INTERNATIONAL STANDARD

ISO 10110-8

Second edition
2010-10-01

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

Part 8: Surface texture; roughness and waviness

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

Partie 8: État de surface; rugosité et ondulation

Reference number
ISO 10110-8:2010(E)

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 10110-8 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 10110-8:1997), 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; roughness and waviness*
- *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 8:
Surface texture; roughness and waviness

1 Scope

ISO 10110 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 the indication of the surface texture of optical elements. Surface texture is the characteristic of a surface that can be effectively described with statistical methods. Typically, surface texture is associated with high spatial frequency errors (roughness) and mid-spatial frequency errors (waviness).

This part of ISO 10110 is primarily intended for the specification of polished optics.

This part of ISO 10110 describes a method for characterizing the residual surface that is left after detrending by subtracting the surface form. The control of the surface form is specified in ISO 10110-5 and ISO 10110-12, it is not specified in this part of ISO 10110.

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 1302:2002, *Geometrical Product Specifications (GPS) — Indication of surface texture in technical product documentation*

ISO 4287:1997, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters*

3 Terms and definitions

For the purposes of this document, terms and definitions given in ISO 4287 and the following apply.

3.1
surface texture
characteristic relating to the profile of an optical surface that can be effectively described with statistical methods

NOTE Localized defects, known as surface imperfections, are specified in ISO 10110-7.

3.2
matt surface
optical surface for which the height variation of the surface texture is not considerably smaller than the wavelength of light

NOTE Matt surfaces are usually produced by brittle grinding of glass or other dielectric material, or by etching.

3.3
optically smooth surface
optical surface for which the height variation of the surface texture is considerably smaller than the wavelength of light

NOTE 1 Due to the smaller height variation, the amount of light scattered is small.

NOTE 2 Optically smooth surfaces are usually produced by polishing or moulding.

3.4
microdefect
small irregularity in an optically smooth surface; i.e. location where the surface height differs from the average surface height by more than twice the standard deviation

NOTE Usually, microdefects are pits remaining after an incomplete polish, although they can also be due to mishandling and contamination during polishing. Microdefects are of concern because they produce large-angle scattering. Microdefects are not considered surface imperfections as treated in ISO 10110-7 because they are usually reasonably uniformly distributed over the surface and thus have a global characteristic associated with texture.

3.5
detrending
fitting and removing a surface form from a set of measured data

NOTE 1 Detrending is usually applied to the input data to avoid masking low-amplitude high frequency errors with the large amplitude, low frequency surface form errors. The resultant set of data points represents the residual surface.

NOTE 2 For the purposes of this part of ISO 10110, the surface form used for detrending is a polynomial fit to the measured surface with an order sufficient to remove all spatial wavelengths longer than the spatial bandwidth of the specification.

3.6
measured surface
Z_m
function of raw surface measurement data, prior to detrending

3.7
surface form
Z_f
fit to a measured surface

NOTE In a typical 2D polynomial fit to a surface, the surface polynomial can be written as a Zernike polynomial or another polynomial equation. For example in Cartesian coordinates:

$$Z_f(x,y) = \sum_{i=1}^{p} \sum_{j=1}^{q} C_{ij} P_{ij}(x,y) \tag{1}$$

where P_{ij} is a polynomial function of order p, q that describes the underlying shape of the surface.

3.8
residual surface
Z
function that is calculated by subtracting the surface form Z_f from a measured surface Z_m

NOTE 1 For example in 2D, this is expressed mathematically as: $Z(x,y) = Z_m(x,y) - Z_f(x,y)$ or in polar coordinates $Z(r,\theta) = Z_m(r,\theta) - Z_f(r,\theta)$.

NOTE 2 Neglecting correction factors for instrument response, the residual surface is taken as the surface height data.

3.9
sampled surface data
residual surface data, $Z(x_m,y_n)$, sampled on a discrete m by n grid of points (x_m,y_n)

3.10
evaluation length
length over which the surface texture is to be evaluated

NOTE Typically this is synonymous with trace length in a profile measurement. The default evaluation length is five times the upper limit of the spatial bandwidth.

3.11
spatial wavelength
peak to peak scale-length of a sinusoidal surface undulation, especially when viewed in a Fourier transform

NOTE See ISO 3274 and ISO 11562 for more information.

3.12
spatial bandwidth
range of surface spatial wavelengths which are to be included in the specification

NOTE This is equivalent to the term “transmission band” as used in ISO 1302. In order to prevent confusion with spectral transmission bands, the term “spatial bandwidth” is used instead of “transmission band” in this part of ISO 10110.

3.13
root mean square roughness
rms roughness
Rq
square root of the mean of the square of the residual surface height in a region for short spatial wavelengths

3.14
root mean square waviness
rms waviness
Wq
square root of the mean of the square of the residual surface height in a region for spatial wavelengths between those of surface roughness and surface form

3.15
power spectral density
PSD
squared magnitude of the Fourier transform of the residual surface height function along one dimension using an appropriate weighting function

3.16
surface lay symbol
symbol indicating the lay of the surface profile parameter

NOTE According to ISO 1302:2002, Table 2, the following symbols are used for surface lay; R (radial), C (circular), X (crossed), = (parallel to projection), ⊥ (perpendicular to projection), etc.

3.17
local slope
Δ
difference between the heights at two points on the residual surface, divided by the distance between the points

NOTE 1 The local slope is expressed in microradians.

NOTE 2 In one dimension, the surface slope points can be computed directly from the surface heights by successive differences:

$$\Delta(x_n) = \frac{1}{\mathrm{d}x}\left[Z(x_{n+1}) - Z(x_n)\right] \text{ where } n = 1,2, \ldots n{-}1 \quad (2)$$

NOTE 3 This differencing calculation always results in one less data point in the slope profile.

NOTE 4 This is the equivalent of the property symbolized by dZ/dX in ISO 4287:1997, but generalized so that it can be calculated along any direction or lay and in any coordinate system.

3.18
root mean square slope
rms slope
$R\Delta q$
square root of the mean of the square of the local slopes in a region on a residual surface

NOTE The root mean square slope is expressed in microradians.

4 Description of surface texture

4.1 General

Surface texture is a global statistical characteristic of the profile of the optical surface, and it is assumed for this part of ISO 10110 that the character and magnitude of the texture in any one area of the surface is similar to that in all other areas of the same surface. This assumption is made so that a measurement made in one part of an indicated test region or surface may be considered representative of the entire test region or surface.

Unless stated otherwise, the indication of surface texture applies to surfaces before coating. This is an exception to the general statement in ISO 10110-1:2006, Clause 3, paragraph 1.

Materials having a crystal structure and production processes such as diamond turning can give rise to non-random surface texture. Care should be used in applying statistical surface properties for surface texture with these types of surfaces.

Because the magnitude of the measured roughness is a function of the spatial wavelengths considered, this part of ISO 10110 provides for the indication of the spatial bandwidth.

This part of ISO 10110 makes use of the terminology of profilometry, as specified in ISO 4287. Although the main effect of surface roughness is optical scattering, no reference is made to scattering measurements because there are causes of scattering other than texture (details of the relationship between surface texture and optical scattering are given in the Bibliography). Although the terminology in this part of ISO 10110 is that of profilometry, areal measurements (that is, measurements over a specified area) can also be used to characterise surface texture.

Surface texture specifications are applicable to matt surfaces as well as to optically smooth surfaces made by polishing or moulding. In this part of ISO 10110, texture also refers to microdefects, such as pits left from an incomplete polish, that are nominally uniformly distributed over a smooth surface. Surface texture also refers to other statistical properties of the surface of longer scale-lengths, such as mid-spatial frequency waviness, which can be specified using root mean square (rms) roughness, rms slope, PSD and other statistical methods.

Depending on the application of a surface and the magnitude of surface height variation, one or more methods outlined below may be appropriate for describing surface texture numerically.

In calculating any statistical surface property, care should be taken regarding the spatial wavelength ranges over which the calculation is to be made. Both limits of the spatial band, in a long-scale length sense and a short-scale length sense, should be carefully considered. Significant errors can be introduced in the process of bandpass filtering or detrending of surface height data.

NOTE Computing the slope between adjacent sampled height points results in a large rms slope number that is usually dominated by instrument noise. To suppress the high frequency slope bias, one needs to first filter the height data with a low-pass filter before differentiating the height profile. The rms slope computed from this filtered data is equivalent to computing the rms slope from the slope PSD over a spatial bandwidth equivalent to the filter cutoff.

4.2 Description of matt surfaces

Matt surfaces shall be specified by indication of the rms height variation, Rq (see ISO 4287:1997, 4.2.2). This quantity depends on the range of spatial wavelengths to be considered. For this reason it may be necessary to specify the lower and upper limits of the spatial bandwidth.

If no spatial bandwidth is specified, the spatial bandwidth is assumed to be 0,002 5 mm to 0,08 mm.

In some cases, functional requirements may dictate a roughness criterion other than Rq. In such cases, that other criterion shall be indicated as shown in ISO 1302:2002.

4.3 Description of optically smooth surfaces

4.3.1 Description methods

There are five statistical methods of describing optically smooth surfaces:

a) by means of the rms roughness, Rq;

b) by rms waviness, Wq;

c) by indication of the density of microdefects;

d) by using a power spectral density (PSD) function;

e) by specifying the rms slope.

These methods can be used in combination, and can be used over various spatial bandwidths in the same region.

4.3.2 Rms roughness and rms waviness

Optically smooth surfaces are commonly specified by indication of the rms roughness, Rq. For longer spatial wavelength ranges, the rms waviness, Wq, is used.

If the surface height variations obey certain statistical distribution properties, the rms value, Rq, can be related to the magnitude of the optical scattering (see Annex B). Note that the rms description is incomplete without indicating the spatial bandwidth limits.

In the event that no spatial bandwidth is specified, the spatial bandwidth is assumed to be 0,002 5 mm to 0,08 mm for Rq and 0,08 mm to 2,5 mm for Wq.

NOTE These default values can be significantly different depending on the requirements for Rq or Wq. Therefore, the correct requirements for Rq or Wq are necessary to ensure that they are consistent with the spatial bandwidth of the specification.

4.3.3 Quantification of microdefects

Microdefects can be understood as being very localized pits in an optically smooth surface. They are quantified by lightly drawing a sharp stylus of a mechanical profilometer across the surface to be measured and noting the number of times, N, that the stylus deviates markedly from the otherwise smooth profile in a 10 mm long scan, which is presumed to have a measurement width of order 1 µm. An optical profilometer, a microscope or a microscopic image comparator may also be used to quantify microdefects. The number of microdefects, N, is taken to be over a 10 mm line scan with resolution of 3 µm, or an area of 300 µm × 300 µm with the same resolution.

4.3.4 Power spectral density (PSD) function

The PSD function is directly related to the frequency spectrum of the surface roughness. It allows a complete description of the surface texture characteristics, and is particularly useful for specifying supersmooth surfaces used in high technology applications, or in controlling mid-spatial frequency waviness on a surface. The PSD function description places no restrictions on the nature of, or the statistical properties of, the measured surface.

In the one-dimensional case, i.e. when the surface texture can be determined by measurement along a line on the surface, the PSD, expressed in $\text{nm}^2 \times \text{mm}$, can be modelled by Equation (3):

$$\text{PSD} = \frac{A}{f^B} \qquad \text{for } \frac{1}{D} < f < \frac{1}{C} \tag{3}$$

where

f is the spatial frequency of the roughness or waviness, in inverse millimetres (mm^{-1});

B is the power to which the spatial frequency is raised;

C and D are the limits of the spatial bandwidth, in millimetres;

A is a constant.

The value of B shall be greater than zero. (For many real surfaces, $1 < B < 3$, see Reference [9]).

In this way, the surface texture requirement may be given by specifying the four values A, B, C and D, for which Equation (3) shall hold.

This one dimensional PSD can be calculated for any line of data. Such a line of data can be generated from 1D surface profilometry, or by averaging multiple lines of 1D surface profilometry, or by averaging an areal image along any axis. In the event that the directionality of the PSD is considered significant, a surface lay symbol is added to the surface texture specification.

NOTE 1 The cartesian 1D PSD of a 2D residual surface can be calculated from sampled surface data by averaging $Z(x,y)$ for all values of x to create an equivalent line trace $Z(y)$, or alternatively averaging $Z(x,y)$ for all values of y to create an equivalent line trace $Z(x)$. These line traces can be used as 1D residual data for PSD calculations.

NOTE 2 The polar coordinate 1D PSD of a 2D residual surface can be calculated by averaging $Z(r,\theta)$ for all values of ρ to create an equivalent line trace $Z(r)$, and then averaging $Z(r,\theta)$ for all values of r to create an equivalent line trace $Z(\theta)$. These line traces can be used as 1D residual data for PSD calculations.

In the event that no spatial bandwidth is specified, the PSD is expected to be evaluated with a spatial bandwidth of 0,08 mm to 2,5 mm.

It is recommended that both limits of the spatial bandwidth are indicated in drawings, since spatial bandwidths depend on the applications, wavelengths of use, and measurement equipment available.

4.3.5 Rms slope

Optically smooth surfaces can also be specified by indication of the root mean square slope, $R\Delta q$.

If the surface slope variations obey certain statistical distribution properties, the rms value, $R\Delta q$, can be related to the image quality, see Reference [10]. Note that the rms slope description is incomplete without indicating the spatial bandwidth limits.

In the event that no spatial bandwidth is specified, the surface slope spatial bandwidth is assumed to be 0,08 mm to 2,5 mm.

5 Indication in drawings

5.1 General

The symbols for indicating surface texture in drawings shall be in accordance with ISO 1302, if necessary, they can be modified as described below.

5.2 Indication for matt surface texture

The matt surface texture is indicated according to ISO 1302:2002, Clause 5, with the addition of the letter G [for "Ground"[1)]] above the horizontal line, as shown in Figure 1. The maximum permissible rms roughness Rq in micrometres, is indicated under the horizontal line. When a single value of Rq is given, it represents the upper limit of the surface roughness parameter. When the roughness is not permitted to lie below a certain value the upper and lower limits of the rms roughness is indicated with a bilateral tolerance according to ISO 1302: 2002, 6.6. The upper limit of the rms roughness is identified with "U", and the lower limit is identified with "L". See Figure 1.

The spatial bandwidth may be indicated under the horizontal line, as shown in Figure 4. The upper limit is separated from the lower limit by a hyphen, and the spatial bandwidth is separated from the Rq notation by an oblique stroke (/). Spatial bandwidth limits shall be expressed in millimetres.

In the event that only the upper limit of the spatial bandwidth is to be specified, it is given as shown in Figure 1, after the hyphen.

EXAMPLE 1 0,002 5–0,8/Rq 2 (example where the spatial bandwidth is specified); see Annex C.

EXAMPLE 2 –0,8/Rq 2 (example where only the upper limit of the spatial bandwidth is specified); see Annex C.

NOTE The default evaluation length is five times the upper limit of the spatial bandwidth.

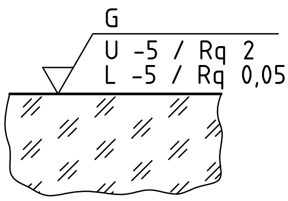

Figure 1 — Indication for matt surface texture with 0,05 µm $\leqslant Rq \leqslant$ 2 µm **and an upper limit of spatial bandwidth of** 5 mm

1) The letter "G" is used to denote all matt surfaces, including those not produced by brittle grinding, e.g. etching.

