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

Part 14: Wavefront deformation tolerance

Optique et photonique — Préparation des dessins pour éléments et systèmes optiques —

Partie 14: Tolérance de déformation du front d'onde

Reference number
ISO 10110-14:2007(E)

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 10110-14 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This second edition cancels and replaces the first edition (ISO 10110-14:2003) which has been technically revised.

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*

— *Part 6: Centring tolerances*

— *Part 7: Surface imperfection tolerances*

— *Part 8: Surface texture*

— *Part 9: Surface treatment and coating*

— *Part 10: Table representing data of optical elements and cemented assemblies*

— *Part 11: Non-toleranced data*

— *Part 12: Aspheric surfaces*

— *Part 14: Wavefront deformation tolerance*

— *Part 17: Laser irradiation damage threshold*

Introduction

This part of ISO 10110 makes it possible to specify a functional tolerance for the performance (expressed as single-pass wavefront deformation) of an optical system, which may have optical power or contain powered optical elements. This tolerance therefore includes the effect of surface form deformations, inhomogeneities, and possible interactions among the various individual errors.

It should be noted that it is possible to specify a tolerance on the wavefront deformation only, without specifying tolerances on the individual surfaces. In this case, the manufacturer must ensure that the wavefront satisfies the specified tolerance, but is not bound by tolerances on the form of the individual surfaces of the element, and is free, for instance, to allow the surface form deformations to be large provided they cancel each other.

It is also possible to supply a tolerance for the wavefront deformation, according to this part of ISO 10110, in addition to tolerances on the form of the individual surfaces and/or inhomogeneity (according to ISO 10110-5 and ISO 10110-4, respectively). In this case, the manufacturer must ensure that all of the individual tolerances (surface deformations and inhomogeneity) are upheld, as well as ensuring that the wavefront is of the specified quality.

Optical elements are often tested in a “double-pass” configuration, in which the wavefront passes through or, in the case of reflective optics, reflects from the element under test twice, as shown in ISO/TR 14999-1:2005, Figure 18.

In the case of double-pass testing, the additional wavefront deformation caused by the second transmission through the element must be accounted for when comparing the measurement results with the specified tolerances. If the wavefront is not severely deformed by passing once through the element under test, and reflects from a high quality mirror, so that it returns through the identical portion of the test element to the interferometer, then the observed deformation of the wavefront is twice the (single-pass) wavefront deformation (defined in 3.2.3 of ISO 14999-4:2007). That is, the wavefront deformation is one-half the observed wavefront deformation.

If the wavefront is severely deformed by the element under test, then the individual rays do not pass through the same positions in the element under test on their return path, and the wavefront deformation is not exactly twice that of the single path case.

If the measurement wavelength is not the specification wavelength, care must be taken. At least the wavefront deformation is to be recalculated.

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

Part 14: Wavefront deformation tolerance

1 Scope

The ISO 10110 series applies to the presentation of design and functional requirements for optical elements and assemblies in technical drawings used for manufacturing and inspection.

This part of ISO 10110 gives rules for the indication of the permissible deformation of a wavefront transmitted through or, in the case of reflective optics, reflected from an optical element or assembly.

The deformation of the wavefront refers to its departure from the desired shape. The tilt of the wavefront with respect to a given reference surface is excluded from the scope of this part of ISO 10110.

There is no requirement that a tolerance for wavefront deformation be indicated. If such a tolerance is specified, it does not take precedence over a tolerance for the surface form according to ISO 10110-5. If tolerances for both the surface form and the wavefront deformation are given, they must both be upheld.

2 Normative references

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

ISO 10110-1:2006, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 1: General*

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

ISO 14999-4:2007, *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 apply.

NOTE ISO 14999-4 provides the definitions for all the deformation functions.

4 Specification of tolerances for wavefront deformation

4.1 General

The tolerances for wavefront deformation are indicated by specifying the maximum permissible values of the sagitta deviation, irregularity, and/or rotationally invariant irregularity. In addition, tolerances for three root-mean-square measures of wavefront deformation (rms total, rms irregularity and rms rotationally varying wavefront deviation) may be specified. See 3.3 of ISO 14999-4:2007 for definitions.

NOTE 1 The sagitta deviation is meaningful only when the location of the image is specified. If the location of the image is unspecified, the sagitta deviation is defined to be zero.

NOTE 2 Methods for determining the amount of sagitta deviation, irregularity and rotationally invariant irregularity of a given wavefront are given in ISO 14999-4.

It is not necessary that tolerances be specified for all types of wavefront deformation.

4.2 Units

The maximum permissible values for sagitta deviation, irregularity, rotationally invariant irregularity and, if applicable, any target aberrations should be specified in units of nanometres. If wavelengths are to be used, the wavelength shall also be indicated on the drawing.

NOTE 1 These quantities are defined with reference to a wavefront passing once through the element under test (single-pass).

If a specification is to be given for one or more rms wavefront deformation types, the specification shall also be in units of nanometres or wavelengths (single-pass, see NOTE 1).

NOTE 2 One "wavelength" is 1 × the wavelength (in nanometres) in which the wavefront deformation is specified.

NOTE 3 The specification of a tolerance for an rms deformation type requires that the optical system be analysed digitally.

4.3 Wavelength

If wavelength units are to be used, the wavelength shall also be indicated on the drawing in order to reduce confusion. If none is provided, the wavelength is assumed to be 546,07 nm.

4.4 Target aberrations

Frequently, the nominal theoretical wavefront is spherical or planar. In some cases, to allow for the presence of small amounts of residual aberration in the design of an optical system, non-zero target values may be specified for polynomial aberration types.

4.5 Cemented (or optically contacted) elements

If two or more optical elements are to be cemented (or optically contacted), the wavefront deformation tolerances given for the individual elements apply also for the elements after assembly, i.e. after cementing (or optically contacting), unless otherwise specified. See 4.8.3 of ISO 10110-1:2006.

5 Indication in drawings

5.1 General

In all cases in which a tolerance for wavefront deformation is to be indicated, the optical axis of the element shall be indicated on the drawing according to 4.2 of ISO 10110-1:2006.

The location of the stop surface or pupil shall be indicated according to 5.3 of ISO 10110-1:2006. See Figure 1.

The tolerance for wavefront deformation shall be indicated by a code number (see 5.2) and the tolerances for sagitta deviation, irregularity, rotationally invariant irregularity and rms deformation types shall be indicated as appropriate (see 5.3).

Wavefront deformation should be specified in nanometres. However if wavelength units are to be used, the wavelength should also be indicated. All quantities shall have their units specified. If no unit is indicated then wavelength units are implied.

No provision is given for the specification of a PV-tolerance for the total wavefront deformation (that is, including both the sagitta deviation and the irregularity). If such a specification is necessary, this information shall be given in a note on the drawing, for example: “Total wavefront deformation shall not exceed 0,25 wavelengths” or “Total wavefront deformation shall not exceed 150 nm.”

NOTE Such a specification might, for example, be useful for optical elements to be used in interferometers.

See Clause 6 for examples of tolerance indications.

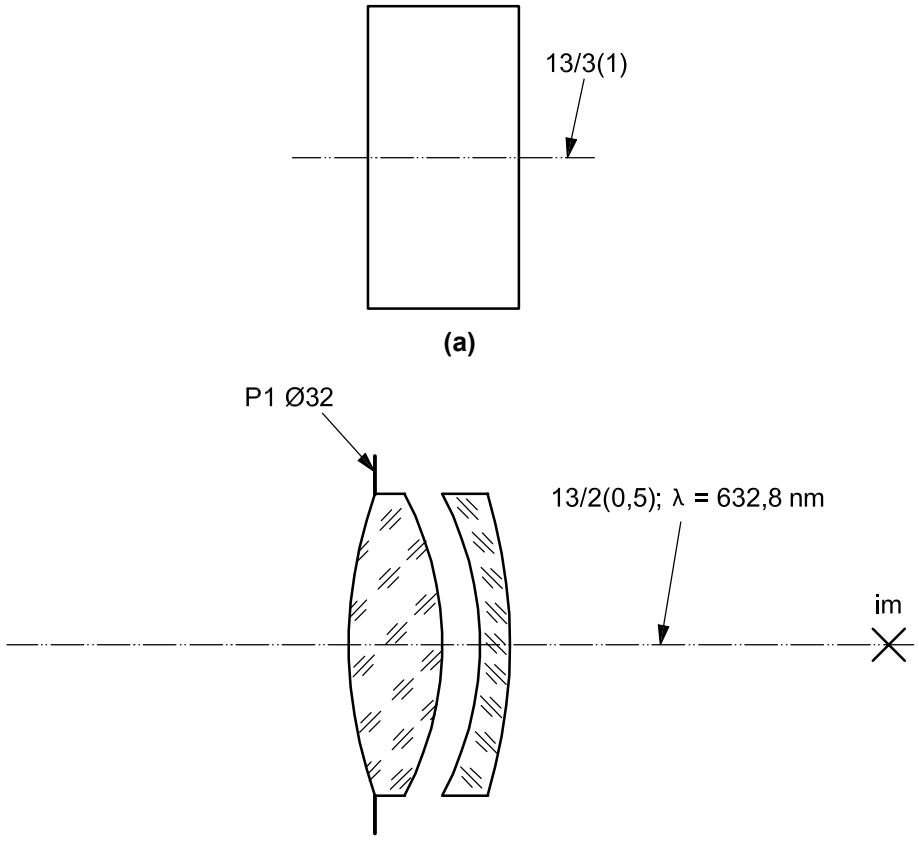


Figure 1 — Examples of an indication of a tolerance for wavefront deformation, with planar illumination

5.2 Code number

The code number for wavefront deformation is 13/.

5.3 Form of the indication

The indication shall have one of the three forms:

13/A (B/C); λ = E or

13/A (B/C) RMSx < D; λ = E (where x is one of the letters t, i or a; see 3.3 of ISO 14999-4:2007) or

13/ — RMSx < D; λ = E (where x is one of the letters t, i or a).

The indication "; λ = E" (last element of the three forms of indication specified above) may be omitted provided the wavelength of specification is λ = 546,07 nm (see 5.1).

The quantity A is either:

1) the maximum permissible (single-pass) sagitta deviation or

2) a dash (—) indicating that no explicit tolerance for sagitta deviation is given.

The quantity B is either:

1) the mixiumum permissible value of (single-pass) irregularity or

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

The quantity C is:

the permissible value of the (single-pass) rotationally invariant irregularity. If no tolerance is given, the slash (/) is replaced by the final parenthesis, i.e. 13/ A (B).

If no tolerance is given for any of the three deformation types, then A, B, C, the divisor line (/) and the parenthesis are replaced by a single dash (—), i.e., 13/—.

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 in 3.3.5, 3.3.6, and 3.3.8 of ISO 14999-4:2007, respectively. 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 7.

The quantity E is:

the wavelength in which the wavefront deformation is specified.

The wavefront deformation 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:

13/ A (B/C) RMSx < D (all ∅...); λ = E

See Clause 6, Example 4.

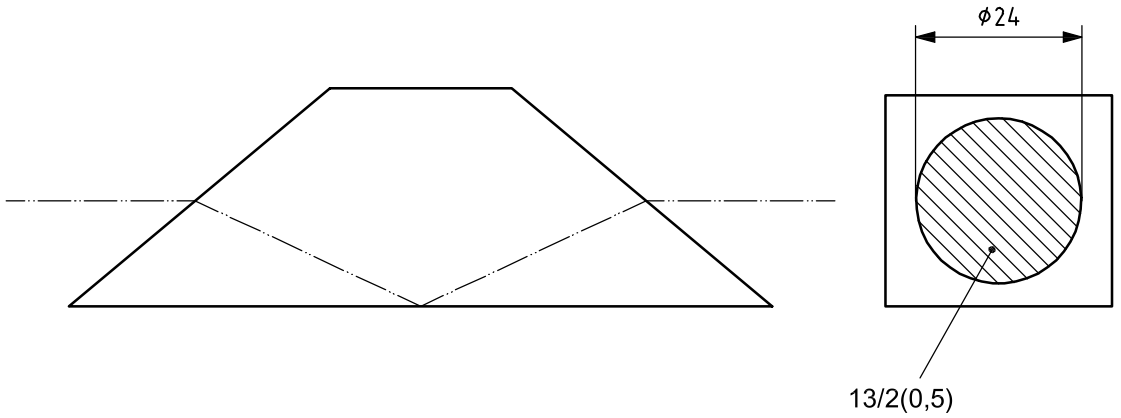
5.4 Location

The indication shall be entered near the optical element to which it refers. If necessary, the indication may be connected to the optical axis by a leader, as shown in Figure 1.

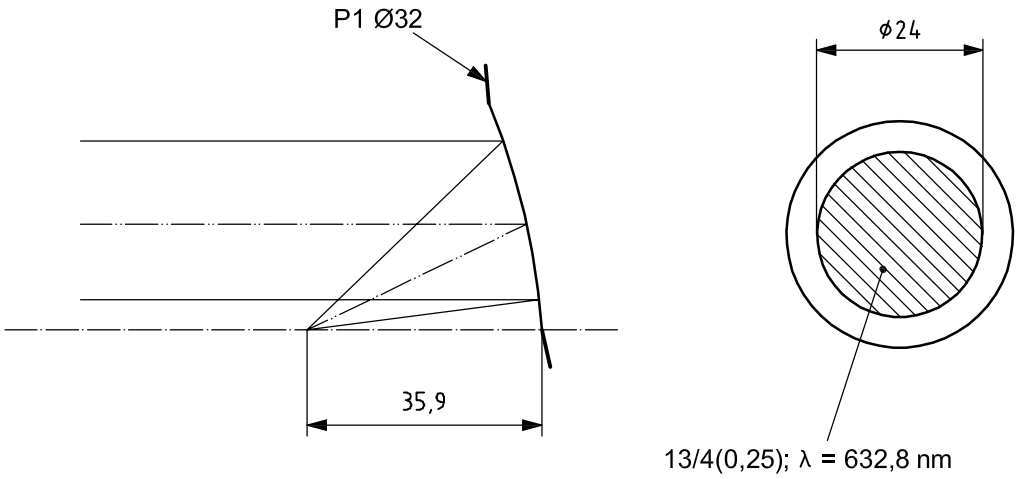
In cases where the optical axis is not normal to the surfaces of the element, it may be necessary to indicate the test region for wavefront deformation in a cross-section perpendicular to the optical axis. In this case the indication of wavefront deformation shall be associated with the test region (see Figure 2).

For elements requiring indications for transmitted wavefront deformation along multiple test paths, the various test paths shall be indicated with reference letters, as shown in Figure 3. The indications for wavefront deformation are to be associated with the letters of the input and output test paths, as shown in Figure 3.

Dimensions in millimetres

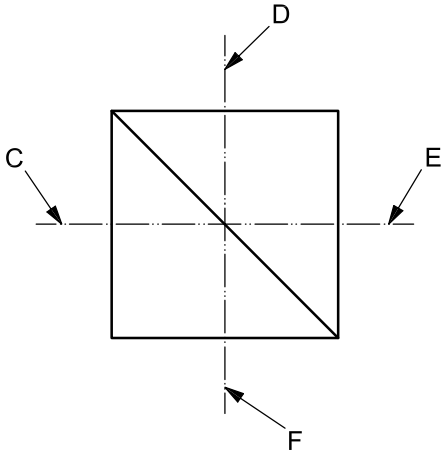


(a)



(b)

Figure 2 — Indication of the wavefront quality specification referencing an indicated test area



CE: 13/ 3(1)

CF: 13/ 1(0,2)

DE: 13/ 3 (1)

DF: 13/ 1(0,2)

Figure 3 — Indication of the wavefront quality specification for an element having multiple test paths

5.5 Indication of illumination

For diverging or converging illumination, the position of the object point shall be indicated on the drawing. See Figure 4.

The absence of an indication of the position of the object point implies collimated (planar wavefront) illumination, as shown in Figures 1, 2 and 3.

Dimensions in millimetres

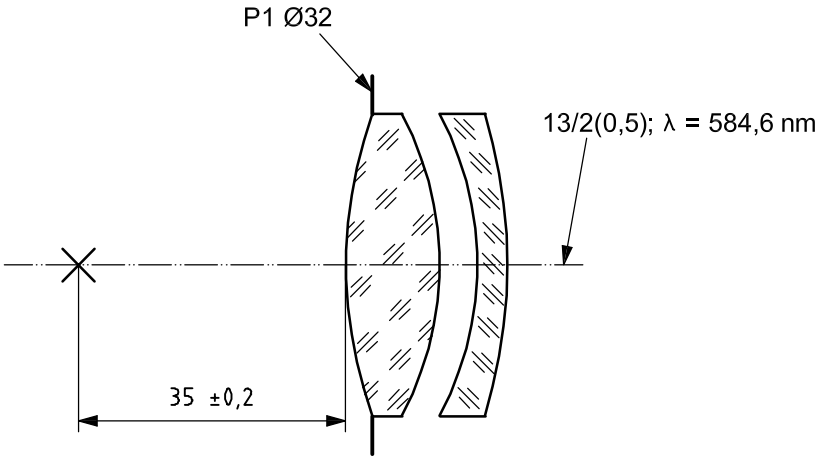


Figure 4 — Example showing the indication of the object point on the drawing

5.6 Specification of the image point location

Optionally, the location of the image point may be given with a dimensional tolerance. If the image location is given, it shall be distinguished from the object location by the letters “im” associated with the indicated position. See Figure 5.

NOTE The sagitta deviation, which is a measure of the extent to which this tolerance is upheld, is not meaningful unless the image position is indicated. If no restrictions are specified on the location of the image of the optical system under test, the reference sphere is identical to the approximating spherical wavefront, and the sagitta deviation is defined to be zero.

Dimensions in millimetres

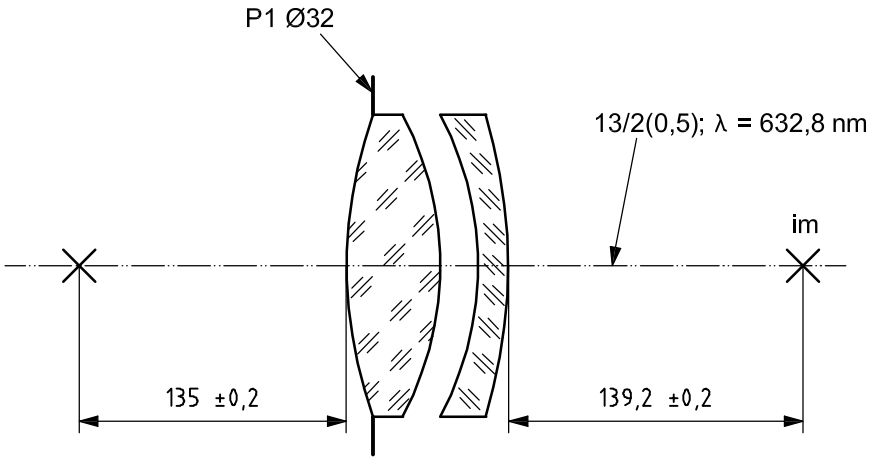


Figure 5 — Example showing the indication of the image position

5.7 Indication of target aberrations

Target values for one or more of the polynomial aberrations defined in Annex A of ISO/TR 14999-2:2005 may be specified following the word “Target”. The form for the indication of a target aberration is as follows:

$$C_i = value$$

where

i is the identifying index of the desired polynomial term;

$value$ is the numerical value of the target.

See Clause 6, Example 8.

6 Examples of tolerance indications

The following examples are designed to illustrate the indications in drawings in accordance with this part of ISO 10110.

EXAMPLE 1: 13/— (1); $\lambda = 632{,}8$ nm

The irregularity shall not exceed 1 wavelength (at $\lambda = 632{,}8$ nm) of single-pass wavefront deformation. No tolerance for sagitta deviation is given.

EXAMPLE 2: 13/ 5 (—) RMSi $< 0,05$; $\lambda = 632,8$ nm

The tolerance for the sagitta deviation (in addition to the amount corresponding to the dimensional tolerance given in the indication of the image position) is 5 wavelengths of single-pass wavefront deformation. No specific tolerance is given for irregularity or rotationally invariant irregularity, but the rms value of the irregularity shall be less than 0,05 wavelengths of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 632,8$ nm.

EXAMPLE 3: 13/ 600 nm (300 nm/150 nm); λ = 632,8 nm

The tolerance for the sagitta deviation is 600 nm of single-pass wavefront deformation. The total irregularity shall not exceed 300 nm. The rotationally invariant irregularity shall be less than 150 nm of single-pass deformation.

EXAMPLE 4-a: 13/3 (1/0,5); (all ∅ 30)

The wavefront deformation tolerances apply to all possible locations of a 30 mm diameter test area within the optically effective test area. The tolerance for the sagitta deviation is 3 wavelengths of single-pass wavefront deformation. The total irregularity shall not exceed 1 wavelength of single-pass wavefront deformation. The rotationally invariant irregularity shall be less than 0,5 wavelengths of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 546,07$ nm.

EXAMPLE 4-b: 13/0,5 — RMSi $< 0,05$ (all ∅ 12)

For all possible positions of a 12 mm diameter test region within the optically effective test area of the element, the (single-pass) sagitta deviation shall not exceed 0,5 wavelengths, and the rms irregularity shall be less than 0,05 wavelengths in single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 546,07$ nm.

EXAMPLE 5: 13/3 (1); $\lambda = 632,8$ nm

The tolerance for the sagitta deviation is 3 wavelengths in single-pass; the total irregularity shall not exceed 1 wavelength of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 632,8$ nm.

EXAMPLE 6: 13/— RMSt $< 0,07$; $\lambda = 546,07$ nm

No specific tolerance for the sagitta deviation, irregularity, or rotationally invariant irregularity is given; however, the total rms difference between the actual wavefront and the theoretical wavefront shall be less than 0,07 wavelengths of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 546,07$ nm.

EXAMPLE 7-a: 13/— RMSi $< 0,07$; RMSa $< 0,03$; $\lambda = 632,8$ nm

No specific tolerance for the sagitta deviation, irregularity, or rotationally invariant irregularity is given; however, the rms irregularity shall be less than 0,07 wavelengths of single-pass wavefront deformation, and the rms rotationally varying wavefront deviation shall be less than 0,03 wavelengths of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications is $\lambda = 632,8$ nm.

EXAMPLE 7-b: 13/— RMSt $< 0,07$; RMSi $< 0,04$

No specific tolerance for the sagitta deviation, irregularity or rotationally invariant irregularity is given; however, the total rms difference between the actual wavefront and the theoretical planar wavefront shall be less than 0,07 wavelengths in single-pass wavefront deformation, and the rms rotationally varying wavefront deviation in single-pass wavefront deformation shall be less than 0,04 wavelengths. The wavelength for all transmitted wavefront deformation specifications is $\lambda = 546,07$ nm.

EXAMPLE 8: 13/— (0,1); $\lambda = 632,8$ nm

Target

$C_8 = 1,24$;

$C_{15} = -0,44$

No specific tolerance is given for the sagitta deviation or the rotationally invariant irregularity. The nominal theoretical wavefront consists of the reference sphere plus the following polynomial:

$$\text{polynomial} = 1{,}24\ Z_8 - 0{,}44\ Z_{15}$$

The tolerance for the irregularity (compared to this aspheric wavefront) is 0,1 wavelengths of single-pass wavefront deformation. The wavelength for all wavefront deformation specifications (including the target aberrations) is $\lambda = 632{,}8$ nm.

EXAMPLE 9 : CE : 13/3 (1)

CF : 13/1 (0,2)

DE : 13/3 (1)

DF : 13/1 (0,2)

The tolerance for the single-pass ray paths from C to E and from D to E is 3 wavelengths for sagitta deviation and 1 wavelength for irregularity. The tolerance for the single-pass ray paths from C to F and from D to F is 1 wavelength for sagitta deviation and 0,2 wavelengths for irregularity. The wavelength for all wavefront deformation specifications is $\lambda = 546{,}07$ nm.

Bibliography

[1] ISO/TR 14999-1:2005, *Optics and photonics — Interferometric measurement of optical elements and optical systems — Part 1: Terms, definitions and fundamental relationships*

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