INTERNATIONAL STANDARD

ISO 10110-12

Second edition
2007-09-01

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

Part 12:
Aspheric surfaces

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

Partie 12: Surfaces asphériques

Reference number
ISO 10110-12:2007(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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.

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 10110-12 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 10110-12:1997) 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*

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

Part 12: Aspheric surfaces

1 Scope

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

This part of ISO 10110 specifies rules for presentation, dimensioning and tolerancing of optically effective surfaces of aspheric form.

This part of ISO 10110 does not apply to discontinuous surfaces such as Fresnel surfaces or gratings.

This part of ISO 10110 does not specify the method by which compliance with the specifications is to be tested.

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 1101:2004, *Geometrical Product Specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

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

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

ISO 10110-6, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 6: Centring tolerances*

ISO 10110-7, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 7: Surface imperfection tolerances*

ISO 10110-8, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 8: Surface texture*

3 Mathematical description of aspheric surfaces

3.1 General

3.1.1 Coordinate system

Aspheric surfaces are described in a right-handed, orthogonal coordinate system in which the Z axis is the optical axis.

Unless otherwise specified, the Z axis is in the plane of the drawing and runs from left to right; if only one cross-section is drawn, the Y axis is in the plane of the drawing and is oriented upwards.

If two cross-sections are drawn, the XZ cross-section shall appear below the YZ cross-section (see Figure 5). For clarity the X- and Y-axes may be shown on the drawing.

The origin of the coordinate system is at the vertex of the aspheric surface (see Figure 1).

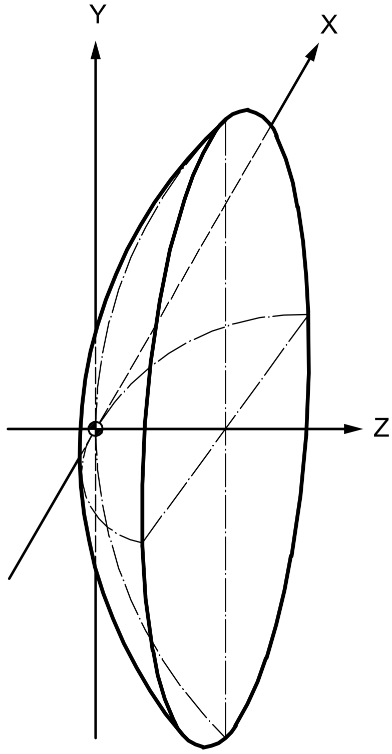


Figure 1 — Coordinate system

3.1.2 Sign conventions

NOTE As will be shown later in this part of ISO 10110, the various types of aspheric surface are given by mathematical equations. In drawings the chosen equation and the corresponding constants and coefficients are specified. To achieve unambiguous indications of the surfaces, sign conventions for the constants and coefficients need to be introduced.

A radius of curvature (commonly given for the vertex) has a positive sign if the centre of curvature is to the right of the vertex and a negative sign if the centre of curvature is to the left of the vertex.

The sagitta of a point of the aspheric surface is positive if this point is to the right of the vertex (XY plane) and negative if it is to the left of the vertex (XY plane).

3.2 Classification of surface type

Two types of surface are of particular importance because of their common application in applied optics:

- generalized surfaces of second order;
- surfaces of higher order.

Generalized surfaces of second order contain conical surfaces, centred quadrics and parabolic surfaces.

Surfaces of higher order contain polynomials, toric surfaces and combinations of surface types, e.g. by adding polynomials to other surface types.

3.3 Special surface types

3.3.1 Surfaces of second order

3.3.1.1 Centred quadrics and parabolic surfaces

In the coordinate system given in 3.1.1, the equation of the surfaces of second order which fall within the scope of this part of ISO 10110 are derived from the canonical forms

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1 \qquad \text{for centred quadrics} \qquad (1)$$

where

a, b are real or imaginary constants;

c is a real constant.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+2z=0 \qquad \text{for parabolic surfaces} \qquad (2)$$

where a, b are real or imaginary constants,

and can be written as

$$z=f(x,y)=\frac{\dfrac{x^2}{R_X}+\dfrac{y^2}{R_Y}}{1+\sqrt{1-(1+\kappa_X)\left(\dfrac{x}{R_X}\right)^2-(1+\kappa_Y)\left(\dfrac{y}{R_Y}\right)^2}} \qquad (3)$$

where

R_X is the radius of curvature in the XZ plane;

R_Y is the radius of curvature in the YZ plane;

κ_X, κ_Y are conic constants.

Using curvatures $C_X = 1/R_X$ and $C_Y = 1/R_Y$ instead of radii yields

$$z = f(x,y) = \frac{x^2 C_X + y^2 C_Y}{1+\sqrt{1-(1+\kappa_X)(xC_X)^2-(1+\kappa_Y)(yC_Y)^2}} \tag{4}$$

If the surface according to Equations (3) or (4) is intersected with the XZ plane ($y = 0$) or the YZ plane ($x = 0$), then, depending on the value of κ_Y (or κ_X), intersection lines of the following types are produced:

$\kappa > 0$	oblate ellipse;
$\kappa = 0$	circle;
$-1 < \kappa < 0$	prolate ellipse;
$\kappa = -1$	parabola;
$\kappa < -1$	hyperbola.

The following special cases of Equations (3) and (4) should be mentioned:

a) Rotationally symmetric surfaces:

Using radii:

For $R = R_X = R_Y$, $\kappa = \kappa_X = \kappa_Y$ and $h^2 = x^2 + y^2$

Equation (3) gives

$$z = f(h) = \frac{h^2}{R\left[1+\sqrt{1-(1+\kappa)\left(\frac{h}{R}\right)^2}\right]} \tag{5}$$

Using curvatures:

For $C = C_X = C_Y$, $\kappa = \kappa_X = \kappa_Y$ and $h^2 = x^2 + y^2$

Equation (4) gives

$$z = f(h) = \frac{h^2 C}{1+\sqrt{1-(1+\kappa)h^2C^2}} \tag{6}$$

Equations (5) and (6) describe a surface rotationally symmetric about the Z axis.

b) Cylindrical surfaces:

Using radii:

For $R_X = \infty$ or $R_Y = \infty$

Equation (3) gives

$$z = f(u) = \frac{u^2}{R_U\left[1+\sqrt{1-(1+\kappa_U)\left(\frac{u}{R_U}\right)^2}\right]} \tag{7}$$

Using curvatures:

For $C_X = 0$ or $C_Y = 0$

Equation (4) gives

$$z = f(u) = \frac{u^2 C_U}{1+\sqrt{1-(1+\kappa_U)u^2{C_U}^2}} \tag{8}$$

Equations (7) and (8) describe a cylinder (due to κ_U not necessarily of circular cross-section), the axis of which for $u = x$ is perpendicular to the XZ plane, and the axis of which for $u = y$ is perpendicular to the YZ plane.

3.3.1.2 Conical surfaces

The canonical form

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=0 \tag{9}$$

where

a, b are imaginary constants;

c is a real constant.

leads to Equation (10)

$$z=f(x,y)=c\sqrt{\frac{x^2}{a^2}+\frac{y^2}{b^2}} \tag{10}$$

where a, b, c are real constants.

This equation describes a cone with its tip at the origin, with elliptical cross-section (if $a \neq b$) or with circular cross-section (if $a = b$).

3.3.2 Surfaces of higher order

3.3.2.1 Polynomials

The equation for polynomial surfaces is

$$z=f(x,y)=A_4x^4+B_4y^4+A_6x^6+B_6y^6+\ldots+C_3|x|^3+\ldots+D_3|y|^3+\ldots \tag{11}$$

A special case of Equation (11) with $h^2 = x^2 + y^2$ is

$$z=f(h)=A_3h^3+A_4h^4+A_5h^5+\ldots \tag{12}$$

Equation (12) describes a rotational symmetric polynomial surface, known as Schmidt surface.

3.3.2.2 Toric surfaces

A toric surface is generated by the rotation of a defining curve, contained in a plane, about an axis which lies in the same plane.

The equation of a toric surface having its defining curve, $z = g(x)$, in the XZ plane and its axis of rotation parallel to the X axis is

$$z=f(x,y)=R_Y\mp\sqrt{\left[R_Y-g(x)\right]^2-y^2} \tag{13}$$

where R_Y is the z-coordinate at which the axis of rotation intersects the Z axis.

For the purpose of this part of ISO 10110, $g(x)$ is derived from Equation (3) by setting $y = 0$.

$$g(x) = \frac{x^2}{R_X\left[1+\sqrt{1-(1+\kappa_X)\left(\frac{x}{R_X}\right)^2}\right]} \tag{14}$$

The equation of a toric surface having its defining curve in the YZ plane and its axis of rotation parallel to the Y axis may be obtained from Equations (13) and (14) by interchanging x with y, R_X with R_Y and κ_X with κ_Y.

The following special case of Equations (13) and (14) should be mentioned:

$\kappa_X = 0$ gives

$$g(x) = R_X\left[1-\sqrt{1-\left(\frac{x}{R_X}\right)^2}\right]$$

and

$$z = f(x,y) = R_Y \mp \sqrt{\left[R_Y - R_X + R_X\sqrt{1-\left(\frac{x}{R_X}\right)^2}\right]^2 - y^2} \tag{15}$$

Equation (15) describes a torus whose defining curve is a circle with radius R_X.

3.3.2.3 Combinations of surface types

If necessary, surface types can be modified by the addition of a power series $f_1(x, y)$ (see Annex A). The complete equation of the surface is then

$$z = f(x, y) + f_1(x, y) \tag{16}$$

where $f(x, y)$ represents the basic form according to Equations (3) and (4) or Equation (10).

In analogy for toric surfaces, the defining curve $g(x)$ can be modified by addition of a power series $g_1(x)$ (see Annex A.)

Care should be taken that the signs of the coefficients in $f_1(x, y)$ and $g_1(x)$ are in accordance with the conventions defined in 3.1.1 and 3.1.2. In the case where the direction of the Z axis shall be reversed, the signs of the radii and curvatures and of the coefficients shall be changed. The signs of the conic constants remain unchanged.

4 Indications in drawings

4.1 Indication of the theoretical surface

An aspheric lens or mirror shall be represented in the same manner as a spherical component (see ISO 10110-1), the indication of the radius on the drawing being replaced by the word "asphere" if $f_1(x, y) \neq 0$, or the type of asphere if the basic equation is not modified by a power series (e.g. "toroid", "paraboloid", etc.).

The equation describing the aspheric surface shall be given in a note, except for cylindrical surfaces with circular cross-section.

The radius of curvature is indicated with a sign, in accordance with 3.1.2.

If the basic equation is modified by a power series an abridged sagitta table having sufficient numerical accuracy shall be included on the drawing (see Figure 2).

4.2 Indication of surface form tolerances

Surface form tolerances shall be indicated in one of the following ways:

a) in accordance with ISO 1101;

b) in accordance with ISO 10110-5; or

c) by a table specifying the permissible deviations of z, i.e. the differences between the nominal values of z according to the specified equation and the actual values of the workpiece (see Figure 2).

NOTE For interferometric measurement the value of Δz is measured along the local normal to the surface.

Because local figuring with small tools is generally used for generating aspherical surfaces, an additional tolerance for the slope deviation, which limits the waviness of the surface, should be introduced in each of these three cases.

The local slope deviation is the angular deviation of the local normal of the actual (real) surface from the local normal of the theoretical surface.

The slope deviation at any point shall be taken as the mean of the local slopes over the slope integration length. The slope integration length is the transverse distance on the surface over which the slope is calculated.

The slope deviation of the surface can be specified as a peak value or as an RMS value. The peak slope deviation is given by the greatest of the slope deviations over the surface. The RMS slope deviation is given by the square root of the sum of the squares of the slope deviations over the surface.

If such a slope tolerance is specified, the slope integration length and spatial sampling resolution shall also be given on the drawing.

Both the form tolerance and the slope tolerance may be different in different sections. See examples in Figures 4 and 5.

4.3 Indication of centring tolerances

Centring tolerances shall be indicated in accordance with either ISO 1101 or ISO 10110-6.

4.4 Indication of surface imperfection and surface texture tolerances

Tolerances for surface imperfections and specifications of mid-spatial frequency ripple and surface texture shall be indicated according to ISO 10110-7 and ISO 10110-8, respectively.

5 Examples

5.1 Parts with a symmetric aspheric surface, coincident mechanical and optical axes

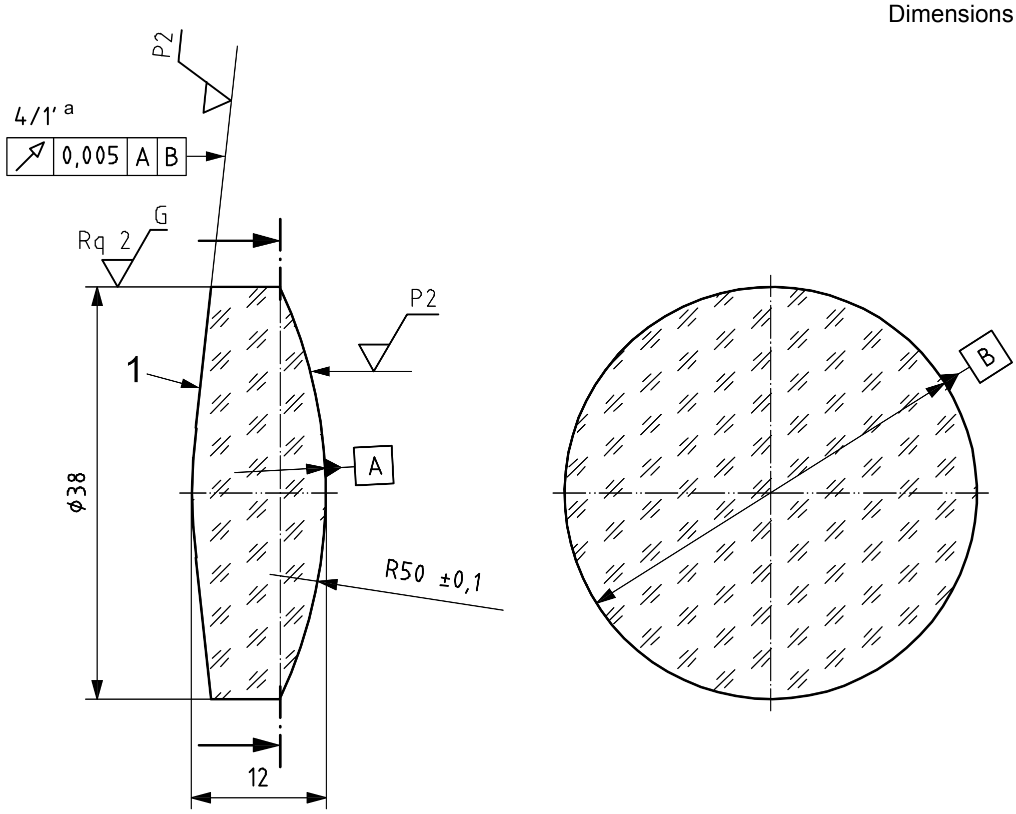
In Figure 2 a), the datum axis runs through the centre of curvature of the spherical surface and the central point of the right surface in accordance with ISO 10110-6.

The form tolerance of the aspheric surface is given in tabular form. Δz is the maximum permissible deviation, in millimetres, in the Z direction for the given H coordinate. In addition, a slope error tolerance is indicated.

The centring tolerance is indicated in accordance with ISO 1101 as the maximum permissible axial run-out, and, alternatively, in accordance with ISO 10110-6 as the maximum permissible tilt angle (marked with index a).

In Figure 2 b) the drawing of an aspherical lens with the same geometrical shape as the lens in Figure 2 a) but turned over (so that the asphere is the right surface) is shown. Note that the signs of the radius, R and of the coefficients A_i have changed. As a result the sagittas, z, have also changed sign.

Dimensions in millimetres



Key

1 asphere

$$z = \frac{h^2}{R\left(1+\sqrt{1-(1+\kappa)h^2/R^2}\right)} + \sum_{i=2}^{5}\left(A_{2i}h^{2i}\right)$$

a Alternative indication of centring tolerance.

h	z	Δz	Slope tolerance
0,0	0,000	0,000	0,3'
5,0	0,219 352	0,002	0,5'
10,0	0,825 330	0,004	0,5'
15,0	1,600 528	0,006	0,8'
19,0	1,938 077	0,008	

R = 56,031

κ = – 3

A_4 = – 0,432 64 E-05

A_6 = – 0,976 14 E-08

A_8 = – 0,108 52 E-11

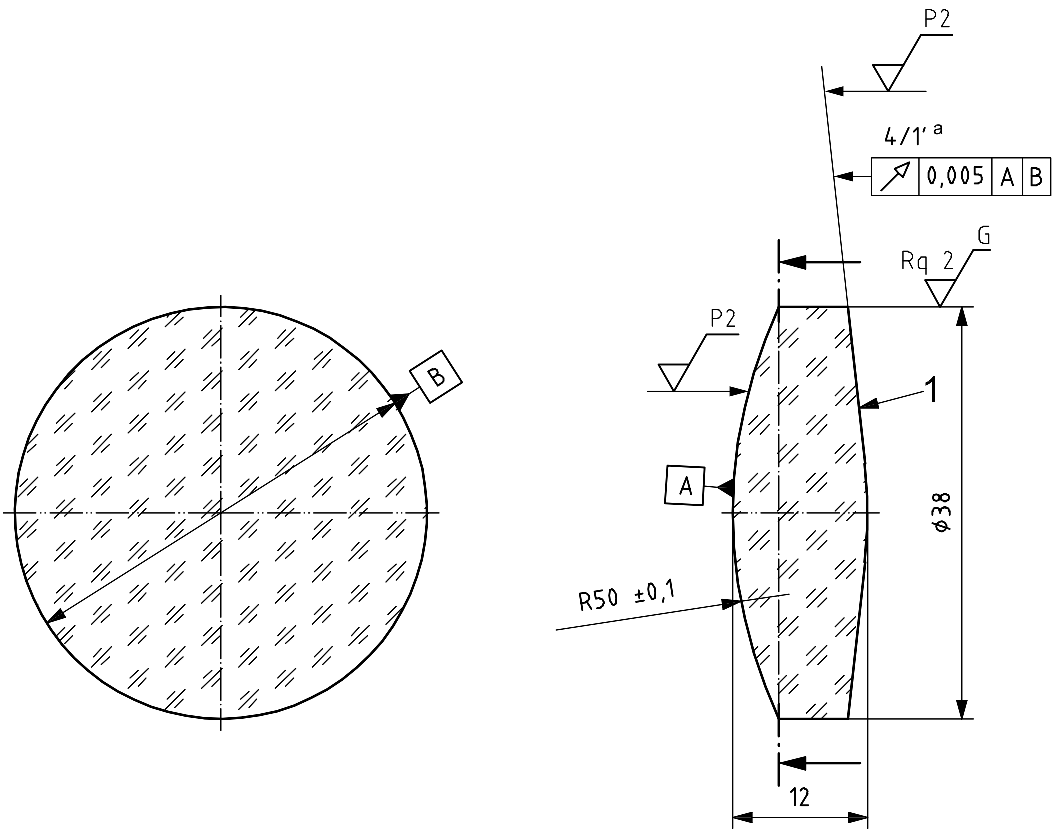
A_{10} = – 0,122 84 E-13

Slope integration length = 1

Spatial sampling resolution = 0,1

a) Lens with a rotationally symmetric aspheric surface

Dimensions in millimetres



Key

1 asphere

$$z = \frac{h^2}{R\left(1+\sqrt{1-(1+\kappa)h^2/R^2}\right)} + \sum_{i=2}^{5}\left(A_{2i}h^{2i}\right)$$

[a] Alternative indication of centring tolerance.

h	z	Δz	Slope tolerance
0,0	0,000	0,000	
			0,3'
5,0	−0,219 352	0,002	
			0,5'
10,0	−0,825 330	0,004	
			0,5'
15,0	−1,600 528	0,006	
			0,8'
19,0	−1,938 077	0,008	

R = −56,031

κ = −3

A_4 = 0,432 64 E-05

A_6 = 0,976 14 E-08

A_8 = 0,108 52 E-11

A_{10} = 0,122 84 E-13

Slope integration length = 1

Spatial sampling resolution = 0,1

b) Same aspheric lens as in Figure 2 a) but turned over

Figure 2 — Lens with a rotationally symmetric aspheric surface

5.2 Parts with a symmetric aspheric surface, with the optical and mechanical axes not coincident

Figure 3 a) shows an off-axis paraboloid with a rectangular cross-section. The surface form tolerance and centring tolerance are indicated in accordance with ISO 1101.

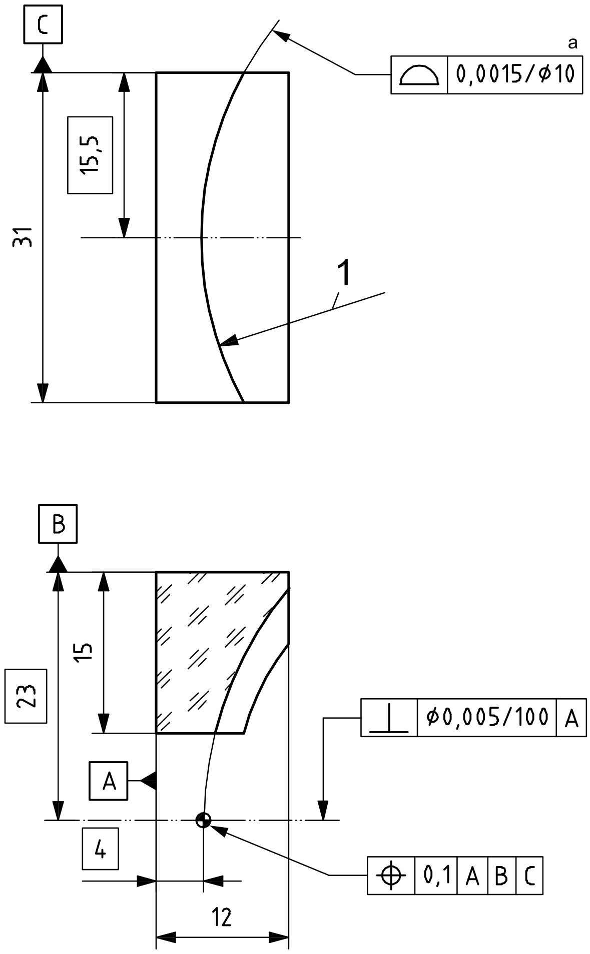
The vertex of the paraboloid shall lie within a cube of edge length 0,1 mm centred on the nominal position.

The rotation axis of the paraboloid shall lie, over a length of 100 mm, within a cylinder perpendicular to the datum A, having a diameter of 0,005 mm.

The surface form tolerance of the optically effective surface is given in accordance with ISO 1101:2004, 14.6. In addition, the slope error tolerance is indicated.

Figure 3 b) shows the same optical element as Figure 3 a); however, the surface form tolerance is indicated here in accordance with ISO 10110-5.

Dimensions in millimetres



Key

1 paraboloid

[a] Slope tolerance = 0,2'

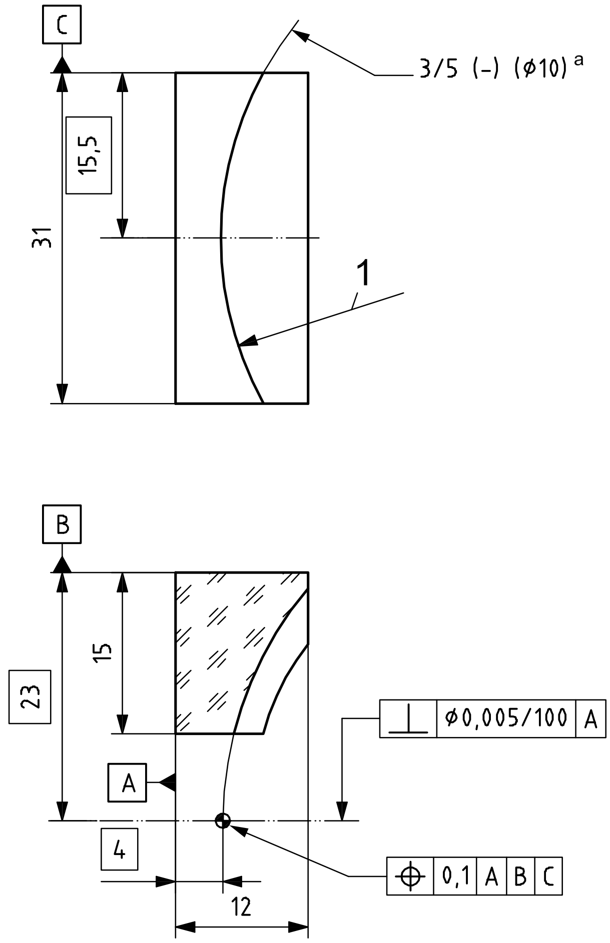
Slope integration length = 2

Spatial sampling resolution = 0,2

$$z = \frac{h^2}{2R} \qquad R = 35{,}741 \pm 0{,}2$$

a) Surface form tolerance indication in accordance with ISO 1101

Dimensions in millimetres



Key

1 paraboloid

[a] Slope tolerance = 0,2'
Slope integration length = 2
Spatial sampling resolution = 0,2

$$z = \frac{h^2}{2R} \qquad R = 35{,}741 \pm 0{,}2$$

b) Surface form tolerance indication in accordance with ISO 10110-5

Figure 3 — Off-axis paraboloid

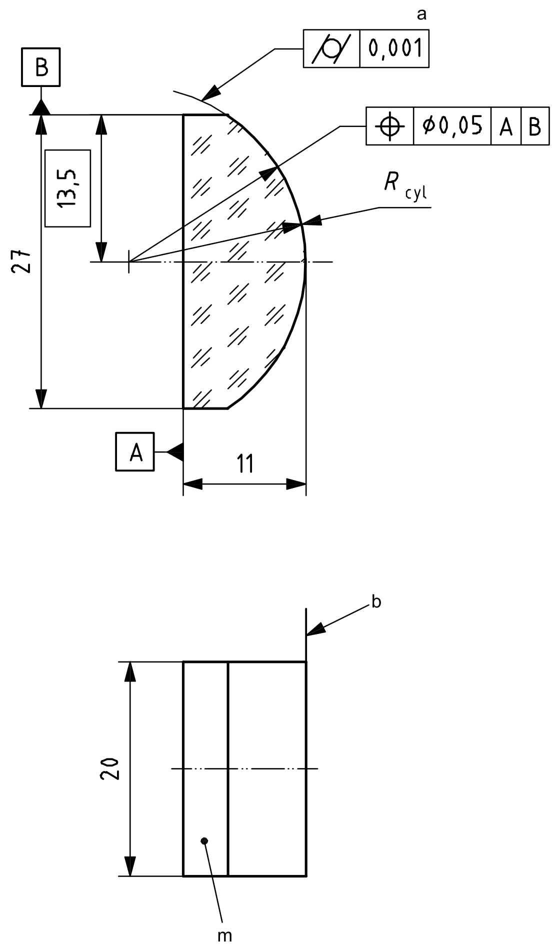
5.3 Parts with a non-rotationally-symmetric aspheric surface

Figure 4 shows a planocylinder lens with rectangular cross-section. The datum axis is given by the intersection of surfaces A and B.

The axis of the cylindrical surface shall be within a cylinder of diameter 0,05 mm.

The form error tolerance is specified in accordance with ISO 1101:2004, 14.4 and additionally by different slope error tolerances in the two sections.

Dimensions in millimetres



Key

m mark for identification

R_{cyl} = 17,2 ± 0,2

[a] Slope tolerance = 0,5'

[b] Slope tolerance = 1,0'

Slope integration length = 2

Spatial sampling resolution = 0,2

Figure 4 — Planocylinder lens

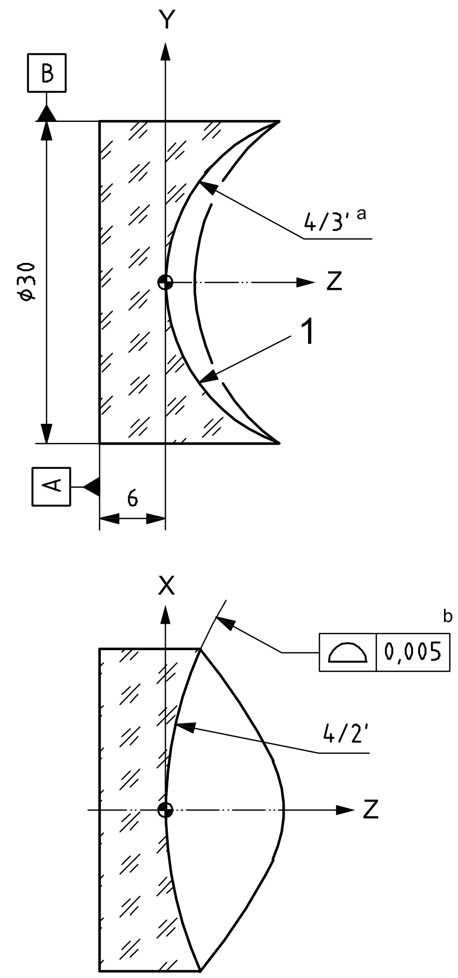
Figure 5 shows a planotoric lens with circular cross-section.

The datum axis is given by the edge cylinder B and the plano surface A.

The surface equation shown in the drawing indicates that defining arc and rotation axis of the surface lie in the XZ plane.

Different tolerances for the surface tilt angles are given in the two sections. Also the (local) slope angle tolerances are different in the two sections.

Dimensions in millimetres



Key

1 torus

$$z = R_Y - \sqrt{\left[R_Y - R_X + \sqrt{R_X^2 - x^2}\right]^2 - y^2}$$

$R_Y = 16 \pm 0{,}1$

$R_X = 40 \pm 0{,}2$

[a] Slope tolerance = 0,5'

[b] Slope tolerance = 0,8'

Slope integration length = 3

Spatial sampling resolution = 0,2

Figure 5 — Planotoric lens

Annex A
(normative)

Summary of aspheric surface types

Class	Basic surface	Basic equation $f(x,y)$ =	Power series $f_1(x,y)$ = [for toric surfaces, $g_1(x)$]
Non-rotationally-symmetric surfaces	Ellipsoid Hyperboloid Paraboloid	$\dfrac{\dfrac{x^2}{R_X}+\dfrac{y^2}{R_Y}}{1+\sqrt{1-(1+\kappa_X)\left(\dfrac{x}{R_X}\right)^2-(1+\kappa_Y)\left(\dfrac{y}{R_Y}\right)^2}}$	$A_4x^4+B_4y^4+A_6x^6+B_6y^6+\ldots$ $\ldots C_3\lvert x\rvert^3+\ldots+D_3\lvert y\rvert^3+\ldots$
$R_X \neq R_Y$ [a] $\kappa_X \neq \kappa_Y$	Cone ($a \neq b$)	$c\sqrt{\dfrac{x^2}{a^2}+\dfrac{y^2}{b^2}}$	
$A_{2i} \neq B_{2i}$ $C_{2i-1} \neq D_{2i-1}$	Cylinder	$\dfrac{u^2}{R_U\left[1+\sqrt{1-(1+\kappa_U)\left(\dfrac{u}{R_U}\right)^2}\right]}$	$A_4x^4+A_6x^6+\ldots+C_3\lvert x\rvert^3$ for $u = x$ $B_4y^4+B_6y^6+\ldots+D_3\lvert y\rvert^3$ for $u = y$
Surfaces rotationally symmetric about Z axis	Ellipsoid Hyperboloid Paraboloid Sphere	$\dfrac{h^2}{R\left[1+\sqrt{1-(1+\kappa)\left(\dfrac{h}{R}\right)^2}\right]}$	$A_3h^3+A_4h^4+A_5h^5+\ldots$
$R_X = R_Y = R$ $\kappa_X = \kappa_Y = \kappa$	Cone ($a = b$)	$\dfrac{c}{a}h$	where $h=\sqrt{x^2+y^2}$
$h^2 = x^2 + y^2$	Plane (Schmidt surface)	0	
Surfaces of revolution; not coincident with coordinate axis	Toric surface	$f(x,y)=R_Y \mp \sqrt{\left[R_Y-g(x)\right]^2-y^2}$ $g(x)=\dfrac{x^2}{R_X\left[1+\sqrt{1-(1+\kappa_X)\left(\dfrac{x}{R_X}\right)^2}\right]}$	$g_1(x)=A_4x^4+A_6x^6+\ldots+C_3\lvert x\rvert^3+C_5\lvert x\rvert^5+\ldots$

[a] If at least one of these inequalities is valid.

Bibliography

[1] ISO 4288, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture*

ICS 01.100.20; 37.020

Price based on 15 pages