INTERNATIONAL STANDARD

ISO 12181-2

First edition
2011-04-01

Geometrical product specifications (GPS) — Roundness —

Part 2:
Specification operators

Spécification géométrique des produits (GPS) — Circularité —

Partie 2: Opérateurs de spécification

Reference number
ISO 12181-2:2011(E)

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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.

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 12181-2 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This first edition of ISO 12181-2 cancels and replaces ISO/TS 12181-2:2003, which has been technically revised.

ISO 12181 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Roundness*:

— *Part 1: Vocabulary and parameters of roundness*

— *Part 2: Specification operators*

Introduction

This part of ISO 12181 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences chain link 3 of the chain of standards on form of line independent of datum.

The ISO/GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO/GPS system of which this document is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

For more detailed information on the relationship of this part of ISO 12181 to other standards and the GPS matrix model, see Annex B.

This part of ISO 12181 specifies the specification operators according to ISO 17450-2 for roundness of integral features.

This part of ISO 12181 does not specify defaults for filter UPR, probe tip radius and method of association (reference circle). This means that it is necessary for a roundness specification to explicitly state which values are to be used for these specification operations in order for it to be unique.

Consequently, if a specification does not explicitly state which values are to be used for one or more of these operators, the specification is ambiguous (see ISO 17450-2) and a supplier can use any value for the operator(s) not specified when proving conformance.

Extracting data always involves applying a certain filtering process. An additional filtering of the extracted data might or might not be applied. This additional filter can be a mean line filter (Gaussian, spline, wavelet, etc.) or a non-linear filter (e.g. morphological filter). The type of filtering influences the definition of roundness and the specification operators and, therefore, needs to be stated unambiguously.

NOTE 1 Stylus filtering is not sufficient on its own to smooth a profile. In certain circumstances, it can create spurious high-frequency content, thus giving incorrect values. To correct this, a longwave pass filter is employed. A Gaussian filter is used, since this is the state-of-the-art. This filter has some shortcomings, e.g. it can distort, rather than eliminate some roughness features and it can distort, rather than transmit correctly some waviness features. It is envisioned that new filters under development within ISO provide better solutions for several of these issues.

NOTE 2 If a smaller tip radius than the one specified is used for a given cut-off length, the resulting measured value is generally higher. This effect is usually insignificant. If a larger tip radius is used, the resulting measured value is generally lower. The amount of change is heavily dependent on the surface measured.

NOTE 3 The measuring force of zero N is chosen to eliminate effects of elastic deformation of the workpiece from the specification operator. On metal surfaces with adequate thickness, the effect of normally occurring measuring forces is negligible.

NOTE 4 Aliasing and other problems during extraction (see Annex A) due to the higher harmonic content of the skin model, in the roundness directions, can cause specification uncertainty.

This part of ISO 12181 is not intended to disallow any means of measuring roundness.

Geometrical product specifications (GPS) — Roundness —

Part 2:
Specification operators

1 Scope

This part of ISO 12181 specifies the complete specification operator for roundness of integral features only and covers complete roundness profiles only, i.e. geometrical characteristics of features of the type circle.

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 11562:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Metrological characteristics of phase correct filters*

ISO 12181-1:2011, *Geometrical product specifications (GPS) — Roundness — Part 1: Vocabulary and parameters of roundness*

ISO 14253-1:1998, *Geometrical Product Specifications (GPS — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformance or non-conformance with specifications*

ISO 17450-2:2011[1)], *Geometrical product specifications (GPS) — General concepts — Part 2: Basic tenets, specifications, operators and uncertainties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12181-1 and ISO 17450-2 apply.

4 Complete specification operator

4.1 General

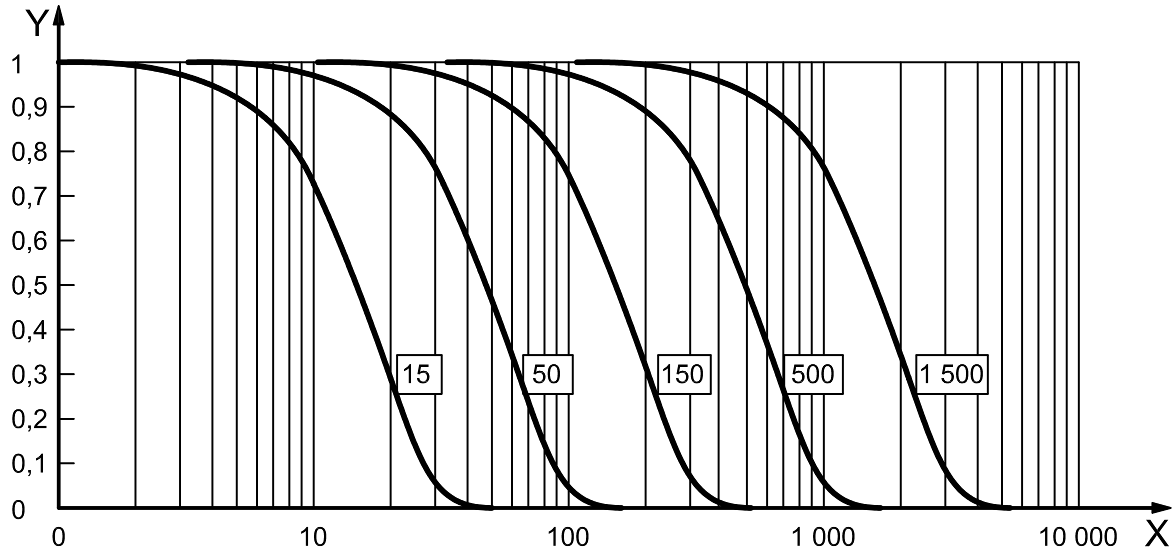
The complete specification operator (see ISO 17450-2) is a full ordered set of unambiguous specification operations in a well-defined order. The complete specification operator defines the transmission band for the roundness profile, together with an appropriate stylus tip geometry.

1) To be published. (Revision of ISO/TS 17450-2:2002)

4.2 Transmission band

4.2.1 Longwave-pass filter

The longwave-pass filter shall be a phase correct filter (in accordance with ISO 11562), transmitting waves from 1 UPR and attenuating profile undulations progressively in the undulation region around the cut-off frequency (in UPR) (see Figure 1).



Key

X undulations per revolution (UPR)

Y transmission

NOTE Other filter values than those shown in this figure can be used, if necessary for the application.

Figure 1 — Transmission characteristic for longwave-pass filter having cut-off frequencies f_c = 15 UPR; 50 UPR; 150 UPR; 500 UPR; 1 500 UPR

The attenuation function is given by Equation (1):

$$\frac{a_1}{a_0} = e^{-\pi\left(\frac{\alpha \times f}{f_c}\right)^2} \qquad (1)$$

where

$$\alpha = \sqrt{\frac{\ln(2)}{\pi}} = 0,469\,7$$

a_0 is the amplitude of sine wave undulation before filtering;

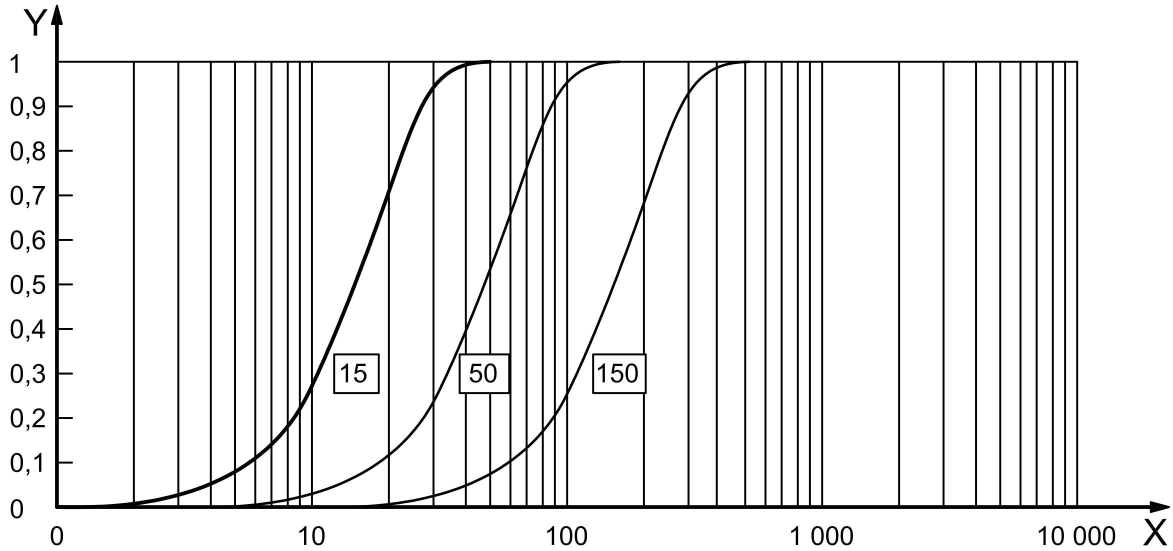
a_1 is the amplitude of this sine wave undulation after filtering;

f_c is the cut-off frequency, in undulations per revolution, of the longwave-pass filter;

f is the frequency of the sine wave, in undulations per revolution.

4.2.2 Shortwave-pass filter

The shortwave-pass filter shall be a phase correct filter (in accordance with ISO 11562), attenuating waves from 1 UPR up to the cut-off frequency (in UPR). It transmits undulations shorter than the cut-off frequency (in UPR) (see Figure 2).



Key

X undulations per revolution (UPR)

Y transmission

NOTE Other filter values than those shown in this figure can be used, if necessary for the application.

Figure 2 — Transmission characteristic for shortwave-pass filter having cut-off frequencies f_c = 15 UPR**;** 50 UPR**;** 150 UPR

The attenuation function is given by Equation (2):

$$\frac{a_2}{a_0} = 1 - e^{-\pi\left(\frac{\alpha \times f}{f_c}\right)^2} \quad (2)$$

where

$$\alpha = \sqrt{\frac{\ln(2)}{\pi}} = 0,469\,7$$

a_0 is the amplitude of sine wave undulation before filtering;

a_2 is the amplitude of this sine wave after filtering;

f_c is the cut-off frequency, in undulations per revolution, of the longwave-pass filter;

f is the frequency of the sine wave, in undulations per revolution.

4.2.3 Limiting UPR values

The wave filter determines the range of periodic sinusoidal undulations per revolution (UPR) of the feature included in the roundness assessment. The range is terminated by values taken from Table 1. Table 1 also gives the minimum number of sample points that shall be used for the extracted circumferential line and the minimum ratio between the feature diameter and the tip radius (d:r) needed to avoid distortion of the roundness profile from the influence of the stylus tip.

Table 1 — Limiting values of UPR

Longwave-pass filters		
Filter transmitting from 1 UPR to	Minimum number of sample points	Minimum d:r ratio[a]
15	105	5
50	350	15
150	1 050	50
500	3 500	150
1 500	10 500	500

[a] The d:r ratio is the ratio between the diameter, d, of the reference circle and the radius, r, of the stylus tip. If the d:r ratio is less than the value stated, the high UPR undulations of the feature within the transmission band are distorted by the influence of the stylus tip.

If a shortwave-pass filter is specified, a longwave-pass filter shall also be specified in conjunction therewith, in order to have a well-defined UPR transmission band.

NOTE 1 A characteristic of both analogue and digital wave filters is that the ratio is dependent only on the wavelength, and it is independent of amplitude, in contrast to mechanical filtering methods (for example by the stylus) which are influenced by wavelength and also by amplitude.

NOTE 2 If a longwave-pass filter is not specified, the assessed roundness deviations are not comparable. The tip radius then often acts as an undefined longwave-pass filter. In many measuring instruments, this is a built-in maximum longwave-pass filter which reacts if no other settings are made.

The number of samples and minimum d:r ratio indicated for the longwave-pass filter apply.

EXAMPLE If a transmission band of 50 UPR to 500 UPR is employed, 3 500 samples and a d:r ratio of at least 150 are used. If the longwave-pass filter is not specified, a 1 500 UPR filter is used.

NOTE 3 When the d:r requirement is fulfilled, the radius of the stylus tip is of comparable size to the wavelength of the shortest undulations transmitted by the wave filter. This is consistent with the stylus tip radius requirements for surface texture measuring instruments (see ISO 3274).

4.3 Probing system

4.3.1 Probing method

A contacting probing system with a stylus tip, as defined in 4.3.2, is part of the specification operator.

4.3.2 Stylus tip geometry

The theoretically exact stylus tip geometry is a sphere.

4.3.3 Probing force

The probing force is 0 N.

5 Compliance with specification

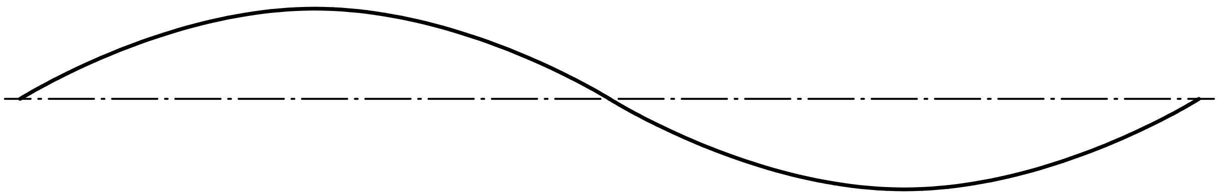
For proving conformance or non-conformance with specification, ISO 14253-1 applies.

Annex A
(informative)

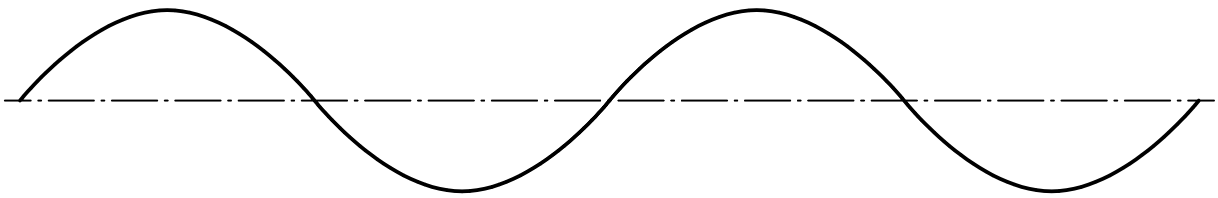
Harmonic content of nominally round workpiece

A.1 Harmonic content

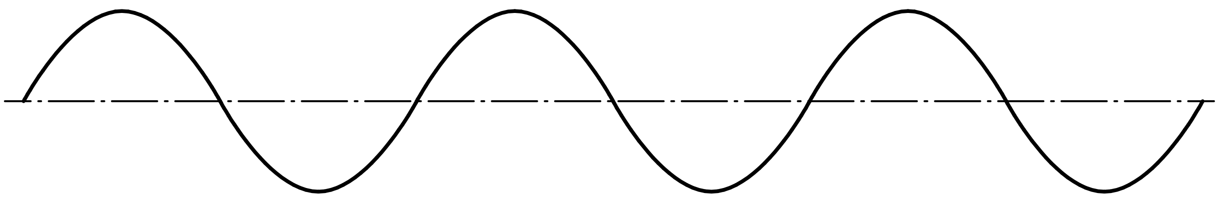
A finite length signal can be decomposed into a number of sinusoidal components called a Fourier series. A Fourier series consists of a fundamental sinusoid whose wavelength is the length of the signal and harmonic sinusoids, whose wavelengths divide into the fundamental wavelength a whole number of times. The fundamental sinusoid is called the first harmonic of the signal. The sinusoid whose wavelength is half the fundamental wavelength is called the second harmonic. The sinusoid whose wavelength is one third the fundamental wavelength is called the third harmonic and so on (see Figure A.1). Thus, the nth harmonic is that sinusoid whose wavelength divides into the fundamental wavelength exactly n times.



a) First harmonic



b) Second harmonic



c) Third harmonic

Figure A.1 — First three harmonics of a signal

A roundness profile is slightly different in that the signal's start and end are joined together. Here, the fundamental wavelength of the Fourier series is the circumference of the circle or 1 undulation per revolution (UPR). The harmonics consist of the higher undulations per revolution (e.g. the second harmonic is the 2 UPR, the 3rd harmonic is the 3 UPR, etc.).

A.2 Aliasing and the Nyquist criterion

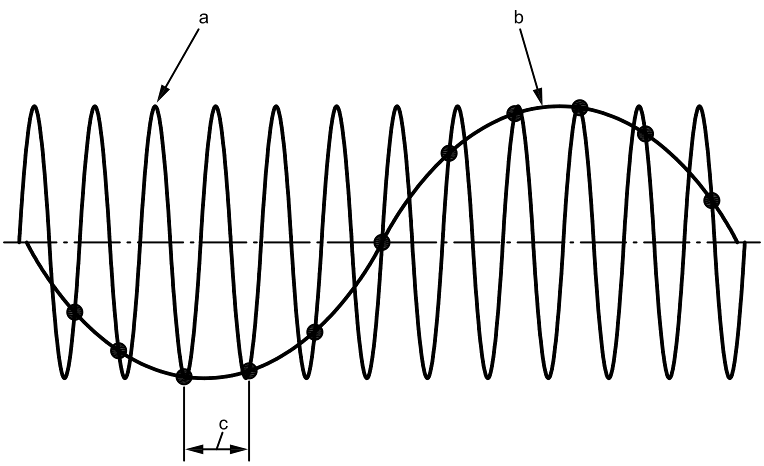
Recording digital data from a signal involves sampling that signal. The separation of the sampling points (the sampling interval) shall be chosen so that the digitized signal is representative of the original signal for the method by which the signal is being analysed.

If the original signal is bandwidth limited, in that there is a shortest wavelength present (highest harmonic) in the signal, then the Nyquist theorem imposes a limitation on the maximum sampling interval possible. The Nyquist theorem states:

> *If it is known that an infinitely long signal contains no wavelengths shorter than a specified wavelength then the signal can be reconstructed from the values of the signal at regularly spaced intervals provided that the interval is smaller than half of the specified wavelength.*

In principle, the Nyquist theorem only applies to infinitely long signals. In practice, the Nyquist criterion of sampling less than half of the shortest wavelength present is still useful even though signals are finite in length.

If a longer sampling interval than the Nyquist criterion is specified, the digitized signal suffers from aliasing distortion. Aliasing is when a short wavelength sinusoid appears to be a longer wave sinusoid due to the sampling interval being too large to define the true shape of the signal (see Figure A.2). Thus, if too large a sampling interval is chosen, the higher harmonics appear to be lower harmonics and distort any subsequent analysis.



a True signal.

b Alias signal.

c Sampling interval.

NOTE The sampling interval is too large to define the true shape of the signal.

Figure A.2 — Aliasing

In practice, many measuring instruments impose an artificial band limitation on the signal to overcome the problem of aliasing. There are many ways to achieve this artificial band limitation. Three common approaches are using the “natural” band limitation of the probe, analogue filters and digital filters or any combination of these. Usually, it is a combination of all three. Once the signal has a band limitation, the Nyquist criterion may be used to impose a theoretical maximum sampling interval as follows:

> Assuming all wavelengths less than the 0,02 % point of the Gaussian filter transmission curve can be ignored, then by applying the Nyquist theorem at least seven sampling points per cut-off are required. This represents the theoretical minimum number of sampling points per cut-off.

Annex B
(informative)

Relationship to the GPS matrix model

B.1 General

For full details about the GPS matrix model, see ISO/TR 14638.

The ISO/GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO/GPS system of which this part of ISO 12181 is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this part of ISO 12181 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 12181, unless otherwise indicated.

B.2 Information about this part of ISO 12181 and its use

This part of ISO 12181 specifies the complete specification operator for roundness, i.e. geometrical characteristics of features of type circle.

B.3 Position in the GPS matrix model

This part of ISO 12181 is a general GPS standard, which influences chain link 3 of the chain of standards on form of line independent of datum in the general GPS matrix, as graphically illustrated in Figure B.1.

Fundamental GPS standards

Global GPS standards

General GPS standards						
Chain link number	**1**	**2**	**3**	**4**	**5**	**6**
Size						
Distance						
Radius						
Angle						
Form of line independent of datum						
Form of line dependent on datum						
Form of surface independent of datum						
Form of surface dependent on datum						
Orientation						
Location						
Circular run-out						
Total run-out						
Datums						
Roughness profile						
Waviness profile						
Primary profile						
Surface defects						
Edges						

Figure B.1 — Position in the GPS matrix model

B.4 Related International Standards

The related International Standards are those of the chains of standards indicated in Figure B.1.

Bibliography

[1] ISO 3274, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments*

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

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

[4] ISO 4292, *Methods for the assessment of departure from roundness — Measurement by two- and three-point methods*

[5] ISO 8015, *Geometrical product specifications (GPS) — Fundamentals — Concepts, principles and rules*

[6] ISO 10360-1, *Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 1: Vocabulary*

[7] ISO/TR 14638, *Geometrical product specification (GPS) — Masterplan*

[8] ISO 14660-1, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

ICS 17.040.20

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