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

**Part 16:
Diffraction surfaces**

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

Partie 16: Surfaces diffractives



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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.

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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

A list of all parts in the ISO 10110 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A diffractive surface contains diffractive structures (see [Annex A](#)), which are very small structures on or in the surface which use the wave properties of the light and work with diffraction and interference. The diffractive optical function is realized by relief structures on or in the surface or by variations of the index of refraction in the coating material. Diffractive surfaces may be also situated inside of optical assemblies.

Due to the large variety of diffractive optical elements for many purposes, this document is divided in several sub clauses. Common diffractive properties and specifications will be described in the beginning of this document. Specific properties and specifications of several basic types are described in the Annex to this document.

The three most applied types of diffractive structures are linear diffractive structures, concentric circular structures and more complex computer generated diffractive structures.

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

Part 16: Diffractive surfaces

1 Scope

This document provides general methods of describing surfaces adding a diffractive optical function on optical surfaces, such as planes, spheres, aspheres or general optical surfaces, in the ISO 10110 series, which standardizes drawing indications for optical elements and systems. The subject of this document is the presentation, description and dimensioning of diffractive surfaces in technical drawings.

This document does not apply to diffractive surfaces with random surface texture, for example stochastic antireflective structures. Also not addressed by this document are all types of 3-dimensionally extended diffractive structures: Bragg gratings, volume holograms (HOE) and acousto-optic modulators.

This document does not address the methods to test and qualify the specifications.

This document does not address tools and methods for manufacturing diffractive surfaces.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *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 10110-14, *Optics and photonics — Preparation of drawings for optical elements and systems — Part 14: Wavefront deformation tolerance*

ISO 15902, *Optics and photonics — Diffractive optics — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15902 and the following apply.

IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1
diffractive structure

structure on or in the optical surface which uses the wave properties of light and works with diffraction and interference

Note 1 to entry: This document does not include random surface textures or coatings which may also have a diffractive optical function.

3.2
diffractive surface

surface of an optical element, which contains *diffractive structures* (3.1)

3.3
diffractive region

single closed diffractive structured part of a *diffractive surface* (3.2)

3.4
diffractive test region

used part of a *diffractive region* (3.3), where the desired specifications are valid

3.5
base surface

finished surface of the substrate before realizing *diffractive structures* (3.1)

Note 1 to entry: The base surface is an intermediate surface state in the technological sequence, which may not exist in some manufacturing processes.

3.6
face view

view perpendicular to the diffractive surface

3.7
diffraction grating

regular periodic diffractive structure, which is unambiguously mathematically describable

3.8
linear grating

diffraction grating (3.7) with translation invariant profile in one dimension (which consists of parallel straight equal lines or grooves)

3.9
circular grating

diffraction grating (3.7) with rotationally invariant profile (which consists of concentric circular lines or grooves)

3.10
computer-generated hologram

CGH
diffractive optical element which is computer designed and fabricated under computer control

Note 1 to entry: Only 2-dimensional CGHs are addressed by this document.

Note 2 to entry: Since CGH is a definition of a surface structure through a production technology, the resulting diffractive structure can be a linear or circular grating. However, it can also be used to fabricate more complex structures. In most cases when referring to a CGH, more complex diffractive structures are meant.

[SOURCE: ISO 15902:2019, 3.2.8]

3.11
transmission grating

diffraction grating (3.7), where incident light and diffracted light are situated on different sides

3.12**reflection grating**

diffraction grating (3.7), where incident light and diffracted light are situated on the same side

3.13**amplitude grating**

diffraction grating (3.7), which consists of lines of non-transparent material on or in the surface, which form periodic light gaps

3.14**phase grating**

diffraction grating (3.7), which works with periodic different retardation of the lightwaves

Note 1 to entry: Phase gratings are subclassified into surface relief gratings and index gratings.

3.15**surface relief grating**

diffraction grating (3.7), which consists of periodic grooves in the surface (periodically changing thickness)

3.16**index grating**

diffraction grating (3.7), which consists of a thin smooth coating on the surface with periodically changing refractive index

3.17**diffractive optical element****DOE**

optical element for which the phenomenon of the diffraction of optical radiation is the operating principle, usually characterized in terms of its periodic spatial structure

Note 1 to entry: All DOEs containing 2-dimensional diffractive structures are addressed by this document.

Note 2 to entry: DOE is the generic term for all optical elements described by this document.

[SOURCE: ISO 15902:2019, 3.2.1]

3.18**reference axis**

theoretical axis of the *base surface* (3.5), given by the optical designer which does not depend on symmetries of the *base surface* (3.5) and which usually represents the centre of the optical path for the main function

Note 1 to entry: In the case of a rotationally invariant base surface the reference axis is the optical axis.

3.19**local reference axis**

theoretical axis of the diffractive structure, given by the optical designer which does not depend on symmetries of the diffractive structure

Note 1 to entry: The intersection point of the local reference axis with the base surface is the origin of the coordinate system of the diffractive structure.

3.20**global coordinate system**

coordinate system of the part

Note 1 to entry: Often, the coordinate system of the part is also the coordinate system of the base surface.

Note 2 to entry: The global coordinate system notation is described in ISO 10110. It may be preferred to define the global coordinate system origin to be the coordinate system origin of the base surface; e.g. the point of intersection of the reference axis and the base surface.

3.21

local coordinate system

coordinate system of the *diffractive surface* (3.2)

Note 1 to entry: The origin of the local coordinate system is the intersection point of the local reference axis with the base surface, where the diffractive structure is located.

4 Coordinate systems

4.1 General

The diffractive structure is referenced with the coordinate systems used in the process chain, e.g. to define centring tolerances according to ISO 10110-6. A diffractive structure can have 2 essential coordinate systems as shown in [Figure 1](#):

- The local coordinate system with the origin of the mathematical description of the diffractive structure;
- The global coordinate system of the optical component (e.g. the optical axis).

Specifications shall be available for the clear orientation of the local coordinate system of the diffractive structure according to its position and orientation relative to the global coordinate system. A diffractive structure has 2 or 3 degrees of freedom for referencing onto the base surface. Two lateral coordinates specify the position of the origin of the diffractive structure with respect to the origin of the base surface. A third lateral coordinate is not necessary, because diffractive structures are always located onto the surface of the base surface. If the diffractive structure is rotationally variant, the azimuthal orientation of the local coordinate system onto the base surface shall be specified by an angle or a preferred direction. This angle, if necessary, is the third degree of freedom.

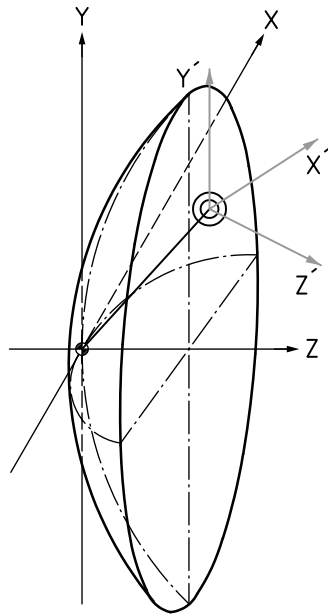
Reference marks in the form of crosses, circles, or lines and combinations of the specified structures can also be specified in this way.

4.2 Description of global and local coordinate systems

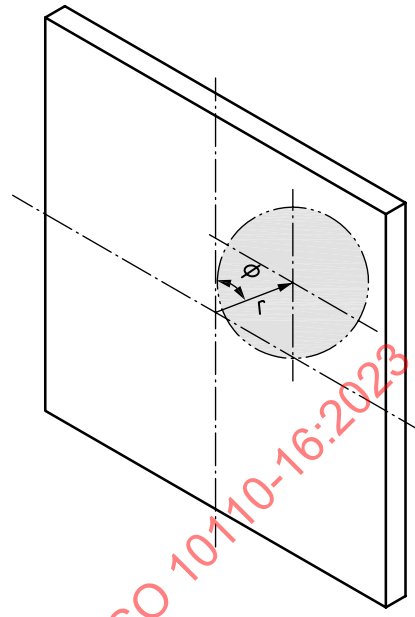
The coordinate system of the optical surface consists of three axes (X, Y, Z) orthogonal to each other and follows the right hand rule (right-handed system). The local coordinate origin of the diffractive structure shall be referenced with respect to the global coordinate system of the diffractive part. The local coordinate system of the diffractive structure has its origin onto the base surface. The local coordinate system has three axes (X', Y', Z') and follows also the right hand rule.

The direction of the local Z' coordinate is parallel to the normal of the local base surface at [X, Y]. The local Z' direction indicates the local reference axis of the diffractive structure, Y' and X' lie within the tangential plane of the local base surface at X, Y. [Figure 1](#) shows the coordinate system of the base surface and the local coordinate system of the diffractive structure.

The general coordinate transformation shall be done in accordance with ISO 10110-1. Further restriction is that the coordinate system of the diffractive structure is located on the base surface of the optical part.



a) Cartesian coordinate system



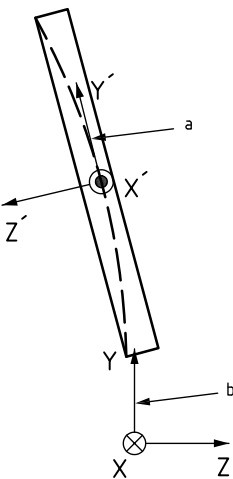
b) Polar coordinate system

NOTE The origin of the local coordinate system is always on the base surface, therefore two position coordinates are sufficient to describe the position on the base surface. The reference axis is labelled with Z, the local reference axis is Z'

Figure 1 — Coordinate system of the base surface and the local origin of the diffractive structure

If global reference axis and local reference axis are not identical then a coordinate transformation rule shall be indicated on the drawing or as a supplement to the optical drawing. This transformation rule includes a sketch of the optical part where the local reference axis and the global reference axis can be seen (see [Figure 2](#)). Second a calculation table shall be given, which describes the transformation sequence mathematically (see [Table 1](#)). And third, one or more tables with explicit data points shall be given. The purpose of these tables is to confirm the correct calculation of the coordinate transformation. The tables shall state clearly to which surface and to which reference axis the table is referring to. The surface types are defined in [Clause 3](#). Examples of such a table can be seen from [Table 2](#) to [Table 4](#). If necessary it is allowed to define multiple reference axes and multiple local reference axes. For all defined axes a coordinate transformation shall be given to indicate the correct positions. If the order of the coordinate transformation from one axis to the next axis is important, the correct order shall be indicated either on the drawing or in the tables.

NOTE A similar type of table is known as “sagitta table” in the optical community and also used in other standards for example ISO 10110-12 on “aspherical surfaces” and ISO 10110-19 on “general surfaces”.



- a Local reference axis.
- b Reference axis.

Figure 2 — Coordinate systems as 2 dimensional image with right handed coordinate system arrow markers

Table 1 — Example for a coordinate transformation table

Transformation sequence		Coordinate transformation					
1	Translation	Translation			Rotation around		
		mm			degrees (°)		
2	Rotation around Z	X	Y	Z	X	Y	Z
3	Rotation around Y						
4	Rotation around X						
Reference axis to local reference axis #1							
Reference axis to local reference axis #2							
.....							
Reference axis to local reference axis #...							

Table 2 — Table for X' coordinate

X' coordinate of the base surface with respect to local reference coordinate system #1 [mm] (parameters from reference coordinate system)								
Y ↓	X →	...	-20	-10	0	10	20	...
...								
-20								
-10								
0								
10								
20								
...								

Table 3 — Table for Y' coordinate

Y' coordinate of the base surface with respect to local reference coordinate system #1 [mm]. (parameters from reference coordinate system)								
Y ↓	X →	...	-20	-10	0	10	20	...
...								
-20								
-10								
0								
10								
20								
...								

Table 4 — Table for Z' coordinate

Z' coordinate of the base surface with respect to local reference coordinate system #1 [mm]. (parameters from reference coordinate system)								
Y ↓	X →	...	-20	-10	0	10	20	...
...								
-20								
-10								
0								
10								
20								
...								

4.3 Sign convention

As described in later clauses of this document, the various diffractive structures are specified by mathematical equations. To achieve clear surface specifications, the following sign conventions for the constants, vectors, and coefficients shall be used.

The sagitta of a point on the diffractive surface is positive if it lies in the positive Z direction from the XY plane and negative if it lies in the negative Z direction from the XY plane.

5 Drawing specifications

5.1 General

Diffractive structures do not have influence on shape and size. They mean a modification of properties and functionality of the optical surface, similar to an optical coating. Therefore, diffractive structures shall be indicated with a symbol in accordance with [Table 5](#). The combination of the symbols from [Table 5](#) at the same surface is allowed and often necessary.

It is mandatory to present each diffractive optical element in face view on the diffractive surface and at least in one side view.

In addition, the drawing should contain a table defining the surface shape at reference points of the diffractive surface. If the base surface, which carries the diffractive structure, is not planar or spherical, then also a sagitta table of this base surface shall be given on the drawing. When a sagitta table is given on the drawing, it shall have a unique title to identify the mathematical formula from where the table

entries are calculated and shall be clearly referenced to the coordinate system used (X, Y, Z) and/or (X', Y', Z'). (see [Table 1](#) to [Table 4](#))

NOTE 1 Recommended reference points are discontinuities, inflection point, fiducials or datum-points. For example the zone positions.

NOTE 2 The diffractive surface form is a combination of the base surface and the diffractive structure. Therefore, the sagitta table of the base surface is only for comparison of mathematical descriptions. The same applies for sagitta tables of the pure diffractive structure.

A note shall be added to the drawing indicating the selected form of mathematical description or a corresponding data file with the corresponding constants, vectors, and coefficients.

If there is no data file for exchanging data between CAD and other systems, the mathematical description shall be specified on the drawing. If there is a data file for exchanging data between CAD and other systems, it shall be specified on the 2D drawing of the individual part near the diffractive surface. An unambiguous file name (e.g. date stamp, version number) including data file extension shall be given. An example of the representation is shown in [B.3](#). Diffractive surfaces can be manufactured by various tools and technologies, however these are not subject of this document.

5.2 Symbols and abbreviations

Table 5 — Symbols for marking of diffractive structures on drawings

Symbol	Meaning
⊕	Diffractive structure
LG	Linear grating
CG	Concentric circular grating
CGH	Computer generated hologram
TG	Transmission grating
RG	Reflection grating
AG	Amplitude grating
SG	Surface relief grating
IG	Index grating

5.3 Marking and hatching

If diffractive structures are specified in the table field, this symbol shall be located at the beginning of the specification. When diffractive structures are specified in the drawing field, this symbol shall be located outside the element and tangent to the diffractively structured surface (see [Figure 3](#)). There are two exceptions from this rule, where the symbol shall be placed inside at the diffractive surface: Diffractive structures with lacquer layer outside and diffractive structures inside of an optical assembly (see [Figure 4](#)).

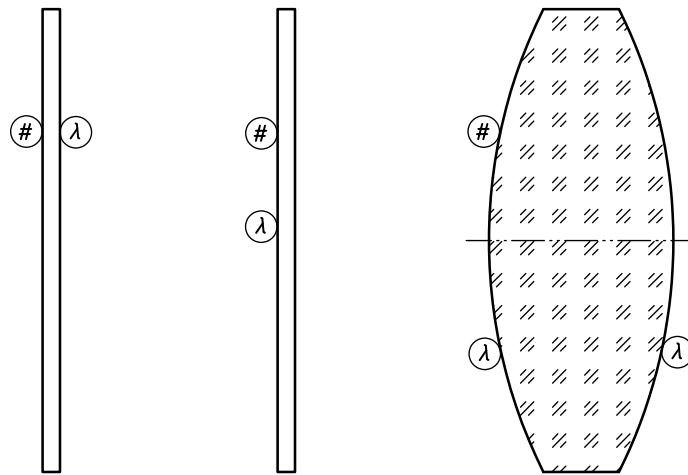
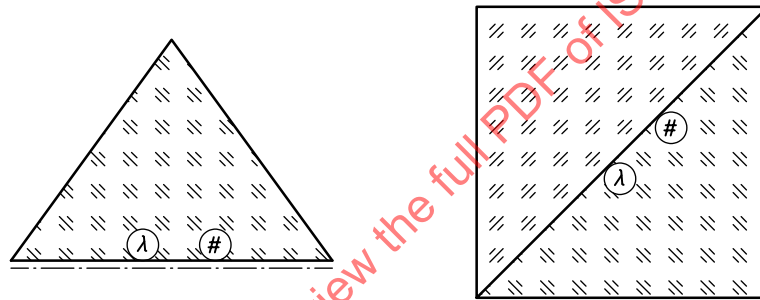


Figure 3 — Usual marking of a diffractive surface in side view or sectional view with symbols on the outside



a) Diffractive surface is under a lacquer layer b) Diffractive structure is at the hypotenuse of the right prism of a beam splitter cube

Figure 4 — Marking of a diffractive surface in sectional view with symbols inside an optical element

In the face view each diffractive region has to be hatched. Linear diffraction gratings shall be hatched with a linear hatch drawn parallel to the real lines or grooves of the diffractive structure. Circular gratings shall be displayed as a concentric circular hatch, if possible. Otherwise it shall be displayed as a cross hatch. If there is more than one diffractive region, each region can be marked with an identification number beginning from 1, then behind a separation blank the next symbol may follow (see [Figure 5](#)).

If optical coating is necessary to achieve AG or IG, the symbol for optical coating shall not be indicated. But in case of AR coating or reflection coating for TG and RG, the symbol for optical coating shall be indicated.

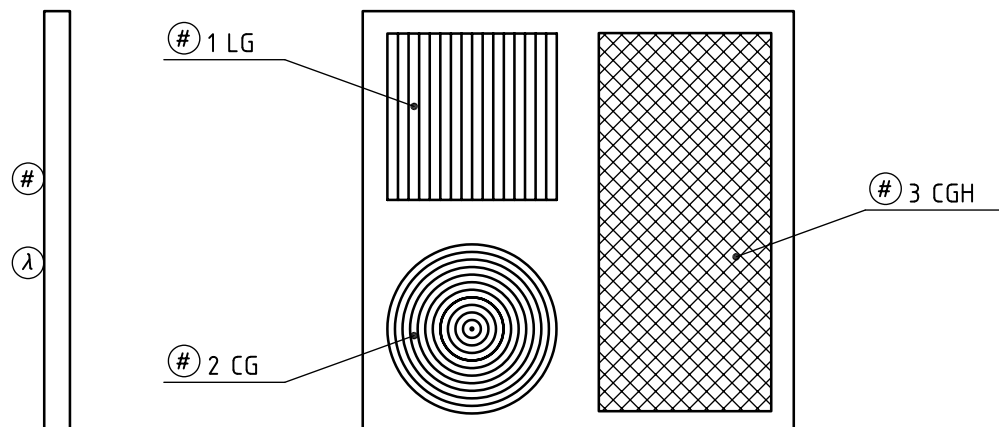


Figure 5 — Hatching, numbering and classification of several diffractive structures on drawings

5.4 Test regions

A diffractive test region is the applicable part of a diffractive region, where the desired specifications have to be valid. The optical surface containing diffractive structures may be subdivided in several zones: Within the whole optical surface of the substrate smaller test regions may be defined. Within a test region smaller coating regions can be located. Within a coating region smaller coating test regions may be defined. Within a coating test region smaller diffractive regions can be located. And within a diffractive region smaller diffractive test regions may be defined. Therefore, it may be necessary to create several drawings. For example:

- a drawing of the substrate with test regions and their specifications;
- a coating drawing with coated regions, coating test regions and their specifications;
- a diffractive drawing with diffractive regions, diffractive test regions and their specifications.

Each diffractive region has to be hatched in the face view (for example see [Figure 5](#)) and may be verified by measurements. Test regions inside the diffractive regions shall not be hatched differently for better clarity (see [Figure 6](#)). The diameter of a circular diffractive region is called diffractive diameter and may be indicated in drawings as $\varnothing_{\#}$.

The diameter of the effective aperture is called effective diameter and may be indicated in drawings as $\varnothing_e$. If no further test regions are specified, then $\varnothing_e$ shall be the diameter of the diffractive test region. (see ISO 10110-1:2019, 5.6)

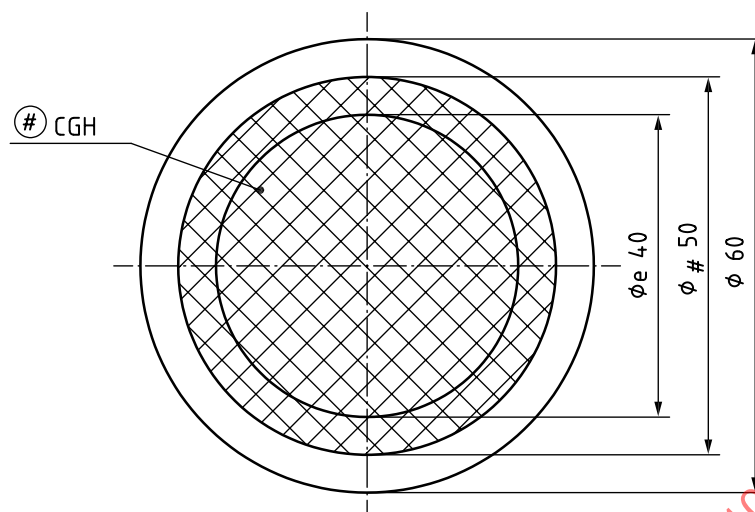


Figure 6 — Indication of the diffractive region and corresponding diffractive test region

The coordinate origin of the diffractive structure shall be indicated on the drawing. If the coordinate origin of the diffractive structure is not the origin of the base surface, then a calculation rule shall be given on the drawing to enable an unambiguous transition from one coordinate system into the other (see [Table 1](#)).

The component references shall be marked and dimensioned to the coordinate system of the diffractive structure.

If there is a mathematical description of the diffractive structure, it shall be indicated on the drawing with respect to the diffractive coordinate origin. This shall be either the exact mathematical formula of the diffractive structure or the reference to a data file. An example for this can be seen in the [B.2](#). In this example the drawing consists of two sheets. It is recommended to distribute complex information onto several sheets.

5.5 Technological parameters:

All necessary geometry parameters to specify the diffractive surface shall be indicated on the drawing or in the data file (for example: edge radii or flange slope of a diffractive structure).

Please note, that it is not recommended to specify any tooling parameter (for example: the tip radius of the diamond-turning tool). The surface geometry should be specified directly and independent from the manufacturing method.

If a particular technology is mandatory for the manufacturing of diffractive structures, the technology may be named and specified on the drawings. One example is the intended sequence of substrate-coating-structuring. Direct writing or replication from a master part is another example which may be marked on the drawing. The diffractive surface may be represented in an exaggerated manner on the drawing to illustrate these factors. The part shall be marked accordingly. The sequence of the symbols in the table on the drawing determines the technological sequence of the surface modification steps.

5.6 Specification of the substrates

5.6.1 Specification of surface form tolerances

Surface form tolerances shall be specified in accordance with ISO 10110-5 (code number 3/).

It shall be noted, that in accordance with ISO 10110-1 the following applies: Unless specified elsewhere, the omission of a permissible deviation or material imperfection from the drawing shall indicate that

the provisions of ISO 10110-11 apply. By definition none of the GPS defaults, including the decision rules, apply unless specifically invoked in ISO 10110.

When using the ISO 10110-5 code number 3/ it is mandatory to indicate the surface and test region where the form tolerance holds. If nothing else is written on the drawing, the surface form tolerance always holds for the diffractive surface.

5.6.2 Specifications for wave front deformation tolerances

Wave front deformation tolerances shall be specified in accordance with ISO 10110-14.

NOTE According to ISO 10110-14, it is possible to specify only one tolerance for the deformation of the wave front without any need to specify tolerances for individual diffractive surfaces.

5.6.3 Specification of other optical tolerances

All other optical tolerances, e.g. centring, imperfections, roughness, etc., shall be specified using the notations described in ISO 10110-1 and the other parts of the ISO 10110 series, as necessary.

6 Data exchange

Uniform transport formats (e.g. XML, STEP) shall be used for transfer of diffractive surface data between software systems and processing and measuring machines. When using the transport formats, it shall be ensured that all the diffractive surface data, including forms of mathematical description, coordinate system, and reference are reliably mapped. When transferring data, it shall be ensured that the data import includes all significant decimal digits and uses the correct unit of measure.

At least one sagitta table shall be specified to test the transferred surface description. Depending on the combination of the base surface and the diffractive structure it may be necessary to specify more than one sagitta table (see 4.2). For example, one sagitta table describes the base surface, whereas another table indicates the diffractive structure. Each sagitta table shall have an unique title to identify the mathematical formula from where the table entries are calculated.

It is recommended that the coordinate system which is used to calculate the sagitta table has the same symmetry compared to the mathematical description as the diffractive surface itself. If the diffractive surface is described with xy polynomials, then the sagitta table shall use Cartesian coordinates (see Table 6). If Zernike Polynomials or other rotationally invariant polynomials are used, then the sagitta table shall use Polar coordinates (see Table 7). The corresponding nominal values for z shall be specified using (x, y) or (ρ, φ) coordinates. Here, it shall be ensured that the specification of both of these values is made with sufficient accuracy. In general, the following will hold for z . The maximum deviation of the values after the data is transferred should be carefully determined.

NOTE 1 For example, the following criteria are recommended:

- 1/100 of the smallest peak-to-valley value; or
- 1/10 of the smallest RMS requirement on this surface.

NOTE 2 The specifications of the sagitta table are necessary, but not sufficient to completely describe the diffractive surface.

Table 6 — Example of a sagitta table in Cartesian coordinates

x	y	z
0,0	0,0	5,213 218
5,0	0,0	7,231 564
5,0	5,0	3,201 487
..	..	..

Table 7 — Example of a sagitta table in polar coordinates

ρ	φ	z
0,0	0,00°	3,346 545
5,0	1,57°	1,357 573
5,0	3,14°	2,346 239
..	..	..

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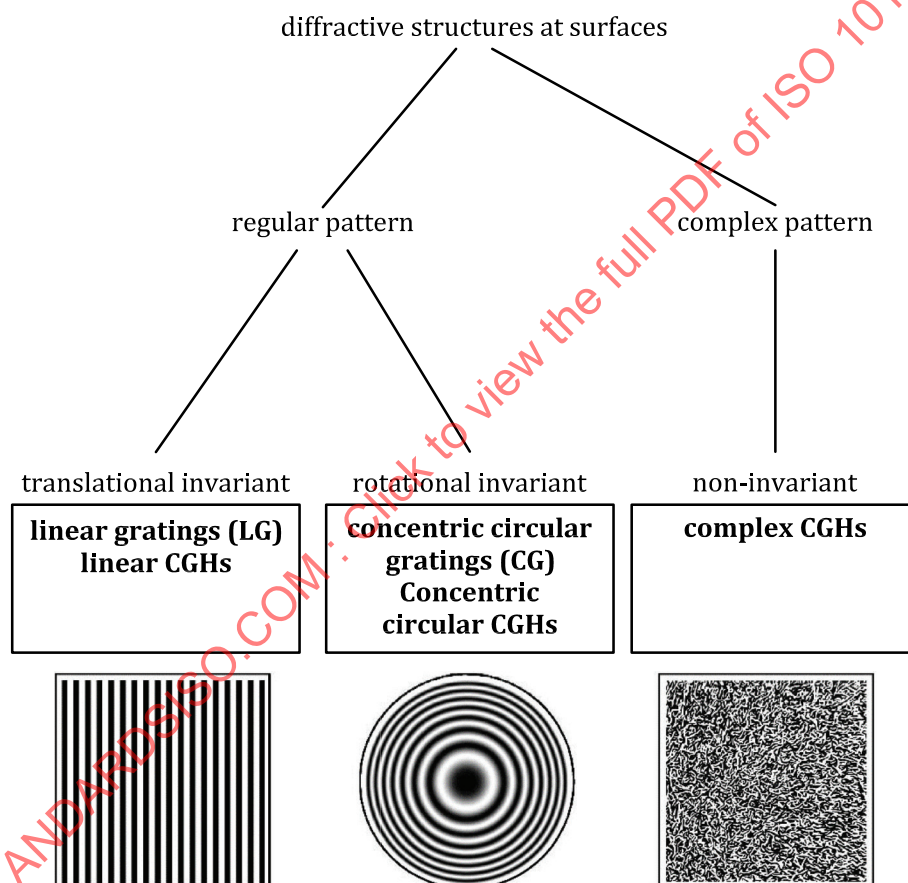
Annex A (informative)

Classification of diffractive structures

Diffractive structures for optical applications exist in many geometric configurations.

ISO 15902 defines the basic terms for diffractive optical elements for free space propagation. However, from a geometric point of view ISO 15902 does not provide a systematic classification of the various diffractive structures.

[Figure A.1](#) therefore gives a classification scheme to allocate the terms used within this document according to its geometric configuration.



NOTE There are also non-equally spaced translationally and rotationally invariant structures.

Figure A.1 — Classification scheme of diffractive structure optical elements

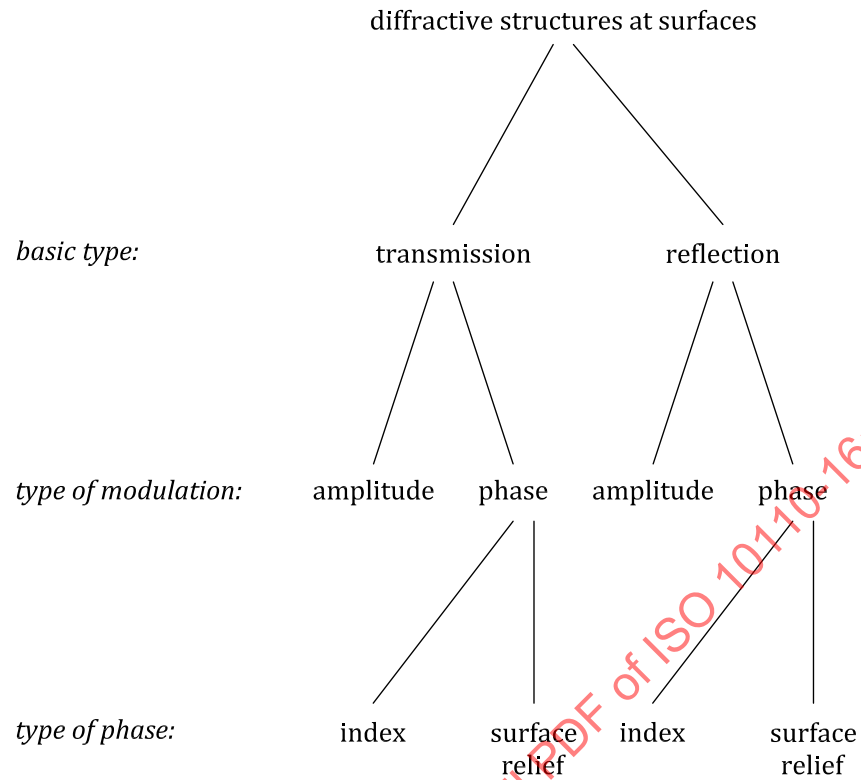


Figure A.2 — Classification scheme of diffractive structures

Annex B (informative)

The three most important types of diffractive structures

B.1 Linear diffractive structures

B.1.1 Definition, basics and types

Linear diffractive structures consist of very small straight parallel equal lines or grooves in or on the surface of an optical component, which are in a scale near to the wavelength of light, using the wave properties of the light and working with diffraction and interference. They are regular, periodic and translationally invariant, therefore they can be called linear diffraction gratings or shortened to linear gratings. They are mostly situated at plane surfaces, but they also may be realized at spherical or cylindrical surfaces with large radii for a more compact design and more efficient correction of optical aberrations of an optical system.

The optical component “plate with linear grating at one surface” is commonly also called “linear diffraction grating” or “linear grating”, also if both optical surfaces are curved with a very large radius. A prism with a linear grating at one surface is called “linear diffraction prism”, “diffraction prism” or “grism”. Linear gratings are used for spectroscopy in analytical measurement, diffractive beam splitters, external laser resonators and wavelength multiplexing in telecommunication.

Regarding the direction of diffracted light, linear gratings are classified into reflection gratings (RG) and transmission gratings (TG). Regarding physics, they are classified into amplitude gratings (AG) and phase gratings, which are further subclassified into surface relief gratings (SG), and index gratings (IG). Each type has advantages and disadvantages for various applications.

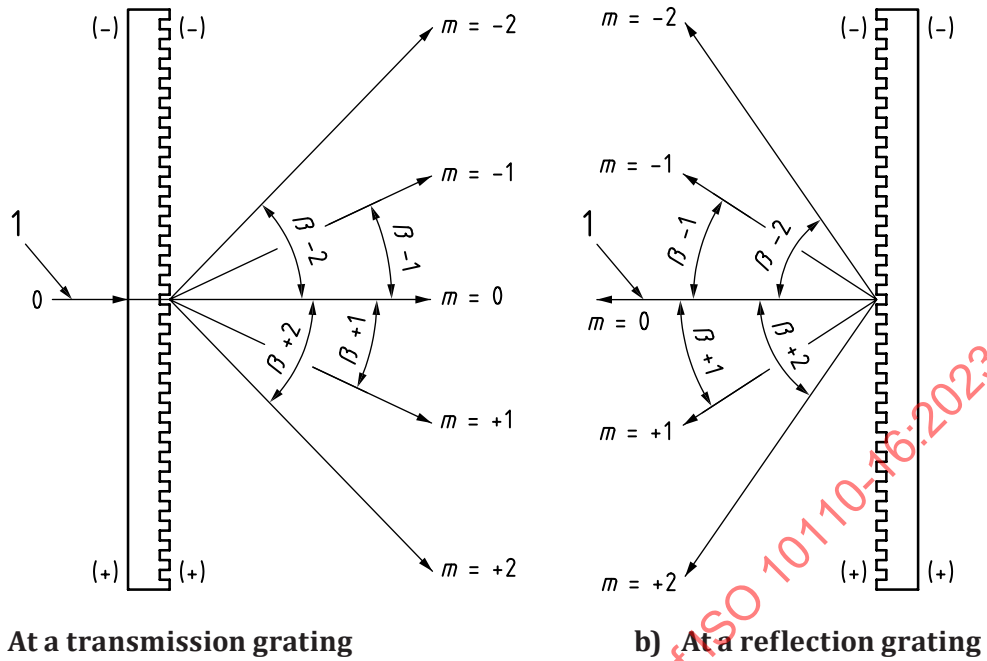
Diffraction gratings work through diffraction and superposition of lightwaves coming from the grooves or gaps of the grating, this is called interference of light. After passing the linear grating, the elementary lightwaves coming from gaps or grooves cause a pattern of stripes with maxima and minima, depending on the angle of incidence α , the wavelength of light, λ , and the grating period, Λ (distance between two adjacent lines or grooves). The reciprocal value of Λ is the spatial frequency, N (also called grating resolution, line density or groove density). The maxima are called orders of diffraction (see [Figures B.1 and B.2](#)). The 0th order of diffraction is the regularly reflected or transmitted light, the next maximum left or right is the first order of diffraction, then the second order and so on may follow. Maxima form at such angles, where the differences of the lightwaves coming from gaps or grooves are integer number multiples of the wavelength of light. The angle between the axis of incidence and the number of maxima m is called diffraction angle β with index, m . At perpendicular incidence of light ($\alpha = 0$) applies the following simplified [Formula \(B.1\)](#):

$$\sin \beta_m = (\lambda \cdot m) / \Lambda \text{ or } \sin \beta_m = \lambda \cdot m \cdot N \quad (\text{B.1})$$

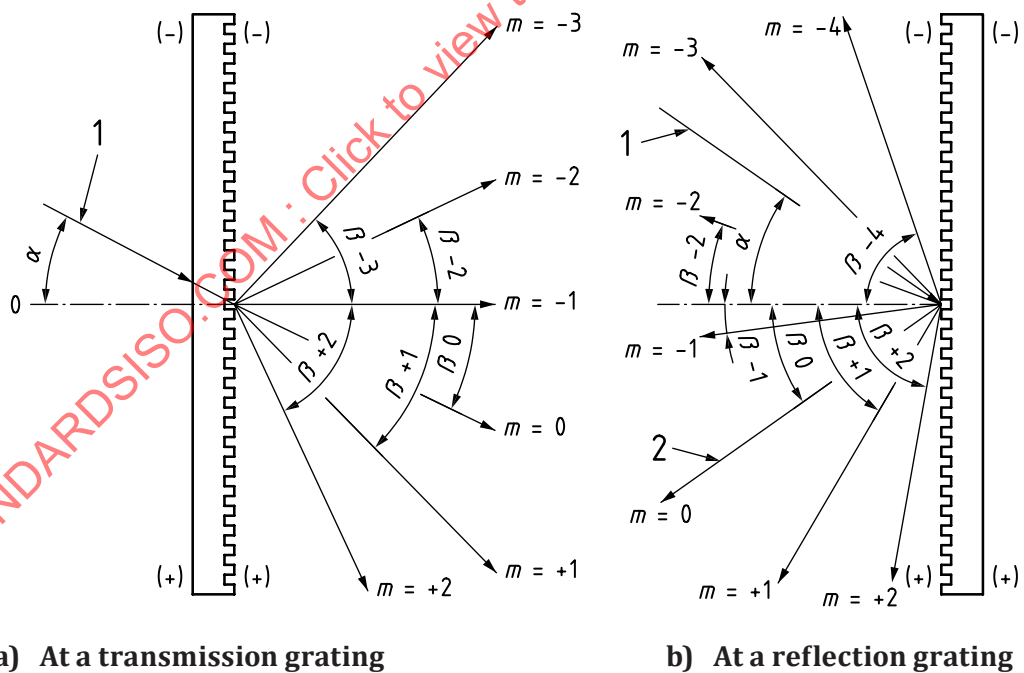
Otherwise with any given incident angle α applies the following [Formula \(B.2\)](#):

$$\sin \alpha + \sin \beta_m = (\lambda \cdot m) / \Lambda \text{ or: } \sin \alpha + \sin \beta_m = \lambda \cdot m \cdot N \quad (\text{B.2})$$

NOTE This sign convention differs from ISO 15902. However, it is widely used in literature and provides the simplest description of the formulae. For example, using this sign convention, the same formulae can be used for transmission and reflection gratings. For more information, see Reference [\[11\]](#).

**Key**

1 incident beam

Figure B.1 — Diffraction orders at perpendicular incidence of light ($\alpha = 0$)**Key**

1 incident beam

2 reflected beam

Figure B.2 — Diffraction orders at non-perpendicular incidence of light ($\alpha < 0$)

Most users want to achieve a great angular resolution and a high amount of light in one desired order of diffraction. This is called high diffraction efficiency. This can be realized by a non-symmetric triangular

profile of the lines. Such linear gratings are called blazed gratings. The angle between the former smooth surface of the substrate (base surface) and the tilted flanks of the triangular grating profile is called blaze angle θ_B . The right blaze angle for maximum diffraction efficiency depends on the desired incident angle, and the desired diffraction angle at a desired wavelength of diffraction (called blaze wavelength, λ_B). A diffraction efficiency of more than 90 % can be achieved at the blaze wavelength. The right blaze angle for a wider wavelength range is always a compromise, and the average diffraction efficiency for an extended wavelength range is always lower than the diffraction efficiency at the blaze wavelength. A linear diffraction grating without any indication of blaze angle and blaze wavelength is always symmetric.

The optimum profile of grating grooves and grating lines for a given arrangement of imaging can be calculated by computer programs, but it cannot always be fully realized by the producing technologies. Regarding profile type, linear diffraction gratings can be classified into two types: rectangular gratings and sinus gratings. A non-symmetric rectangular profile is often called saw-tooth profile. Profile imperfections and slight random deviations of the line paths decrease the diffraction efficiency. Tiny local defects cause scattering of light. A good quality of a linear diffraction grating means a high diffraction efficiency and very low scattered light.

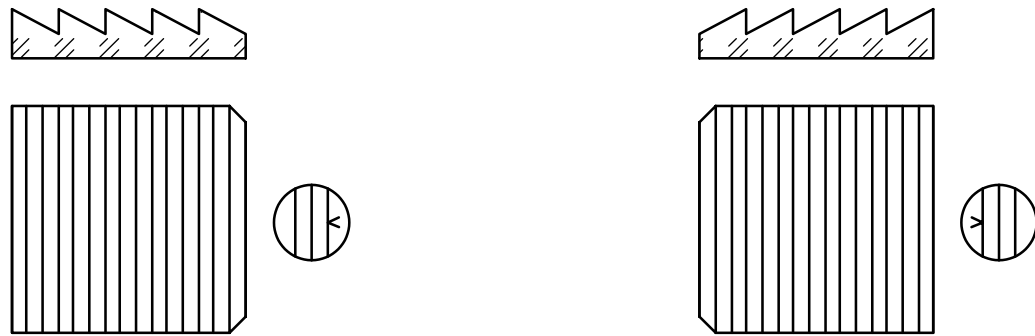
B.1.2 Presentation in drawings, required specifications and indications

For the presentation of the substrates (sometimes called blanks) and the coatings of the linear diffraction gratings all usual drawing standards are valid. Often it is necessary to create separate drawings for the polished substrate, the coated substrate and the structured optical element. In the face view, the diffractive area of a linear grating has to be shown as a linear hatch in the technical drawing, surrounded by a small continuous line. The lines of the hatch shall be drawn parallel to the tiny lines or grooves of the linear grating, they shall indicate the direction of the diffractive lines and grooves. A horizontal or vertical position of the lines shall be preferred.

It is permitted to specify an angle including a tolerance between the direction of the tiny grating lines and a straight datum surface or datum edge. However, in CAD software, this angle cannot be indicated directly at the hatch lines. Therefore, the datum has to be marked as usual with a capital letter, and the angle including a tolerance has to be indicated in the table field with the specifications of this diffractive structure. In the context of linear diffraction grating, this angle is defined with the symbol Ψ with an index of the capital letter, which marks the datum.

In face view from each diffractive area one small straight continuous tilted line (non-horizontal and non-vertical) shall guide across the surface to the outside of the optical component. At the outer end of this line a small short horizontal continuous line has to begin. Above this line the symbol of diffractive structure has to be written: # in a small circle, followed by the abbreviation LG for linear grating. If there is more than one diffractive area on the component, an identity number beginning from one shall follow directly. See also [Figure 5](#).

At blazed linear gratings (non-symmetric profile of the grating lines) the direction towards the rising flanks (across the lines) shall be indicated by the symbol > or <. This symbol has to be set beside the face view outside at 3 small short lines in parallel to the hatch (marking the direction of the tiny grating lines), surrounded by a circle, like a detail (See [Figure B.3](#)). Components with blazed linear gratings shall have either a non-symmetric shape or any kind of mark to indicate the rising blaze direction to ensure a correct assembling.



NOTE The two cut corners serve as marks to ensure the correct assembling.

Figure B.3 — Indication of the rising blaze direction of a non-symmetric linear grating
(exaggerated principle presentation)

- In the first text line after the diffractive symbol the following classification shall be indicated:
 - LG (linear grating = basic type of diffractive structure);
 - TG or RG (direction of diffracted light: transmission grating or reflection grating);
 - AG or SG or IG
(type of structure: amplitude grating or surface relief grating or index grating);
 - /rec or /sin or /tri or /tsi (profile type, written directly after the type of structure: rectangular profile or sinusoidal profile or triangular profile or truncated sinusoidal profile);
- If desired: basic type of technology: “ruled grating” or “embossed grating” or “replicated grating” or “lithographical grating”.
- If desired: either “master” or “first-order replica” or “second-order replica”.
- If desired: nonverbal technology code or additional information about technology.
- Spatial frequency, N , in lines/mm or grating period, Λ , either in nm or in μm .
- For amplitude gratings: either gap-line ratio or duty cycle D (ratio of gap to grating period).
- For blazed gratings: blaze angle, θ_B , in degrees.
- For blazed gratings: blaze wavelength, λ_B , in nm (at incident angle α in degrees; at an angle of diffraction β_m).
- Used wavelength range in nm (from minimum wavelength to maximum wavelength).
- Minimum diffraction efficiency, η , in %, (at wavelength λ ; at incident angle α ; at diffraction angle β_m) (multiple indications are possible, the method of measuring may be added in the following text line).
- Average diffraction efficiency, η_{AV} , at a defined wavelength range (method of measurement may be added in the following text line).
- Maximum of light scattering in ppm (method of measurement may be added in following text line; indications about permitted structural defects and permitted scale division errors are possible, but not recommended. The indication and measurement of the resulting functional properties of diffraction efficiency η and light scattering is preferred.).
- If necessary: damage threshold either in kW/cm^2 or MW/cm^2 (with addition: CW or pulsed)
- If necessary: angle ψ_A between the grating lines and a straight reference surface or reference edge A (The reference edge A shall be marked with a capital in the face view).

Finally two very special types of linear gratings shall be mentioned:

- a) There are so-called cross gratings, where straight grating lines cross each other. In this case the grating type “cross grating” has to be inserted as second text line. The several directions of grating lines cause a cross-hatch in face view, each has to be indicated with a number of direction k starting with 1. As result there are several angles ψ_{Ak} (k is the number of direction). If grating period and grating profile of the directions are different, they have to be indicated separately one below the other in the text field.
- b) There are so-called chirp gratings, where the spatial frequency of the linear grating changes with a function on both sides starting from the middle line. In this case the grating type “chirp grating” has to be inserted as second text line, and instead of a constant spatial frequency, N , either a variable spatial frequency $f(d)$ as a function of the distance, d , from the middle line or a data file name has to be indicated.

(More complex types of linear diffraction gratings shall be regarded as CGH.)

B.1.3 Examples of drawings

See [Figures B.4](#) and [B.5](#).

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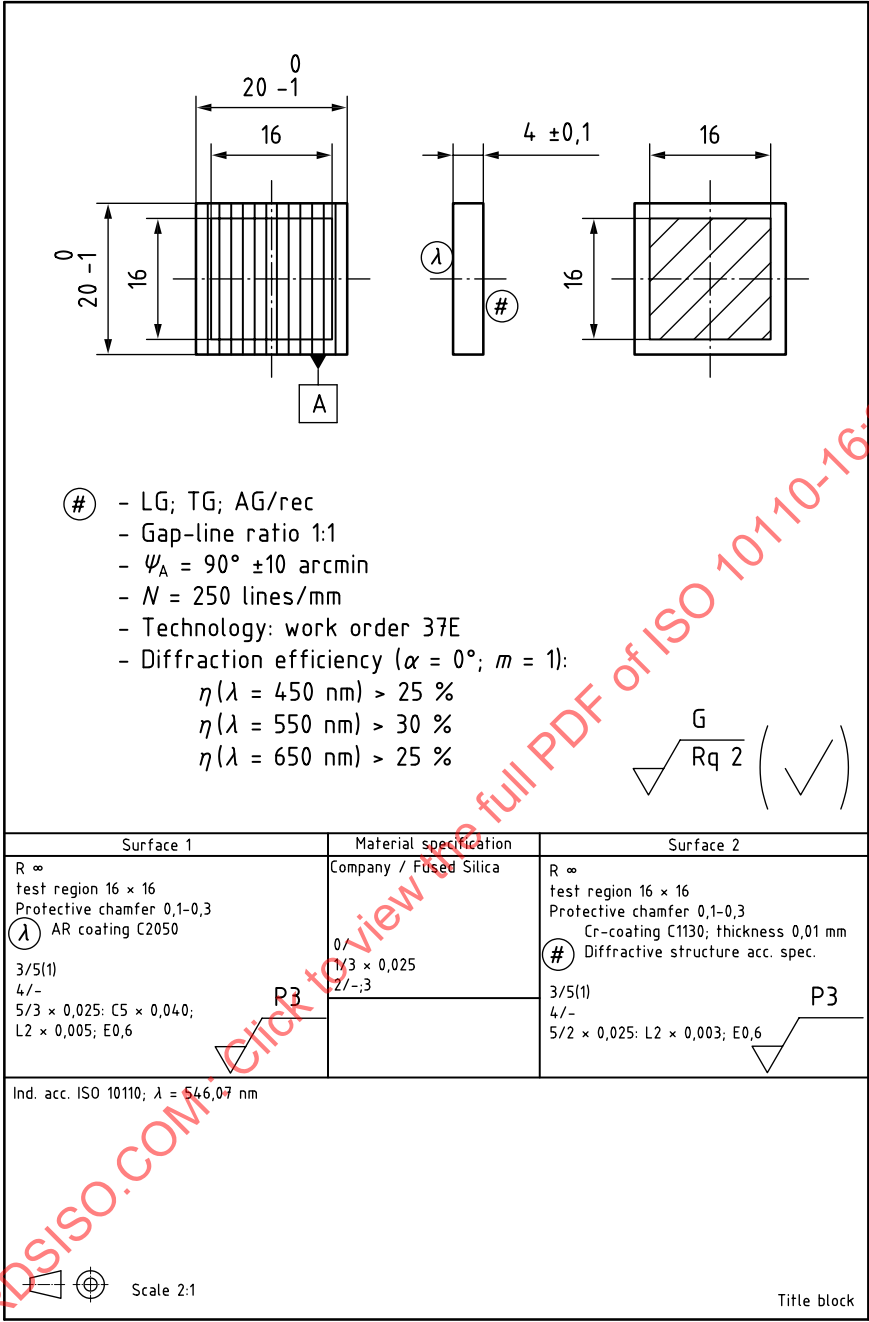


Figure B.4 — Example: linear diffraction grating

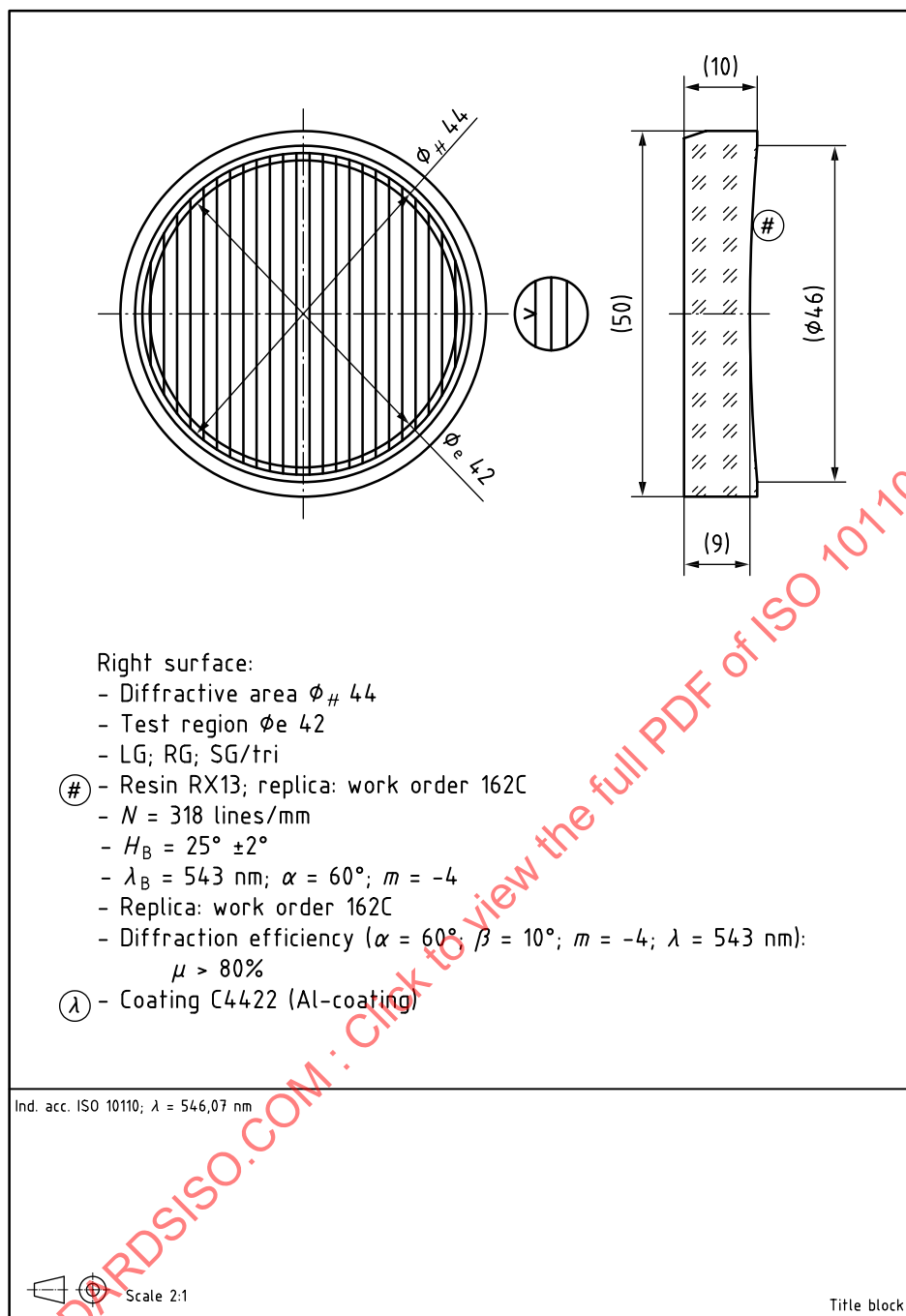


Figure B.5 — Example: blazed diffraction grating on curved base surface

B.2 Concentric circular diffractive structures (ring gratings)

B.2.1 Definition, basics and types of concentric circular diffractive structures

Concentric circular diffractive structures have a rotationally invariant profile and consist of concentric circular lines or grooves. These lines or grooves are not equal, but can be calculated and described mathematically, therefore they are called circular diffraction gratings or shorter circular gratings (CG), and sometimes they are called ring gratings.