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Optics and photonics — Interferometric measurement of optical elements and optical systems —

Part 4: Interpretation and evaluation of tolerances specified in ISO 10110

Optique et photonique — Mesurage interférométrique de composants et de systèmes optiques —

Partie 4: Directives pour l'évaluation des tolérances spécifiées dans l'ISO 10110

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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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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 second edition cancels and replaces the first edition (ISO 14999-4:2007), which constitutes the following changes:

a) clauses for tolerancing cylindrical and torical wavefronts, the representation of the measured wavefront deformation in terms of Zernike coefficients, and for tolerancing of the slope deviation have been added;

b) the name of quantity A has been changed to power deviation. For further details, see 3.3.1, Note 2 to entry.

ISO 14999 consists of the following parts, under the general title *Optics and photonics — Interferometric measurement of optical elements and optical systems*:

— *Part 1: Terms, definitions and fundamental relationships* [Technical Report]

— *Part 2: Measurement and evaluation techniques* [Technical Report]

— *Part 3: Calibration and validation of interferometric test equipment and measurements* [Technical Report]

— *Part 4: Interpretation and evaluation of tolerances specified in ISO 10110*

Introduction

This part of ISO 14999 provides a theoretical frame upon which are based indications from ISO 10110-5 and/or ISO 10110-14.

A table listing the corresponding nomenclature, functions, and values used in ISO 10110-5 and ISO 14999-4 is given in ISO 10110-5, Annex B.

ISO 10110-5 refers to deformations in the form of an optical surface and provides a means for specifying tolerances for certain types of surface deformations in terms of “nanometers”.

ISO 10110-14 refers to deformations of a wavefront transmitted once through an optical system and provides a means of specifying similar deformation types in terms of optical “wavelengths”.

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. One “fringe spacing” (as defined in ISO 10110-5) is equal to a surface deformation that causes a deformation of the reflected wavefront of one wavelength.

Certain scaling factors apply depending on the type of interferometric arrangement, e.g. whether the test object is being measured in single pass or double pass.

Due to the potential for confusion and misinterpretation, units of nanometres rather than units of “fringe spacings” or “wavelengths” are to be used for the value of surface form deviation or the value of wavefront deformation, where possible. Where “fringe spacings” or “wavelengths” are used as units, the wavelength is also to be specified.

Optics and photonics — Interferometric measurement of optical elements and optical systems —

Part 4: Interpretation and evaluation of tolerances specified in ISO 10110

1 Scope

This part of ISO 14999 applies to the interpretation of interferometric data relating to the measurement of optical elements.

This part of ISO 14999 gives definitions of the optical functions and values specified in the preparation of drawings for optical elements and systems, made in accordance with ISO 10110-5 and/or ISO 10110-14 for which the corresponding nomenclature, functions, and values are listed in ISO 10110-5, Annex B. It also provides guidance for their interferometric evaluation by visual analysis.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10110-5, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 5: Surface form tolerances*

ISO 10110-14, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 14: Wavefront deformation tolerance*

ISO/TR 14999-2, *Optics and photonics — Interferometric measurement of optical elements and optical systems — Part 2: Measurement and evaluation techniques*

3 Terms and definitions

3.1 Mathematical definitions

3.1.1
function
mathematical description of the measured wavefront deformation and its decomposition into components

Note 1 to entry: The functions used in this part of ISO 14999 are scalar functions.

3.1.2
peak-to-valley value
PV (f)
<of a function f> maximum value of the function within the region of interest minus the minimum value of the function within the region of interest

3.1.3
root mean square value
rms (f)
<of a function f over a given area A> value given by either of the following integral expressions:

a) Cartesian variables x and y

$$\mathrm{rms}\,(f)=\left[\frac{\int\limits_{x}\int\limits_{y}\left[f(x,y)\right]^{2}\,\mathrm{d}x\,\mathrm{d}y}{\int\limits_{x}\int\limits_{y}\mathrm{d}x\,\mathrm{d}y}\right]^{1/2}\quad \text{where } (x,y)\in A$$

b) Polar variables r and θ

$$\mathrm{rms}\,(f)=\left[\frac{\int\limits_{\theta}\int\limits_{r}\left[f(r,\theta)\right]^{2}\,r\,\mathrm{d}r\,\mathrm{d}\theta}{\int\limits_{\theta}\int\limits_{r}r\,\mathrm{d}r\,\mathrm{d}\theta}\right]^{1/2}\quad \text{where } (r,\theta)\in A$$

Note 1 to entry: This integral may be approximated by the standard deviation if the usage includes removal of the mean value of the wavefront (piston) and provided that the measurement resolution is specified and is sufficient.

3.2 Definition of optical functions

NOTE 1 For the relationship of interferometric measurements to surface form deviation and transmitted wavefront deformation, see Clause 4.

NOTE 2 The optical functions given in this subclause are used either for rotationally invariant (spherical or aspherical) wavefronts (depicted in Figure 1) or cylindrical wavefronts (depicted in Figure 2). The functions corresponding to each are grouped together; the functions for rotationally invariant wavefronts first and the functions for cylindrical wavefronts follow. The functions for rotationally invariant wavefronts are unchanged with respect to ISO 14999-4:2007.

NOTE 3 The term cylindrical waveform is used here as synonym for circular cylindrical, non-circular cylindrical, and torical wavefronts. The functions can also be applied for general wavefronts that are close to cylindrical or torical ones.

3.2.1
measured wavefront deformation

f_{MWD}

function representing the distances between the measured wavefront and the nominal theoretical wavefront, measured normal to the nominal theoretical wavefront

Note 1 to entry: See Figure 1 a) and Figure 2 a).

Note 2 to entry: In case of tactile measurement where the measurement values are usually taken along z-direction, the measurement values have to be converted to the measured wavefront deformation f_{MWD} (distance perpendicular to the theoretical surface).

3.2.2
tilt

f_{TLT}

plane function representing the best (in the sense of the rms fit) linear approximation to the measured wavefront deformation f_{MWD}

Note 1 to entry: See Figure 1 b) and Figure 2 b).

3.2.3
twist-function describing rotational misalignment for cylindrical wavefronts

f_{TWST}

function of the saddle form used for eliminating rotational misalignment

$$f_{\mathrm{TWST}}(x,y)=const.*x*y$$

Note 1 to entry: See Figure 2 c).

Note 2 to entry: A rotational misalignment (twist) of the cylindrical axes of the test wave and the surface (respectively, the object under test and the optics generating or compensating the cylindrical or torical phase front) results in an additive term in the form of a saddle. This term could be eliminated or minimized by careful alignment of the setup. In most practical cases, it is more useful to eliminate this term by removing it mathematically.

3.2.4
wavefront deformation
f_{WD}
function resulting after subtraction of the tilt f_{TLT} from the measured wavefront deformation f_{MWD}

$$f_{\mathrm{WD}} = f_{\mathrm{MWD}} - f_{\mathrm{TLT}}$$

Note 1 to entry: See Figure 1 c).

3.2.5
wavefront deformation for cylindrical wavefronts
$f_{\mathrm{WD,CY}}$
function resulting after subtraction of the tilt f_{TLT} and f_{TWST} from the measured wavefront deformation, f_{MWD}

$$f_{\mathrm{WD,CY}}(x,y) = f_{\mathrm{MWD}}(x,y) - f_{\mathrm{TLT}}(x,y) - f_{\mathrm{TWST}}(x,y)$$

Note 1 to entry: See Figure 2 d).

3.2.6
wavefront spherical approximation
f_{WS}
function of spherical form that best (in the sense of the rms fit) approximates the wavefront deformation f_{WD}

Note 1 to entry: See Figure 1 d).

3.2.7
wavefront circular cylindrical approximation
$f_{\mathrm{WC,\,x}}$, $f_{\mathrm{WC,\,y}}$
functions of cylindrical form that best (in the sense of the rms fit) approximate the wavefront deformation $f_{\mathrm{WD,CY}}$

$$f_{\mathrm{WC,x}}(x,y) = R_{\mathrm{x,fit}} - \sqrt{{R_{\mathrm{x,fit}}}^2 - x^2} + const.$$

$$f_{\mathrm{WC,y}}(x,y) = R_{\mathrm{y,fit}} - \sqrt{{R_{\mathrm{y,fit}}}^2 - y^2} + const.$$

Note 1 to entry: See Figure 2 e) and Figure 2 f).

3.2.8
wavefront irregularity
f_{WI}
function resulting after subtraction of the wavefront spherical approximation f_{WS} from the wavefront deformation f_{WD}

$$f_{\mathrm{WI}} = f_{\mathrm{WD}} - f_{\mathrm{WS}}$$

Note 1 to entry: See Figure 1 e).

3.2.9
wavefront irregularity for cylindrical wavefronts
$f_{\mathrm{WI,\,CY}}$
function resulting after subtraction of the wavefront circular cylindrical approximations $f_{\mathrm{WC,\,x}}$ and $f_{\mathrm{WC,\,y}}$

$$f_{\mathrm{WI,\,CY}}(x,y) = f_{\mathrm{WD,\,CY}}(x,y) - f_{\mathrm{WC,x}}(x,y) - f_{\mathrm{WC,y}}(x,y)$$

Note 1 to entry: See Figure 2 g).

3.2.10
wavefront aspheric approximation
f_{WRI}
rotationally invariant aspherical function that best (in the sense of the rms fit) approximates the wavefront irregularity, f_{WI}

Note 1 to entry: See Figure 1 f).

3.2.11
wavefront non-circular cylindrical approximation
$f_{\mathrm{WTI,\,x}}$, $f_{\mathrm{WTI,\,y}}$
translationally invariant non-circular cylindrical function that best (in the sense of the rms fit) approximates the wavefront irregularity for cylindrical wavefronts, $f_{\mathrm{WI,\,CY}}$ in x and y direction, respectively

$$f_{\mathrm{WTI,x}}(x,y) = f_{\mathrm{WTI,x}}(x)$$

$$f_{\mathrm{WTI,y}}(x,y) = f_{\mathrm{WTI,y}}(y)$$

Note 1 to entry: See Figure 2 h) and Figure 2 i).

3.2.12
rotationally varying wavefront deviation
f_{WRV}
function resulting after subtraction of the wavefront aspheric approximation f_{WRI} from the wavefront irregularity f_{WI}

$$f_{\mathrm{WRV}} = f_{\mathrm{WI}} - f_{\mathrm{WRI}}$$

Note 1 to entry: See Figure 1 g).

3.2.13
translationally varying wavefront deviation
f_{WTV}
function resulting after subtraction of the wavefront non-circular cylindrical approximation $f_{\mathrm{WTI,\,x}}$ and $f_{\mathrm{WTI,\,y}}$

$$f_{\mathrm{WTV}} = f_{\mathrm{WI,CY}} - f_{\mathrm{WTI,x}} - f_{\mathrm{WTI,y}}$$

Note 1 to entry: See Figure 2 j).

3.3 Definition of values related to the optical functions defined in 3.2

3.3.1
power deviation
PV (f_{WS})
peak-to-valley value of the approximating spherical wavefront

Note 1 to entry: PV (f_{WS}) corresponds to the quantity A in ISO 10110-5 and ISO 10110-14.

Note 2 to entry: Previous versions of this part of ISO 14999 used the term sagitta deviation to represent this value. For better clarity, the term sagitta deviation has been replaced with power deviation to more accurately reflect the distance normal to a reference surface, whereas sagitta deviation refers to the distance parallel to the *z* axis to the surface.

3.3.2
power deviation for cylindrical wavefronts
PV ($f_{WC, x}$), PV ($f_{WC, y}$)
peak-to-valley value of the approximating circular cylindrical wavefronts in *x* and *y* direction, respectively

Note 1 to entry: PV ($f_{WC, x}$) corresponds to the quantity AX and PV ($f_{WC, y}$) to the quantity AY in ISO 10110-5 and ISO 10110-14.

3.3.3
irregularity
PV (f_{WI})
peak-to-valley value of the wavefront irregularity

Note 1 to entry: PV (f_{WI}) corresponds to the quantity B in ISO 10110-5 and ISO 10110-14.

3.3.4
irregularity for cylindrical wavefronts
PV ($f_{WI, CY}$)
peak-to-valley value of the wavefront irregularity for cylindrical wavefronts

Note 1 to entry: PV ($f_{WI, CY}$) corresponds to the quantity B in ISO 10110-5 and ISO 10110-14.

3.3.5
rotationally invariant irregularity
PV (f_{WRI})
peak-to-valley value of the wavefront aspheric approximation

Note 1 to entry: PV (f_{WRI}) corresponds to the quantity C in ISO 10110-5 and ISO 10110-14.

3.3.6
translationally invariant irregularity for cylindrical wavefronts
PV ($f_{WTI, x}$), PV ($f_{WTI, y}$)
peak-to-valley value of the wavefront non-circular cylindrical approximation

Note 1 to entry: PV ($f_{WTI, x}$) corresponds to the quantity CX and PV ($f_{WTI, y}$) to the quantity CY in ISO 10110-5 and ISO 10110-14.

3.3.7
rotationally varying irregularity
PV (f_{WRV})
peak-to-valley value of the remaining rotationally varying wavefront deviation

3.3.8
translationally varying irregularity
PV(f_{WTV})
peak-to-valley value of the remaining translational varying wavefront deviation

3.3.9
rms total
rms (f_{WD})
root-mean-square value of the wavefront deformation

Note 1 to entry: rms (f_{WD}) corresponds to the quantity RMSt in ISO 10110-5 and ISO 10110-14.

3.3.10
rms total for cylindrical wavefronts
rms ($f_{\mathrm{WD,\,CY}}$)
root-mean-square value of the wavefront deformation for cylindrical wavefronts

Note 1 to entry: rms ($f_{\mathrm{WD,\,CY}}$) corresponds to the quantity RMSt in ISO 10110-5 and ISO 10110-14.

3.3.11
rms irregularity
rms (f_{WI})
root-mean-square value of the wavefront irregularity

Note 1 to entry: rms (f_{WI}) corresponds to the quantity RMSi in ISO 10110-5 and ISO 10110-14.

3.3.12
rms irregularity for cylindrical wavefronts
rms ($f_{\mathrm{WI,\,CY}}$)
root-mean-square value of the wavefront irregularity for cylindrical wavefronts

Note 1 to entry: rms ($f_{\mathrm{WI,\,CY}}$) corresponds to the quantity RMSi in ISO 10110-5 and ISO 10110-14.

3.3.13
rms rotationally invariant irregularity
rms (f_{WRI})
root-mean-square value of the wavefront aspheric approximation

3.3.14
rms translationally invariant irregularity
rms ($f_{\mathrm{WTI},\,x}$), rms ($f_{\mathrm{WTI},\,y}$)
root-mean-square value of the wavefront non-circular cylindrical approximation

3.3.15
rms rotationally varying irregularity
rms (f_{WRV})
root-mean-square value of the remaining rotationally varying wavefront deviation

Note 1 to entry: rms (f_{WRV}) corresponds to the quantity RMSa in ISO 10110-5 and ISO 10110-14.

3.3.16
rms translationally varying irregularity
rms (f_{WTV})
root-mean-square value of the remaining translational varying wavefront deviation

Note 1 to entry: rms (f_{WTV}) corresponds to the quantity RMSa in ISO 10110-5 and ISO 10110-14.

3.3.17
peak–to-valley deviation
PV (f_{WD})
peak-to-valley deviation of the wavefront deformation

Note 1 to entry: PV(f_{WD}) corresponds to the quantity of PV(Q) in ISO 10110-5 and ISO 10110-14.

3.3.18
peak-to-valley deviation for cylindrical wavefronts
PV($f_{\mathrm{WD,cy}}$)
peak-to-valley deviation of the wavefront deformation for cylindrical wavefronts

Note 1 to entry: PV($f_{\mathrm{WD,cy}}$) corresponds to the quantity of PV(Q) in ISO 10110-5 and ISO 10110-14.