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

Part 5:
Surface form tolerances

Optique et photonique — Indications sur les dessins pour éléments et systèmes optiques —

Partie 5: Tolérances de forme de surface

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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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary Information.

The committee responsible for this document is ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This third edition cancels and replaces the second edition (ISO 10110-5:2007), which has been technically revised with the following changes:

a) "nanometres" have been introduced as the standard unit for specifying tolerances for certain types of surface form deviation replacing the former standard unit "fringe spacings";

b) expansion of the scope now including surfaces of higher order such as aspheric, non-circular cylindric, and general surfaces;

c) specification of deviations in tabular form has been added;

d) a definition of sagitta deviation has been added;

e) the name of quantity A has been changed to power deviation (reflecting the change in ISO 14999-4). For further details, see 5.2.3, NOTE 3;

f) an informative Annex B has been added giving a comparison of ISO 10110-5 and ISO 14999-4 regarding corresponding nomenclature, functions, and values.

ISO 10110 consists of the following parts, under the general title *Optics and photonics — 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*

Introduction

This part of ISO 10110 refers to deviations in the form (shape) of an optical surface and provides a means of specifying tolerances for certain types of surface form deviation in terms of nanometres.

As it is common practice to measure the surface form deviation interferometrically as the wavefront deformation caused by a single reflection from the optical surface at normal (90° to surface) incidence, it is possible to describe a single definition of interferometric data reduction that can be used in both cases, i.e. in surface form deviation as well as wavefront deformation. As the analysis of most measurements is software based, the deviations are expressed in nanometres. Interferometrical measurements, however, use the unit "fringe spacings". One "fringe spacing" is equal to a surface form deviation that causes a deformation of the reflected wavefront of one wavelength. A value expressed in nanometres is an indication of the actual height deviation of the surface itself (and not that of the reflected wavefront).

The surface under test, together with the test glass is, for example, such an interferometer. The surface form deviation is represented by the wavefront deformation which is the difference between the wavefront reflected by the actual surface and that reflected by the test glass surface.

Due to the potential for confusion and misinterpretation, nanometres rather than fringe spacings are to be used. Where fringe spacings are used as units, the wavelength is also to be specified.

In addition, tolerances for slope deviations of surfaces can be given in units of mrad, μrad, arcmin, or arcsec.

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

Part 5:
Surface form tolerances

1 Scope

This International Standard 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 deviation.

NOTE   The terminology of interferometry employing the unit "fringe spacings" is widely used for the specification of tolerances. However, the usage of non-interferometric methods for testing of optical parts has recently become more important. Therefore, unlike in the earlier versions of this part of ISO 10110, nanometres shall now be the preferred and standard unit to express surface form deviations. The usage of fringe spacings is still permitted given that the base wavelength is explicitly stated.

This part of ISO 10110 applies to surfaces of plano, spherical, aspheric, circular and non-circular cylindric, and toric form as well as to surfaces of other non-spherical shape such as generally described surfaces. It does not apply to diffractive surfaces, Fresnel surfaces, and micro-optical surfaces.

2 Normative references

The following referenced documents, in whole or in part, 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 10110-1, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 1: General*

ISO 10110-10, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 10: Table representing data of optical elements and cemented assemblies*

ISO 10110-19, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 19: General description of surfaces and components*

ISO 14999-4, *Optics and photonics — Interferometric measurement of optical elements and optical systems — Part 4: Interpretation and evaluation of tolerances specified in ISO 10110*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14999-4 and the following apply.

3.1
surface form deviation
function representing the distances normal to the surface between a nominal optical surface form and a measured form described as a measured wavefront deformation f_{WD} or $f_{WD,CY}$ as defined in ISO 14999-4

Note 1 to entry: ISO 14999-4 provides the definitions for the deformation functions.

3.2
sagitta deviation
ΔZ
function representing the distances along the z-axis between a nominal optical surface form and a measured form

Note 1 to entry: Based on interferometric measurement, the values are available along the local surface normal and have to be converted to deviations in the z direction in order to compare them with ΔZ.

Note 2 to entry: For simple optical surfaces, the z-axis is often also the optical axis.

4 Specification of tolerances for surface form deviation

4.1 General

The tolerances for surface form deviation are indicated by specifying the maximum permissible values of the power deviation, irregularity, rotationally and/or translationally invariant irregularity. In addition, tolerances for root-mean-square (rms) measures of surface form deviation (rms total, rms irregularity, and rms rotationally and/or translationally varying wavefront irregularity) and tolerances for slope deviation (max and rms values) may be specified (see ISO 14999-4 for definitions). A surface form deviation based on a sagitta table can also be given in the z-direction and as irregularity as well as slope.

Both the surface form tolerances and the tolerances of the slope deviations can vary in different sections and different orientations (x, y) or (ρ, φ). In this case, the sampling length and the spatial sampling interval can also deviate from each other.

The surface form tolerance can also be defined as coefficients of a Zernike polynomial.

NOTE 1   ISO 10110-14 provides a means of specifying only one single tolerance for the wavefront deformation without any need to specify tolerances for individual surfaces.

NOTE 2   Methods for determining the amount of power deviation, irregularity, rotationally and/or translationally invariant irregularity, and slope deviation of a given surface are given in ISO 14999-4.

Specifying a slope deviation tolerance or rms slope is recommended for non-spherical surfaces like aspheric, non-circular cylindric, or general surfaces. Depending on the application and complexity, the permissible max slope deviation might also be indicated as an absolute quantity in direction (x, y) or (ρ, φ).

It is not necessary that tolerances are specified for all types of surface form deviation.

All deviations of the surface but one is defined perpendicular to the theoretical surface. The sagitta deviation, ΔZ, is defined along the z-axis.

4.2 Units

The maximum permissible values for power deviation, irregularity, and rotationally and/or translationally invariant irregularity shall be specified in units of nanometres or, if preferred, micrometers or fringe spacings. If a specification is to be given for one or more rms deviation types, it shall be given in units of nanometres or, if preferred, micrometers or fringe spacings.

To avoid confusion, the unit "wavelength of light" should never be used for surface form deviations.

When a surface is tested interferometrically by reflection at normal incidence, a surface form deviation of one-half the wavelength of light causes a wavefront deviation of one full wavelength. This results in an interference pattern in which the intensity varies from one bright fringe to the next or from one dark fringe to the next, i.e. 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 wavelengths of wavefront deviation.

NOTE 1   One fringe spacing is 1 × 1/2 × the wavelength (in nanometres) in which a surface form deviation is actually specified.

NOTE 2   The specification of a tolerance for an rms deviation type requires that the optical system is analysed digitally.

Deviations based on a sagitta table along the z-axis shall be given in metric units like μm or nm.

The maximum permissible values for max and rms slope deviation shall be specified with preferred units of mrad. The corresponding units of degree, μrad, arc minutes (...'), and arc seconds (...'') can be used as well. The unit shall always be indicated.

4.3   Wavelength

Applying the unit fringe spacings the wavelength shall be given.

NOTE 1   In earlier versions of this part of ISO 10110, unless otherwise specified, the wavelength was the green spectral line of mercury (e-line), λ = 546,07 nm, according to ISO 7944.

NOTE 2   Specifications can be converted from one reference wavelength to another using Formula (1).

$$N_{\lambda 2} = N_{\lambda 1} \times \left(\lambda_1 / \lambda_2 \right) \tag{1}$$

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

5   Indication in drawings

5.1   General

The surface form tolerance is indicated by a code number and indications of the tolerances for power deviation, irregularity, rotationally and/or translationally invariant irregularity, max slope, and rms slope deviation types as appropriate. Irregularity, form deviation in z-direction, max slope, and rms slope deviation may also be indicated in a table in conjunction with the sagitta table. Both specifications can be used in combination. It shall be ensured that both are not contrary to each other.

The use of indications is not limited in general by the kind of form like spherical or cylindrical specified. However, not all specifications are helpful for all surface forms. All quantities shall have their units specified. If no unit is indicated, then fringe spacing is implied.

5.2   Structure of the indication based on code number

5.2.1   General

The indication shall consist of one basic form and may be supplemented by additional forms. Multiple forms shall be separated by a semicolon.

5.2.2   Code number

The code number for surface form tolerance is 3/.

5.2.3   Basic forms

3/A(B/C)

or

3/A(B/C) RMSx < D

where x is one of the letters t, i or a (see below quantity D).

or

3/RMSx < D

where x is one of the letters t, I, or a (see below quantity D).

or

3/AX;AY (B/CX;CY)

or

3/

NOTE   In former editions, 3/— RMS$_x$ was used.

Applying the unit fringe spacings, the indication "; $\lambda = E$" shall be added in order to specify the wavelength.

The quantity A is either

a)   the maximum permissible power deviation (peak-to-valley value) PV(f_{WS}) as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings, or

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

The quantities AX, AY are either

a)   the maximum permissible power deviation (peak-to-valley value) PV($f_{WC,x}$) and PV($f_{WC,y}$) for cylindric and similar surfaces as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings, or

b)   a dash (—) indicating that the entire radius of curvature tolerance is contained in the specification of the radius of curvature.

If no power deviation is allowed, then A, AX, or AY shall be 0. In this case, all the deviation including also that part that could be interpreted as a power deviation shall be included in irregularity B.

A shall be set to 0 in cases of surfaces without symmetry when no kind of power deviation is applicable.

NOTE 1   It is often the case that the tolerance for power deviation is calculated by converting a part of the tolerance shown against the radius of curvature tolerance into a tolerance for power deviation using the formulae given in Annex A.

NOTE 2   If no tolerance on the radius of curvature is specified combined with a dash for the power deviation, then defaults in ISO 10110-11 apply.

NOTE 3   Previous versions of this part of ISO 10110 used the term sagitta to represent this quantity A. This is not correct since the true sagitta deviation is the distance evaluated parallel to the z-axis. For better clarity, we have changed the name of quantity A everywhere to power deviation (reflecting the change in ISO 14999-4), so that the true sagitta can be used correctly.

NOTE 4   Care should be taken in the specification of quantity A for surfaces with large amounts of curvature as the value of the power can vary significantly compared to the measured value of the deviation of the radius of curvature.

The quantity B is either

a)   the maximum permissible value (peak-to-valley value) PV(f_{WI}) of irregularity as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings when A is used,

b)   the maximum permissible value (peak-to-valley value) PV($f_{WI,CY}$) of irregularity for cylindric and similar surfaces as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings when AX and/or AY are used, or

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

The quantity C is either

a)   the maximum permissible value (peak-to-valley) PV- (f_{WRI}) of rotationally invariant irregularity, expressed in nanometres, micrometers, or fringe spacings as defined in ISO 14999-4, or

b)   a dash (—) indicating that no explicit rotationally invariant irregularity tolerance is given.

If no tolerance is given, the slash (/) is replaced by the closing parenthesis, i.e. 3/A(B).

The quantities CX and CY are either

a)   the maximum permissible value (peak-to-valley) PV($f_{WTI,x}$), PV($f_{WTI,y}$) of translationally invariant irregularity for cylindric and similar surfaces, expressed in nanometres, micrometres, or fringe spacings as defined in ISO 14999-4. CX and CY are used for the symmetry specification across the x and y-axis, or

b)   a dash (—) indicating that no explicit translationally invariant irregularity tolerance for both or one of them is given.

If no tolerance is given, the slash (/) is replaced by the closing parenthesis, i.e. 3/AX;AY(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/—.

The 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

a)   for rotationally symmetric surfaces according to ISO 14999-4:

- for t (total): rms total rms(f_{WD})

- for i (irregular): rms irregularity rms(f_{WI})

- for a (asymmetric): rms rotationally varying (asymmetric) irregularity rms(f_{WRV})

b)   for cylindric and similar surfaces according to ISO 14999-4:

- for t (total): rms total rms($f_{WD,CY}$)

- for i (irregular): rms irregularity rms($f_{WI,CY}$)

- for a (asymmetric): rms translationally varying (asymmetric) irregularity rms(f_{WTV})

The specification of more than one type of rms deviation is allowed. These specifications shall be separated by a semicolon as shown in Clause 6, Example 5.

The quantity E is the wavelength in nanometres in which the surface form deviation is defined for the unit fringe spacings.

NOTE 5   The quantities A and C are best used for types of rotationally invariant or similar surfaces. The quantities AX, AY, as well as CX and CY are best used for types of cylindrical, toric, or similar surfaces.

NOTE 6   Generally, for all kinds of surfaces, either the 1-dimensional specification A and C or the 2-dimensional specification AX and AY as well as CX and CY can be helpful depending on the departure of the surface form from rotational invariance and on the functionality of the optical system. The values B and D are always applicable.

5.2.4   Additional forms

5.2.4.1   max and rms surface slope deviation

$\Delta S_{v,w}(F/G/H)$;

and

$RMS\Delta S_{v,w}(K/L/M)$;

where

v   is one of 1-dim or 2-dim or nothing;

w   is one of the orientations x, y, ρ, and φ or nothing for arbitrary directions.

The quantity F is either

a)   the maximum permissible 1-dim slope deviation ξ_{1-dim} as defined in ISO 14999-4 where v is 1-dim in the orientation specified by w and where w is one of the letters/orientation x, y, ρ, and φ or if missing in all,

b)   the maximum permissible 1-dim slope deviation ξ_{1-dim} as defined in ISO 14999-4 if v is missing, but w is specified as one of the letters/orientation x, y, ρ, and φ,

c)   the maximum permissible orientation-independent 2-dim slope deviation ξ_{2-dim} as defined in ISO 14999-4 if v is 2-dim (here, the specification of w is omitted), or

d)   maximum permissible slope deviation where, if v and w are missing, it is permissible to choose between 1-dim in all orientations or 2-dim.

The quantity G is either

a)   the sampling length for 1-dim as defined in ISO 14999-4, or

b)   the edge length of sampling area in 2-dim as defined in ISO 14999-4 to be used for determining the slope deviation (quantity F).

The quantity H is the spatial sampling interval as defined in ISO 14999-4 to be used for determining the slope deviation (quantity F).

The quantity K is either

a)   the maximum permissible rms quantity of 1-dim slope deviation ξ_{1-dim} as defined in ISO 14999-4 where v is 1-dim in the orientation specified by w, where w is one of the letters/orientation x, y, ρ, and φ, or if missing in all,

b)   the maximum permissible rms quantity of 1-dim slope deviation ξ_{1-dim} as defined in ISO 14999-4 where v is missing, but w is specified as one of the letters/orientation x, y, ρ, and φ,

c)   the maximum permissible orientation-independent rms quantity of 2-dim slope deviation ξ_{2-dim} as defined in ISO 14999-4 where v is 2-dim (here, the specification of w is omitted), or

d) the maximum permissible rms quantity of slope deviation where, where v and w are missing, it is free to choose between 1-dim in all orientations or 2-dim.

The quantity L is either

a) the sampling length for 1-dim as defined in ISO 14999-4, or

b) the edge length of sampling area in 2-dim as defined in ISO 14999-4 to be used for determining the slope deviation (quantity K).

The quantity M is the spatial sampling interval to be used for determining the slope deviation (quantity K) as defined in ISO 14999-4 to be calculated in K.

More than one tolerance specification is permissible for max and rms slope deviations. These specifications are listed and separated by a semicolon as specified in 6.1, Example 9.

For max and rms 1-dim slope deviation tolerances, the orientation of the slope analysis shall be defined in the drawing.

The requested orientation in general does not directly specify the measurement method to be used. If 1-dim measurement methods are used, the orientation of the measurement shall be specified in the orientation.

When a 1-dim measurement method is used and the orientation of the slope is not specified, the measurement of all directions might not be practically possible. Then, the most critical orientation with respect to the manufacturing method shall be measured.

Specifications made in 1-dim can also be proven based on a 2-dim measurement. Then, the measurement data shall be analysed based on the 1-dim method in the requested orientation.

Calculations of max and rms slope deviations are performed on the function f_{det} after detrending. By default f_{det} equals one of the following functions: wavefront irregularity f_{WI} or wavefront irregularity for cylindrical wavefronts $f_{WI,CY}$. All quantities are defined in ISO 14999-4. A note on the drawing is required if method other than the default is used to calculate f_{det}.

5.2.4.2 Surface form deviation described by Zernike coefficients

Z(n,m) (PV < O; RMS < P)

where

(n,m)   are indices for one or a set of tuples which reflect a degree of Zernike polynomials.

The quantity O is the maximum permissible peak-to-valley value of the surface form deviation that is described by one or the combined function of a set of Zernike polynomials as defined in ISO 14999-4 where (n,m) are indices for one or a set of Zernike polynomial(s) according to ISO 14999-4.

The quantity P is the maximum permissible rms value of the surface form deviation that is described by one or the combined function of a set of Zernike polynomials as defined in ISO 14999-4, where (n,m) are indices for one or a set of Zernike polynomial(s) according to ISO 14999-4.

A set of Zernike polynomials Z(n1,m1), Z(n2,m2), Z(n3,m3), or Z(N = x) is interpreted as the sum function of these Zernike polynomials. Especially for mathematically complex or multiple tolerances for Zernike polynomials, the values shall be given in a table(see 5.4).

Peak-to-valley and rms surface form deviations described by Zernike coefficients are taking the radius correction into account. Thus, an applicable radius correction reduces the peak-to-valley and rms values rather than a power deviation which does not.

Both peak-to-valley as well as rms Zernike specifications are only applicable for circular apertures.

5.2.4.3 PV and robust PV surface deviation

PV(Q)

and

PVr(R)

The quantity Q is the maximum permissible peak-to-valley value of the total surface deviation $PV(f_{WD})$ as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings.

The quantity R is the maximum permissible robust peak-to-valley value of the total surface deviation $PVr(f_{WD})$ as defined in ISO 14999-4, expressed in nanometres, micrometres, or fringe spacings.

PV and PVr values are taking a radius correction into account. Thus, an applicable radius correction reduces the peak-to-valley and robust peak-to-valley values rather than a power deviation which does not.

Due to the usage of Zernike polynomials, PVr is only applicable for circular apertures.

5.2.5 Area

The surface form tolerance indicated applies to the complete optically effective area if no constraints are given.

If the indication is to be applied to a smaller test field within a larger test area, as defined in ISO 10110-1, then the test field dimension shall be appended to the tolerance.

3/A(B/C) RMSx < D (all $\varnothing$ ...)

See Clause 6, Example 3.

Indicating tolerances in a table as given in Table 1 gives a second way to apply tolerances to smaller areas.

A test field in any shape (e.g. rectangular) can be defined and shown in any position within the test region as a dimensioned area. Appropriate requirements indicated by a leader naming "3/ Test field" to this test field shall apply to all possible positions of the test field within the test region. In this case, the geometric shape of the test field shall be appended to the appropriate tolerance indication as follows.

3/A(B/C) RMSx < D (all ... x ...,)

See Clause 6, Example 7.

5.2.6 Location

The indication based on code number shall be shown in a table in accordance with ISO 10110-10.

Alternatively, for lens elements, the indication may be given 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 an indication is given in ISO 10110-1.

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

5.3 Structure of the indication in tabular form

As an alternative to the specification in 5.2, the form tolerance may also be made in tabular form as shown in Table 1. The specification of these tolerances shall be made in conjunction with the sagitta table defined in ISO 10110-19 by adding additional columns. The surface form can be specified as irregularity (perpendicular to the surface) or as deviation along the *z*-axis. Slope deviations can be specified in various orientations.

Table 1 — Sagitta table in accordance with ISO 10110-19 with additional tabular definition of form tolerances

..	..	Z	S	ΔZ	I	$\Delta S_{v,\,w}$	$RMS\Delta S_{v,\,w}$	...
			.					
			.					
			.					
						(G/H)	(L/M)	

The main reason for use of the tabular form is the feasibility to easily define different specifications for different areas. A distinction according to the position on the surface is possible for all the parameters.

NOTE 1   In 5.3, the same identifiers for quantities are used like in 5.2.

The values for the quantity ΔZ are the maximum permissible sagitta deviation defined in 3.2.

The values for the quantity I specify the maximum permissible irregularity $PV(f_{WI})$ or $PV(f_{WI,CY})$ defined in ISO 14999-4.

The values for the quantity $\Delta S_{v,w}$ specify the maximum permissible slope deviation $\xi_{1\text{-dim}}$ and $\xi_{2\text{-dim}}$ according to ISO 14999-4.

The values for the quantity $RMS\Delta S_{v,w}$ specify the maximum permissible rms slope deviation of $\xi_{1\text{-dim}}$ and $\xi_{2\text{-dim}}$ according to ISO 14999-4.

The applicable values for slope deviation for sampling length/edge length of sampling area G for maximum and L for rms as well as the spatial sampling interval H for maximum and M for rms shall be given in the same column in an additional row in the bottom. Multiple indications/columns for slope deviations are allowed. The sampling length and edge length of sampling area shall be smaller than the length/area defined by the sag table, respectively.

The specifications always apply to the position values written and the area towards the origin down to the next position value that is closer to the origin. The combination of polar coordinates as base definition in the sagitta table with a specification of slope in Cartesian coordinates and vice versa is also possible. Then, the position and orientation of the origin of that second coordinate system shall be expressed.

5.4 Specification of deviations in sets of Zernike coefficients in tabular form

Alternative to 5.2, surface form deviations described by one or a set of Zernike coefficients can also be defined in a table (see Table 2).

In addition, mathematical combinations like sums or more difficult combinations like quotients can be defined. Peak-to-valley and rms values can also be described (see ISO 14999-4).

NOTE   In 5.4, the same identifiers for quantities are used as in 5.2.

The indices (n,m) for the quantity Z are one, a set or a mathematical combination of degrees of Zernike polynomial(s) according ISO 14999-4.

The quantity O is either

a)   the maximum permissible peak-to-valley value of the surface form deviation that is described by one or the combined function of a set of Zernike polynomials as defined in ISO 14999-4, or

b)   the maximum permissible value of the equation based on the peak-to-valley value of the used Zernike coefficients.

The quantity P

a)   are the maximum permissible rms values of the surface form deviation that are described by one or the combined function of a set of Zernike polynomials as defined in ISO 14999-4, or

b)   is the maximum permissible value of the equation based on the rms value of the used Zernike coefficients.

Table 2 — Specification of deviations in sets of Zernike coefficients in tabular form

Z	PV	RMS
Z(n,m)	O	P

6   Examples of tolerance indications

6.1   Examples for indication based on code number

EXAMPLE 1

3/900 nm (250 nm)

The tolerance for power deviation is 900 nm. The irregularity may not exceed 250 nm.

EXAMPLE 2

3/5(—) RMSi < 0,05; λ=632,8 nm

The tolerance for power deviation is 5 fringe spacings. No specific tolerance is given for irregularity or rotationally invariant irregularity, but the rms value of the irregularity may not exceed 0,05 fringe spacings. The wavelength for all surface form deviation specifications is λ=632,8 nm.

EXAMPLE 3

3/3(1/0,5); λ = 632,8 nm (all $\varnothing$ 20)

The tolerance for power deviation is 3 fringe spacings. The irregularity may not exceed 1 fringe spacing. The rotationally invariant irregularity may not exceed 0,5 fringe spacings. These tolerances apply for all possible test fields of 20 mm diameter within the total test area. The wavelength for all surface form deviation specifications is λ = 632,8 nm.

NOTE 1   In case of nanometre indication: 3/949,2 nm (316,4 nm/158,2 nm) (all $\varnothing$ 20)

EXAMPLE 4

3/—(0,28 µm)

No specific tolerance for power deviation is given. The tolerance on the radius of curvature shall be taken from the radius of curvature indication. The irregularity may not exceed 0,28 μm.

EXAMPLE 5

3/—RMSt < 0,05 μm; RMSa < 0,025 μm

No specific tolerance for power deviation, irregularity, or rotationally invariant irregularity is given. The tolerance on the radius of curvature shall be taken from the radius of curvature indication. However, when the surface is compared with the desired theoretical surface, the rms total surface form deviation shall be less than 0,05 μm and the rms asymmetric irregularity is less than 0,025 μm.

NOTE 2   If no tolerance on the radius of curvature is specified, then ISO 10110-11, applies.

EXAMPLE 6

3/ 600 nm (300 nm/150 nm) (all ∅ 20)

The tolerance for power deviation is 600 nm. The irregularity shall be less than 300 nm. The rotationally invariant irregularity shall be less than 150 nm. These tolerances apply for all possible test fields of 20 mm diameter within the total test area.

EXAMPLE 7

3/ 5 μm (0,5 μm) (all 10 × 15)

The tolerance for power deviation is 5 μm. The irregularity shall be less than 0,5 μm. These tolerances apply for all possible rectangular test fields of 10 × 15 mm within the total test area.

EXAMPLE 8

3/ 3 (1/–); λ = 546,07 nm ΔS(0,3 / 1 / 0,1)

A specification for an aspheric surface with power deviation, irregularity, and maximum slope deviation is shown. The tolerance for power deviation is 3 fringe spacings. The irregularity may not exceed 1 fringe spacing. The maximum permissible 1-dim slope deviation in all directions or 2-dim slope deviation respectively is 0,3 mrad. The sampling length for 1-dim is 1 mm. The spatial sampling interval is 0,1 mm.

EXAMPLE 9

3/ 700 nm;– (120 nm/–) RMSi < 30 nm

A cylindrical power deviation of 700 nm in X is given. In y-direction, the radius tolerance or ISO 10110-11 applies. In addition, the peak-to-valley (120 nm) and rms (30 nm) of the irregularity is toleranced. Such a tolerance belongs to a toric surface or even an off-axis parabolic surface.

EXAMPLE 10

3/ 10; 1 (1/0,5; 0,3) ; λ = 546,07 nm ΔS$_{1\text{-dim, X}}$ (0,4 / 2 / 0,1); ΔS$_{1\text{-dim, Y}}$ (0,2 / 1 / 0,1)

A tolerance for a cylindric surface with its axis in Y is shown. The power deviation along the x-axis with 10 fringe and in y-direction with 1 fringe is given. Beside an irregularity of 1 fringe spacing, translationally invariant irregularities in X of 0,5 and in Y of 0,3 fringe spacing are specified. In addition, a 1-dim slope deviation is specified in both directions.

EXAMPLE 11

3/ 10; 2 (1 / –; 0,3); λ = 546,07 nm ΔS$_{1\text{-dim, Y}}$ (1' / 1/ 0,1)

A toroid with X = large radius and Y = short radius is toleranced. A line formed with them shall be homogeneously narrow across the length, thus avoid waviness, e.g. in Y.

EXAMPLE 12

11

3/ 2;0 (1/−) RMSi < 0,2; Z(*N* = 4) (RMS < 0,4); Z(6,0)(PV < 0,2); *λ* = 546,07 nm

An off-axis (along X) segment of an aspheric surface is toleranced. Beside a power deviation in X and a peak-to-valley and rms tolerance for the irregularity is used. In addition, the rms deviation of Zernike polynomial fit for the set *N* = 4 and the peak-to-valley tolerance for Z(6,0) are defined.

EXAMPLE 13

3/ 2µm (1µm/−) RMSi < 0,2µm; Z(4, 0) (PV < 0,5); *λ* = 546,07 nm

A specification for an aspheric surface with power deviation, peak-to-valley and rms of the irregularity and a peak-to-valley deviation specification of Z(4,0) is given.

EXAMPLE 14

Radius tolerance +- 0,2 mm

3/ —PV (0,5 µm)

A specification for a peak-to-valley surface deviation which takes the radius tolerance into account.

EXAMPLE 15

3/ 1 (-) RMSi < 10 nm; PVr (50 nm)

A specification for a robust peak-to-valley surface deviation without a radius tolerance is given. In addition, a power deviation and the rms of the irregularity is specified as well. The power deviation does influence the RMSi but not the PVr.

EXAMPLE 16

Radius tolerance +- 0,1 mm

3/ —Z(3,1),Z(3,-1),Z(2,2),Z(2,-2) (RMS < 50 nm)

A specification for a surface is shown where, after radius correction of maximum 0,1 mm, the maximum rms deviation of the Zernike-polynomial-fit of the combined function of Z(3,1),Z(3,-1),Z(2,2), and Z(2,-2) is specified.

6.2 Examples for indication based on a table

6.2.1 Aspheric surface

Table 3 shows a sagitta table for an aspheric surface. A specification for maximum permissible sagitta deviation and a maximum slope deviation is given. The sampling length is 1 mm, the spatial sampling interval 0,1 mm.

Table 3 — Example of the specification of form and slope deviation for an asphere in a table

h	*Z*	Δ*Z*	Δ*S*
0,0	0,0	-	-
5,0	7,231564	0,0005	0,5'
10	3,201487	0,0007	0,9'
..	..	..	..
			(1/0,1)

6.2.2 XY - polynomials described surface (Cartesian coordinates)

Table 4 shows an example for a specification of surface form deviations and slope deviations in Cartesian coordinates. The left four columns display the sagitta and slope table to be specified for testing the data transfer in accordance with ISO 10110-19.

Specifications for form tolerances are specified in additional columns to the right. Here, specification of irregularity is used.

A 1-dim slope deviation tolerance in x-orientation is specified. The last column of the table illustrates the specification of an orientation-independent 2-dim slope deviation tolerance $\Delta S_{2\text{-dim}}$ in arc minutes. The sampling length and the spatial sampling interval to be used are, in both cases, specified in the last line of the column.

Table 4 — Example of the specification of permissible surface form deviations in Cartesian coordinates

X	Y	Z	S	I	$\Delta S_{1\text{-dim,X}}$	$\Delta S_{2\text{-dim}}$
0,0	0,0	0,0	7,023156°	-	-	-
5,0	0,0	7,231564	1,213648°	-	-	-
0,0	5,0	3,201487	5,81236°	-	-	-
5,0	5,0	3,024566	2,84748°	0,5 μm	0,3'	0,1'
−5,0	5,0	4,55879	1,8347°	0,7 μm	0,5'	0,3'
..	..	..	..	..	..	..
15	−10	12,3453	2,45534°	1 μm	0,9'	0,4'
					(1/0,1)	(4/0,2)

6.2.3 ρφ-polynomials described surface (polar coordinates)

Similar to 6.2.2, the tabular specification of form tolerances can also be made based on polar coordinates. Table 5 shows a possible specification.

Table 5 — Example of the specification of permissible surface form deviations in polar coordinates

ρ	φ	Z	S	ΔZ	$\Delta S_{1\text{-dim, }\varphi}$
0,0	0°	0,0	10,24565°	-	-
5,0	30°	1,357573	8,145679°	700nm	0,15 mrad
5,0	60°	2,346239	2,145876°	1000nm	0,1 mrad
..	..	..	..	..	..
					(1/0,1)

6.2.4 Example for specification of deviations in sets of Zernike coefficients in tabular form

See Table 6, Table 7, Table 8, and Table 9

Table 6 — Individual coefficients

Z	PV
Z(4,0)	15 nm
Z(6,0)	10 nm

Table 6 *(continued)*

Z	PV
Z(2,2)	10 nm
Z(2,-2)	10 nm

Table 7 — Mathematical combination of coefficients

Z	PV
Sqrt(Z(2,2)^2+Z(2,-2)^2)	80 nm
Z(6,0)+Z(8,0)	80 nm

Table 8 — Peak-to-valley and rms values of the combined function described by the Zernike polynomials of 4th group and Z(6,0)

Z	PV	RMS
Z(N = 4), Z(6,0)	150 nm	50 nm

Table 9 — Peak-to-valley value of the combined function described by the Zernike polynomials of Z(2,2) and Z(−2,2)

Z	PV
Z(2,2),Z(2,-2)	15 nm

Annex A
(informative)

Relationship between power deviation tolerance and radius of curvature tolerance

The maximum permissible number of fringe spacings, N, corresponding to a dimensional radius of curvature tolerance, ΔR, is given by the following formula, provided that the ratio $(\Delta R/R)$ is small.

$$N \approx \left(2\Delta R / \lambda\right) \times \left\{1 - \sqrt{1 - \left[d/(2R)\right]^2}\right\}$$

If the ratio (d/R) is small, this formula may be approximated by

$$N \approx \left[d/(2R)\right]^2 \times \left(\Delta R / \lambda\right)$$

where

R is the radius of curvature;

ΔR is the dimensional radius of curvature tolerance;

d is the diameter of the test area;

λ is the wavelength (usually 546,07 nm);

N is the number of fringe spacings.

Annex B
(informative)

Comparison of ISO 10110-5 and ISO 14999-4 corresponding nomenclature, functions, and values

Table B.1 — Explanation

Surface form tolerance	Nomenclature ISO 10110-5	Function ISO 14999-4	Value ISO 14999-4	Explanation
total surface deviation	3/ PV(Q)	f_{WD}	$PV(f_{WD})$	peak-to-valley of total wavefront deformation after subtraction of tilt
		$f_{WD, CY}$	$PV(f_{WD,CY})$	peak-to-valley of total (circular) cylindric wavefront deformation after subtraction of tilt and twist
total surface deviation RMS	3/ RMSt < D	f_{WD}	$rms(f_{WD})$	rms of total wavefront deformation after subtraction of tilt
		$f_{WD, CY}$	$rms(f_{WD,CY})$	rms of total (circular) cylindric wavefront deformation after subtraction of tilt and twist
power deviation	3/ A(-/-)	f_{WS}	$PV(f_{WS})$	peak-to-valley of best-fit-sphere of wavefront deformation after substraction of tilt
	3/ AX; AY(-/-)	$f_{WC,x}$, $f_{WC,y}$	$PV(f_{WC,x})$, $PV(f_{WC,y})$	peak-to-valley of best-fit-(circular-) cylinder of wavefront deformation in x, y after subtraction of tilt and twist
irregularity	3/ -(B/-)	f_{WI}	$PV(f_{WI})$	peak-to-valley of wavefront irregularity after subtraction of best-fit-sphere
		$f_{WI, CY}$	$PV(f_{WI,CY})$	peak-to-valley of cylindric wavefront irregularity after subtraction of best-fit-(circular-) cylinder in x, y
irregularity RMS	3/ RMSi < D	f_{WI}	$rms(f_{WI})$	rms of wavefront irregularity after subtraction of best-fit-sphere
		$f_{WI, CY}$	$rms(f_{WI,CY})$	rms of cylindric wavefront irregularity after subtraction of best-fit-(circular-) cylinder in x, y
rotationally invariant irregularity	3/ -(-/C)	f_{WRI}	$PV(f_{WRI})$	peak-to-valley of rotationally invariant irregularity (=best-fit asphere rotationally symmetric) of wavefront irregularity)
translationally invariant irregularity	3/ -(-/CX; CY)	$f_{WTI,x}$, $f_{WTI,y}$	$PV(f_{WTI,x})$, $PV(f_{WTI,y})$	peak-to-valley of translationally invariant irregularity (=best-fit. non-circular-cylinder of wavefront irregularity in x, y)
rotationally invariant irregularity RMS	not defined	f_{WRI}	$rms(f_{WRI})$	rms of rotationally invariant irregularity (=best-fit asphere rotationally symmetric) of wavefront irregularity)
translationally invariant irregularity RMS	not defined	$f_{WTI,x}$, $f_{WTI,y}$	$rms(f_{WTI,x})$, $rms(f_{WTI,y})$	rms of translationally invariant irregularity (=best-fit non-circular-cylinder of wavefront irregularity in x, y)
rotationally varying irregularity	not defined	f_{WRV}	$PV(f_{WRV})$	peak-to-valley of rotationally varying irregularity after subtraction of best-fit-asphere
translationally varying irregularity	not defined	f_{WTV}	$PV(f_{WTV})$	peak-to-valley of translationally varying irregularity after subtraction of best-fit-non-circular-cylinder in x, y