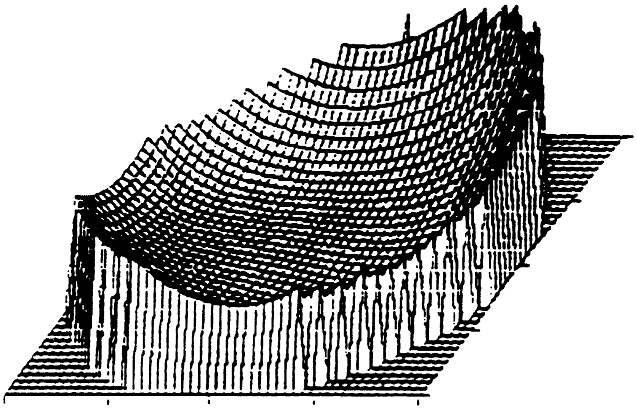
3.13 rms asymmetry, RMSa: Root-mean-square value of the difference between irregularity function and the approximating aspheric surface. [See figure 1 e).]

4 Types of surface form deviation

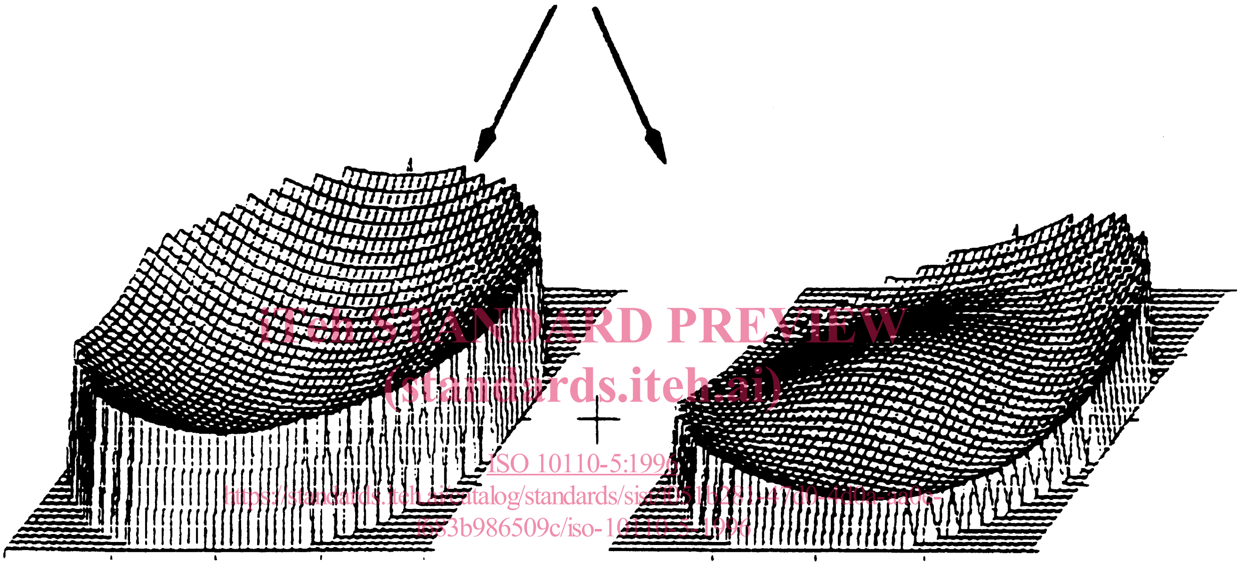
The tolerances for surface form deviation are indicated by specifying the maximum permissible values of the sagitta error (see 3.6), irregularity (see 3.8), and/or rotationally symmetric irregularity (see 3.10). In addition, tolerances for three root-mean-square (rms) measures of surface form deviation may be specified (see 3.11, 3.12 and 3.13). These rms measures of the deviation represent the rms value of the function remaining after the subtraction of various surface deviation types.

A method for determining the amount of sagitta error, irregularity and rotationally symmetric irregularity of a given surface using digital interferogram analysis techniques is given in annex A. Methods by which these quantities can be estimated using test glasses or visual interpretation of interferograms are given in annex B.

A method for calculating the total rms deviation, the rms irregularity, and the rms asymmetry is given in annex A. These rms measures of surface form deviation cannot be estimated visually.

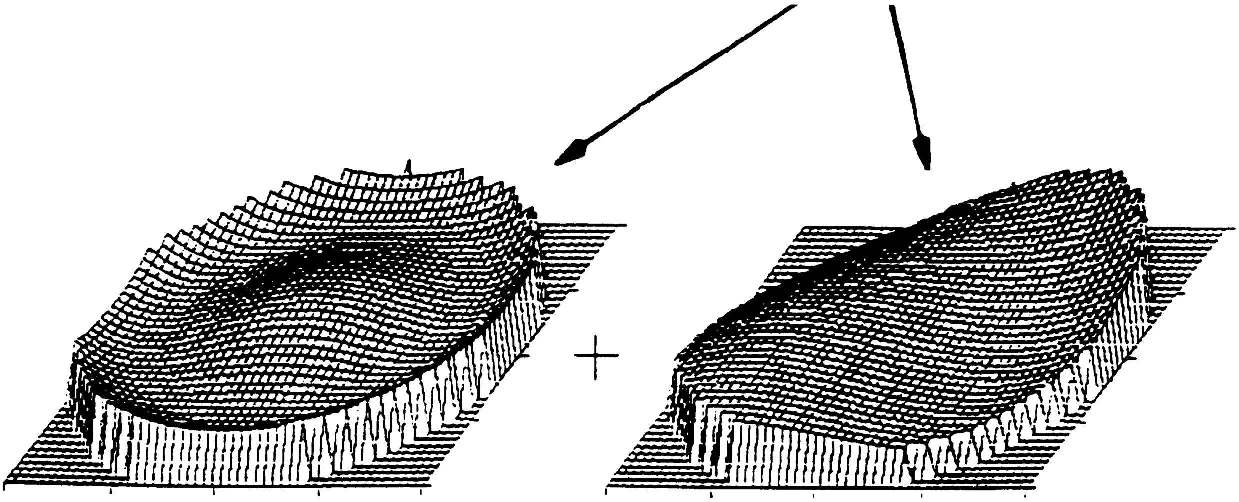


a) The measured surface deviation



b) The approximating spherical surface, which determines the sagitta error

c) The irregularity function, which determines the irregularity



d) The (rotationally symmetric) approximating aspheric surface, which determines the rotationally symmetric irregularity

e) The surface remaining after removal of b) and d), which determines the rms asymmetry

Figure 1 — Example of a measured surface and its decomposition into surface error types

5 Non-circular test areas

For non-circular test areas, the peak-to-valley (PV) and root-mean-square (rms) values given in clause 4 shall be calculated within the actual test area only.

It is important to note that for non-circular test areas, the spherical surface which minimizes the rms difference to the total surface deviation function (3.4) is not the spherical part of an approximating surface which is aspheric. Also, the rotationally symmetric surface which minimizes the rms difference to the irregularity function (3.7) is not the rotationally symmetric part of an approximating surface which is not rotationally symmetric (see annex A).

6 Specification of tolerances for surface form deviation

For the specification of tolerances for surface form deviation, the following stipulations apply.

6.1 The maximum permissable values for sagitta error, irregularity, and rotationally symmetric irregularity shall be specified in units of fringe spacings (see 3.3).

If a specification is to be given for one or more rms deviation types, it shall be done in units of fringe spacings. It is to be noted that the specification of a tolerance for an rms deviation type requires that the surface be analyzed digitally.

NOTE 12 It is not necessary that tolerances be specified for all types of surface form deviation.

6.2 Unless otherwise specified, the wavelength shall be that of the green spectral line of mercury (e-line), $\lambda = 546.07$ nm in accordance with ISO 7944.

NOTE 13 Specifications may be converted from one reference wavelength to another using the formula:

$$N_{\lambda 2} = N_{\lambda 1} \times \frac{\lambda_1}{\lambda_2}$$

where $N_{\lambda 1}$ and $N_{\lambda 2}$ are the numbers of fringe spacings at λ_1 and λ_2, respectively.

7 Indication in drawings

7.1 The surface form tolerance is indicated by a code number and the indications of the tolerances for sagitta error, irregularity, rotationally symmetric irregularity, and rms deviation types, as appropriate.

7.2 The code number for surface form tolerance is 3.

7.3 The indication shall have one of three forms:

$3/A(B/C)$

or

$3/A(B/C)$ RMSx $< D$ (where x is one of the letters t, i or a).

or

3/—RMSx $< D$ (where x is one of the letters t, i, or a).

Quantity A is either

1) the maximum permissible sagitta error, as defined in 3.6, expressed in fringe spacings; or

2) a dash (—) indicating that the total radius of curvature tolerance is given in the radius of curvature dimension (not applicable for planar surfaces).

NOTE 14 It is often the case that the tolerance for sagitta error is calculated by converting only part of the tolerance shown against the radius of curvature tolerance into a tolerance for sagitta error, in accordance with clause 8.

Quantity B is either

1) the maximum permissible value of irregularity, as defined in 3.8, expressed in fringe spacings; or

2) a dash (—) indicating that no explicit irregularity tolerance is given.

Quantity C is the permissible rotationally symmetric irregularity expressed in fringe spacings, as defined in 3.10. If no tolerance is given, the slash (/) is replaced by the final parenthesis, i.e. $3/A(B)$.

If no tolerance is given for all three deviation types, then A, B, C, the slash (/) and the parentheses are replaced by a single dash (—), i.e. 3/—.

Quantity D is the maximum permissible value of the rms quantity of the type specified by x where x is one of the letters t, i or a. These deviations are defined in 3.11 to 3.13. The specification of more than one type of rms deviation is allowed. These specifications shall be separated by a semicolon, as shown in example 5.

The surface form tolerance indicated applies to the optically effective area, except when the indication is to apply to a smaller test field for all possible positions within the optically effective area. In this case the diameter of the test field shall be appended to the tolerance indication, as follows:

$3/A(B/C)$ RMSx $< D$ (all Ø...)

See example 3.

No provision is given for the specification of a PV-tolerance for the total surface deviation (that is, including both sagitta error and irregularity). If such a specification is necessary, this information shall be given in a note on the drawing; for example "Total surface deviation not to exceed 0,25λ".

NOTE 15 Such a specification might, for example, be useful for interferometer flats.

7.4 The indication shall be shown in connection with a leader to the surface to which it relates and will be associated with centring errors and surface imperfections. An example of such indication is given in ISO 10110-1:1996, annex A.

Alternatively, for lens elements, the indication may be given in a table in accordance with ISO 10110-10.

If two or more optical elements are to be cemented (or optically contacted), the surface form tolerances given for the individual elements apply also for the surfaces of the optical sub-assembly, i.e. after cementing (or optically contacting), unless otherwise specified. See ISO 10110-1:1996, subclause 4.8.3.

8 Relationship between sagitta error tolerance and radius of curvature tolerance

The maximum permissible number of fringe spacings corresponding to a dimensional radius of curvature tolerance, is given by the following formula, provided that the ratio $\frac{\Delta R}{R}$ is small:

$$N = \frac{2\Delta R}{\lambda}\left\{1 - \sqrt{1 - \left(\frac{\varnothing}{2R}\right)^2}\right\}$$

If the ratio $\frac{\varnothing}{R}$ is small, this formula may be approximated by:

$$N \approx \left[\frac{\varnothing}{2R}\right]^2 \frac{\Delta R}{\lambda}$$

where

R	is the radius of curvature;
ΔR	is the dimensional radius of curvature tolerance;
Ø	is the diameter of the test area; and
λ	is the wavelength (normally 546,07 nm).

9 Examples of tolerance indications

EXAMPLE 1

3/3(1)

The tolerance for sagitta error is 3 fringe spacings. The irregularity may not exceed 1 fringe spacing.

EXAMPLE 2

3/5(—) RMSi < 0,05

The tolerance for sagitta error is 5 fringe spacings. No specific tolerance is given for irregularity or rotationally symmetric irregularity, but the rms value of the irregularity may not exceed 0,05 fringe spacings.

EXAMPLE 3

3/3(1/0,5) (all Ø 20)

The tolerance for sagitta error is 3 fringe spacings. The total irregularity may not exceed 1 fringe spacing. The rotationally symmetric irregularity may not exceed 0,5 fringe spacings. These tolerances apply for all possible test fields of diameter 20 mm within the total test area.

EXAMPLE 4

3/—(1)

No specific tolerance for sagitta error is given; the tolerance on the radius of curvature is to be taken from the radius of curvature indication. The total irregularity may not exceed 1 fringe spacing.

NOTE 16 If no tolerance on the radius of curvature is specified, then ISO 10110-11:1996, table 1, applies.

EXAMPLE 5

3/—RMSt < 0,07; RMSa < 0,035

No specific tolerance for sagitta error, irregularity, or rotationally symmetric irregularity is given; the tolerance on the radius of curvature is to be taken from the radius of curvature indication; however, when the surface is compared with the desired theoretical surface, the total rms deviation shall be less than 0,07 fringe spacings, and the rms asymmetry less than 0,035 fringe spacings.

NOTE 17 If no tolerance on the radius of curvature is specified, then ISO 10110-11:1996, table 1, applies.

Annex A
(informative)

Digital interferogram analysis

This annex provides a method for the analysis of surfaces which can be described in terms of polynomials.

The contents of this annex are important for users of digital interferometers as well as for developers of software for interferometry.

Examples of surfaces to which this method does not apply, are surfaces having interferometric error functions which are cone-shaped and surfaces with spatially localized errors.

A.1 General

The amounts of the various types of surface form deviation are determined through a process of successive fitting and removal of surface form deviation types; at each stage, the removal of one type of surface form deviation exposes the next type of deviation.

The procedure by which a function of a certain type which "best fits" a certain original function is determined, is the well-known method of least squares, which minimizes the rms error between the original function and the approximation to it. The rms value of a function is defined in A.4.

A.1.1 Effective reference surface

When testing curved surfaces interferometrically, the surface under test is compared with a reference wavefront. The resulting fringe pattern represents the difference between the surface under test and the projection of the reference wavefront into the location of the surface under test. This projected wavefront is called the effective reference surface.

The apparent surface figure deviations as measured by the interferometer (including the relative tilt between the surface under test and the interferometric reference surface) will be referred to in this annex as the wavefront error function, $W(r, \theta)$.

A.1.2 Coordinate system

The optical surface under test is described in polar coordinates by the variables r and θ; the origin of the coordinate system is the centre of the test area, and r is normalized to one at the edge of the test area. For non-circular test areas, the "centre" of the test area refers to its centroid, and the radius of the test area refers to the distance from the centre to the most distant point. Parameter r ranges therefore between zero and one.

Various approximations to the surface are represented as linear combinations of the polynomials — commonly called Zernike polynomials — $Z_0(r, \theta)$, $Z_1(r, \theta)$..., given in A.3. These combinations are given by corresponding coefficients C_0, C_1, ...

A.2 Procedure

The procedure for finding the amounts of the various surface form deviations is given in A.2.1 to A.2.7. Although this procedure is described in terms of the Zernike polynomials (see A.3), any mathematically equivalent procedure, based on another set of functions, may be used; however, the deviations must be determined and subtracted in the order specified here.

A.2.1 Total surface deviation

To the measured wavefront error function $W(r, \theta)$, the best fitting plane $P(r, \theta) = C_0 Z_0 + C_1 Z_1 + C_2 Z_2$ is found by the least squares procedure. The total surface deviation function (TSD) is found by subtracting the best fitting plane from the measured wavefront error:

$$\mathrm{TSD}(r, \theta) = W(r, \theta) - P(r, \theta)$$

A.2.2 Total rms deviation, RMSt

If the radius of the effective reference surface is equal to the radius of the desired theoretical surface, then the total rms deviation (RMSt), (see 3.11) is equal to the rms value of the total surface deviation function, $\mathrm{TSD}(r, \theta)$. The quantity RMSt cannot be directly determined if the effective reference surface and the theoretical surface have different radii.