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

## Part 14: Wavefront deformation tolerance



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

*Partie 14: Tolérance de déformation des fronts d'onde*



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# Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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ISO 10110-14 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*
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- *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 16: Aspheric diffractive surfaces*
- *Part 17: Laser irradiation damage threshold*

## Introduction

This part of ISO 10110 makes it possible to specify a functional tolerance for the performance (expressed in wavelengths of single-pass wavefront deformation) for an optical system. This tolerance therefore includes the effect of surface deformations, inhomogeneities, and possible interactions among the various individual errors.

The quality of an optical system depends not only on the quality of the surfaces, but also on several other factors, such as the homogeneity of the optical material and how the optical surfaces of the system interact with each other. Because of this effect, the selection of tolerances for individual degradations (such as surfaces and inhomogeneity) may be difficult. For instance, the effect of glass inhomogeneities upon the optical quality of a prism depends greatly upon the form and orientation of the inhomogeneities; this is particularly true when light passes through the glass in more than one direction, as in the case of a penta-prism. In the case of a thin optical element, it often happens that the deformations of the rear surface correspond closely to those of the front surface, due to bending of the system during fabrication. Unfortunately, it is usually not known in advance that this will be the case, and for this reason, in the absence of a wavefront deformation tolerance, the tolerances for the individual surfaces of a system must often be very tight to guard against the possibility that the deformations might add to each other rather than cancel one another.

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 individual surfaces of the element, and is free, for instance, to allow the surface 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 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.

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

## Part 14: Wavefront deformation tolerance

## 1 Scope

International Standard ISO 10110 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 provides rules for the indication of the allowable 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 ("Nominal theoretical wavefront"). 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 deformation according to ISO 10110-5. If tolerances for both the surface deformation and the wavefront deformation are given, they must both be upheld.



NOTE In this part of ISO 10110, the term "wavefront" used alone stands for either "transmitted wavefront" or "reflected wavefront", according to the type of system to be specified.

## 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 7944:1998, *Optics and optical instruments — Reference wavelengths*

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

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1**
**wavefront deformation**
distance between a wavefront transmitted and/or reflected once through, or in the case of reflective optics, reflected once from, the optical element or assembly under test and the nominal theoretical wavefront, measured normal to the nominal theoretical wavefront

 

NOTE 1 See also 3.13.

NOTE 2 The illuminating wavefront may be specified to be planar, convergent or divergent. See 7.5 and 7.6.

**3.2**
**peak-to-valley difference between two wavefronts**
**PV difference between two wavefronts**
maximum distance minus the minimum distance between the wavefronts

NOTE It is possible that the wavefronts cross, in which case the minimum distance between the wavefronts is a negative number; the sign must be taken into account in computing the PV difference.

**3.3**
**total wavefront deformation function**
theoretical surface defined by the difference between the wavefront transmitted and/or reflected once through the optical system under test and the nominal theoretical wavefront, measured normal to the nominal theoretical wavefront

See Figure 1a).

**3.4**
**approximating spherical wavefront**
theoretical spherical wavefront tangent to the exit pupil of the system under test for which the root-mean-square difference to the wavefront transmitted and/or reflected once through the optical system under test is a minimum



See Figure 1b).



NOTE 1 For the purpose of this definition, “spherical wavefronts” include the “planar wavefront”. (The planar wavefront is considered to be a particular case of the spherical wavefront.)



NOTE 2 See Clause 5 in the case of non-circular test areas.



**3.5**
**wavefront sagitta error**
peak-to-valley difference between the approximating spherical wavefront and the reference sphere

NOTE 1 The wavefront sagitta error represents the extent to which the radius of curvature of the approximating wavefront departs from that of the nominal theoretical wavefront.

NOTE 2 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 wavefront sagitta error is defined to be zero.

**3.6**
**wavefront irregularity function**
theoretical surface defined by the difference between the total wavefront deformation function and the approximating spherical wavefront

See Figure 1c).

**3.7**
**wavefront irregularity**
peak-to-valley difference between the wavefront irregularity function and the plane which best approximates it

NOTE The wavefront irregularity represents the departure of the wavefront from sphericity.

**3.8**
**approximating aspheric wavefront**
rotationally symmetric aspheric wavefront for which the root-mean-square difference to the wavefront irregularity function is a minimum

See Figure 1d).

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

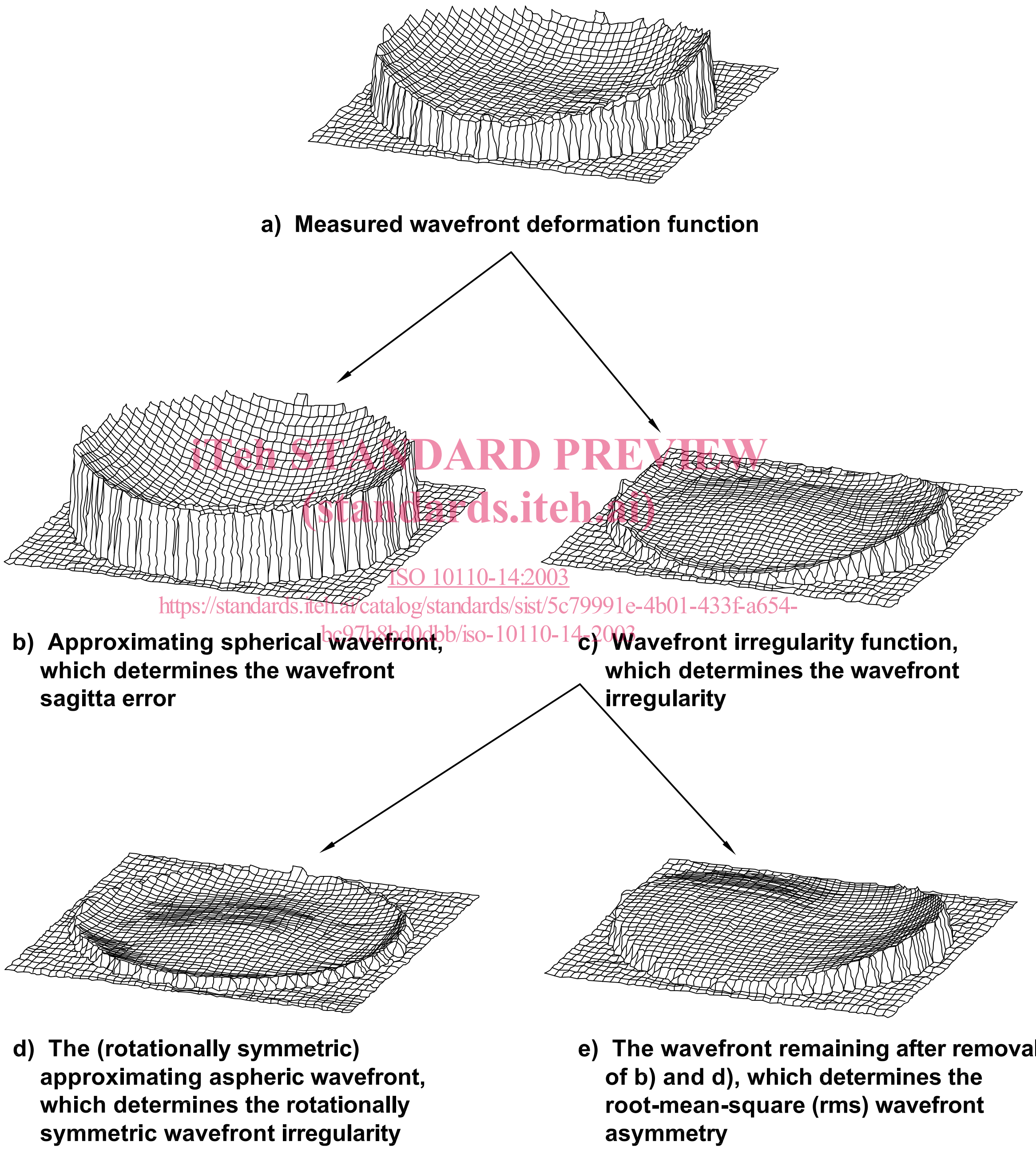




**Figure 1 — Example of a measured wavefront and its decomposition into wavefront deformation types**

**3.9**
**rotationally symmetric wavefront irregularity**
peak-to-valley difference between the approximating aspheric wavefront and the plane which best approximates it

NOTE The rotationally symmetric wavefront irregularity is the rotationally symmetric irregularity of the wavefront irregularity function. Its value cannot exceed that of the wavefront irregularity function.

**3.10**
**total rms wavefront deformation**
RMSt
root-mean-square difference between the wavefront transmitted once through, and/or reflected once from, the optical system under test and the nominal theoretical wavefront, which includes any specified target aberrations

**3.11**
**rms wavefront irregularity**
RMSi
root-mean-square value of the wavefront irregularity function defined in 3.6

**3.12**
**rms wavefront asymmetry**
RMSa
root-mean-square value of the difference between the wavefront irregularity function and the approximating aspheric wavefront

See Figure 1e).



**3.13**
**single-pass**
testing arrangement in which the light beam passes once through, or in the case of reflective optics, is reflected once by, the element under test.



NOTE 1 For corner-cubes, roof prisms, “cat's eyes”, and other types of retroreflectors, a single retroreflection from the element constitutes a “single-pass” configuration, even though the light actually passes through much of the element twice.

NOTE 2 Although the wavefront deformation as defined in 3.1 refers to a “single-pass” measurement, many types of optical systems are commonly tested in a “double-pass” configuration, in which the light passes through or reflects from the element twice. In many cases, when an element is tested in a double-pass configuration, the observed deformation of the wavefront is approximately twice the wavefront deformation as defined in 3.1. Regardless of how the system is actually to be tested or used, the tolerance for wavefront deformation always refers to the “wavefront deformation” as defined in 3.1, that is, as if used in a single-pass configuration.

NOTE 3 When an element of poor optical quality is tested in a double-pass configuration, it is possible that the rays of the test beam are disturbed sufficiently (for example, made divergent or convergent) so that they do not pass through the same positions of the test element on the second transmission. In this case, the wavefront deformation is not equal to one-half the observed deformation, and a precise determination of the (single-pass) wavefront deformation is difficult.

NOTE 4 In some cases, the double-pass wavefront deformation is not even approximately equal to twice the single-pass wavefront deformation. For instance, an optical system containing a wedged prism will convert a test beam of circular cross-section into one having an elliptical cross-section. When converting between single-pass and double-pass results, it is necessary to take such effects into account.

**3.14**
**target aberrations**
aspheric deformations of the wavefront which have been specified for inclusion in the nominal theoretical wavefront

**3.15**
**nominal theoretical wavefront**
theoretical wavefront equal to the reference sphere plus any target aberrations which may be specified

NOTE This is the “Desired shape” of the wavefront mentioned in Clause 1.

**3.16**
**reference sphere**
the theoretical spherical wavefront tangent to the exit pupil of the system under test, for which the root-mean-square difference to the wavefront transmitted once through and/or reflected once from the optical system under test is a minimum, and consistent with any restrictions which may be specified for the location of the image of the system

NOTE 1 See Clause 5 in the case of non-circular test areas.

NOTE 2 If no restrictions are specified on the image position, the reference sphere is identical to the approximating spherical surface.

## 4 Tolerances for wavefront deformation

The tolerances for wavefront deformation are indicated by specifying the maximum permissible values of the wavefront sagitta error (3.5), wavefront irregularity (3.7), and/or rotationally symmetric wavefront irregularity (3.9). In addition, tolerances for three root-mean-square (rms) measures of wavefront deformation may be specified (see 3.10, 3.11 and 3.12). These rms measures of the wavefront deformation represent the rms value of the function remaining after the subtraction of various types of wavefront deformation.

The wavefront sagitta error is meaningful only when the location of the image is specified. If the location of the image is left unspecified, the wavefront sagitta error, as defined in 3.5, is defined to be zero, and shall not be specified.

NOTE 1 A method for determining the amount of wavefront sagitta error, wavefront irregularity, and rotationally symmetric wavefront irregularity of a given wavefront using digital interferogram analysis is described in Annex A. Methods by which these quantities can be estimated using visual interpretation of interferograms are described in Annex B.



NOTE 2 A method for calculating the total rms wavefront deformation, the rms wavefront irregularity, and the rms wavefront asymmetry is described in Annex A. These rms measures of wavefront deformation cannot be estimated visually.



## 5 Non-circular test areas

The peak-to-valley (PV) and root-mean-square (RMS) wavefront deformation types given in Clause 3 refer to values calculated within the actual test area. In the case of non-circular test areas, these error types shall be calculated only over the actual test area.

The approximating spherical wavefront (3.4) is the spherical wavefront which best approximates the wavefront. If the test area is non-circular, it is important that this approximation be made by a wavefront that is spherical. In particular, the spherical part of an aspheric approximating function shall not be substituted for the approximating spherical wavefront.

The approximating aspheric wavefront (see 3.8) is the rotationally symmetric wavefront which best approximates the wavefront irregularity function. If the test area is non-circular, it is important that this approximation be made by a wavefront that is rotationally symmetric. In particular, the rotationally symmetric part of a non-symmetric approximating wavefront shall not be substituted for the approximating aspheric wavefront (see 3.8).

NOTE 1 If the test area is non-circular, the various wavefront deformation types defined in Clause 3 are not mathematically orthogonal. Nevertheless, these wavefront deformation types are well-defined (not ambiguous) provided the above restrictions are upheld.

NOTE 2 Annex A describes a method for calculating the amounts of the various types of wavefront deformation, regardless of whether or not the test area is circular.

## 6 Specification of tolerances for wavefront deformation

### 6.1 General

For the specification of tolerances for wavefront deformation, the stipulations given in 6.2 to 6.5 apply.

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

### 6.2 Units

The maximum permissible values for wavefront sagitta error, wavefront irregularity, rotationally symmetric wavefront irregularity and, if applicable, any target aberrations (3.14) shall be specified in units of wavelengths.

These quantities are defined with reference to a wavefront passing once through the element under test (single-pass). See the appropriate definitions given in Clause 3.

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

### 6.3 Wavelength

Unless otherwise specified, the wavelength is that of the green spectral line of mercury (e-line), $\lambda$ = 546,07 nm, according to ISO 7944.



If other than $\lambda$ = 546,07 nm, the wavelength in which the wavefront deformation is specified shall be indicated on the drawing. See Example 2 in Figure 2. See Clause 7.



### 6.4 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 the polynomial aberration types defined in Annex A.

### 6.5 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 also apply for the elements after assembly, i.e. after cementing (or optically contacting), unless otherwise specified. See ISO 10110-1:1996, 4.8.3.

## 7 Indication in drawings

### 7.1 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 ISO 10110-1:1996, 4.2.

The location of the stop surface or pupil shall be indicated according to ISO 10110-1:1996, 5.3. See Figure 2.

The tolerance for wavefront deformation shall be indicated by a code number (see 7.2) and the indications of the tolerances for wavefront sagitta error, wavefront irregularity, rotationally symmetric wavefront irregularity and rms deformation types, as appropriate (see 7.3).

For any type of wavefront deformation indicated on the drawing, the specified wavelength shall be indicated in accordance with 6.3.