INTERNATIONAL STANDARD

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Geometrical product specifications (GPS) — Flatness —

Part 2:
Specification operators

Spécification géométrique des produits (GPS) — Planéité —

Partie 2: Opérateurs de spécification

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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 12781-2 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This first edition of ISO 12781-2 cancels and replaces ISO/TS 12781-2:2003, which has been technically revised.

ISO 12781 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Flatness*:

— *Part 1: Vocabulary and parameters of flatness*

— *Part 2: Specification operators*

Introduction

This part of ISO 12781 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 a surface (independent of a datum).

The ISO/GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO/GPS system of which this part of ISO 12781 is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this part of ISO 12781 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 12781, unless otherwise indicated.

For more detailed information on the relationship of this part of ISO 12781 to other standards and the GPS matrix model, see Annex C.

This part of ISO 12781 specifies the specification operators according to ISO 17450-2 for flatness of integral features.

ISO 12780-2 does not specify defaults for filter cut-off, probe tip radius and method of association (reference plane). This means that it is necessary for a flatness 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 flatness 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 can be 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 0 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 straightness directions, can cause specification uncertainty.

This part of ISO 12781 is not intended to disallow any means of measuring flatness.

Geometrical product specifications (GPS) — Flatness —

Part 2:
Specification operators

1 Scope

This part of ISO 12781 specifies the complete specification operator for flatness of complete integral features only, i.e. geometrical characteristics of individual features of type plane.

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 12781-1:2011, *Geometrical product specifications (GPS) — Flatness — Part 1: Vocabulary and parameters of flatness*

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:—[1], *Geometrical product specifications (GPS) — General concepts — Part 2: Basic temets, specifications, operators and uncertainties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12781-1 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 flatness surface, together with an appropriate stylus tip geometry.

NOTE In practice, it is unrealistic to achieve comprehensive coverage of the flatness feature given by the theoretical minimum density of points (see Annex B) within an acceptable time span using current technology. Therefore, more limited extraction strategies are employed that give specific rather than general information concerning the deviations from flat form.

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

4.2 Probing system

4.2.1 Probing method

A contacting probing system with a stylus tip, as defined in 4.2.2, is part of the specification operator.

4.2.2 Stylus tip geometry

The theoretically exact stylus tip geometry is a sphere.

4.2.3 Probing force

The probing force is 0 N.

5 Compliance with the specification

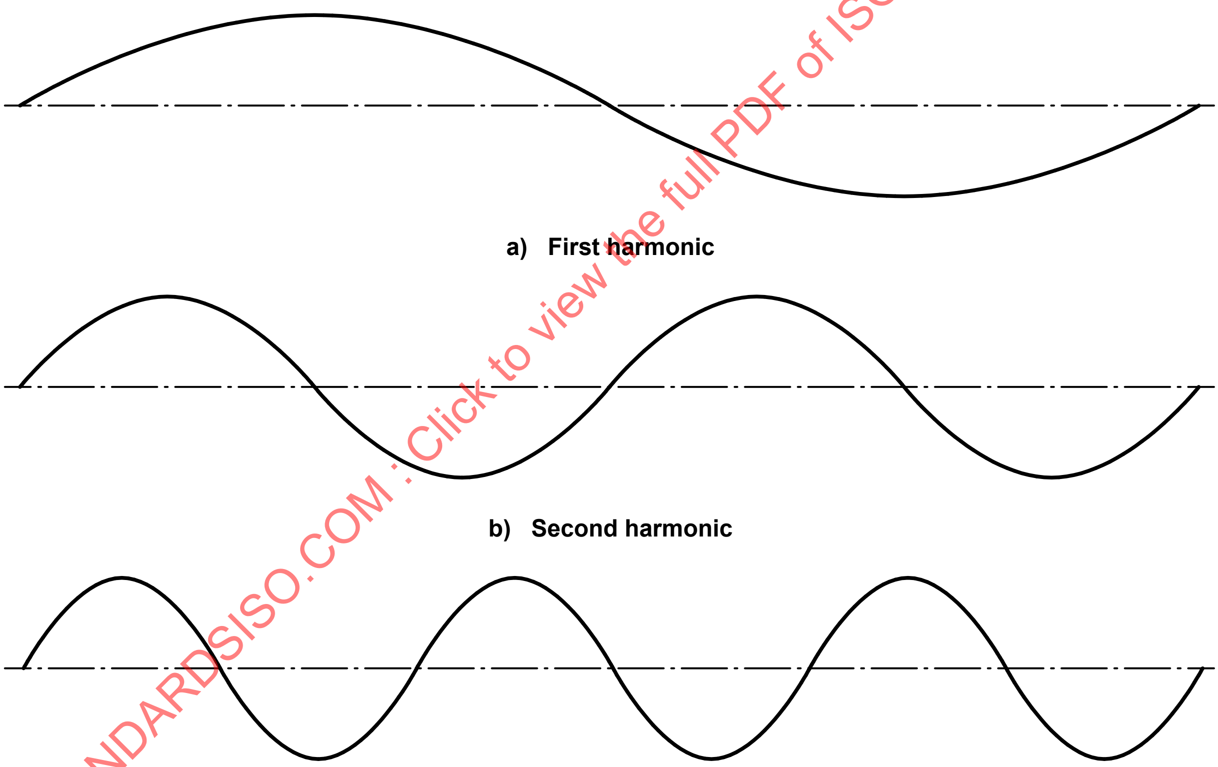
For proving conformance or non-conformance with the specification, ISO 14253-1 applies.

Annex A
(informative)

Harmonic content of a nominally flat workpiece and extraction strategy

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, etc. (see Figure A.1). Thus, the *n*th 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

All of the above signals decomposed into Fourier series are profiles, whereas the surface of a plane is an area. An area can be thought of as the combination of two profiles where the directions of the two profiles can be used to establish a coordinate system for the area. In the case of a plane, the two profiles are orthogonal to each other within the plane, with any position on the plane being located by giving its coordinates with respect to its distance in the direction of one profile and distance in the other profile's direction from an origin.

In a similar way, an area can be decomposed into a combination of two Fourier series. In practice, this area has a finite length in each of the two directions defined by the orthogonal profiles. Each individual component of this decomposition has two harmonic numbers; the first corresponds to the number of the harmonic in the direction of the first profile and the second number corresponds to the harmonic number in the direction of the second profile. The individual component is a combination of these two specified harmonic components.

For example the (6,4) harmonic consists of a term that is a combination of the sixth harmonic of the first profile (i.e. 6 waves across its length) and the fourth harmonic on the other profile (i.e. 4 waves along the other profile length). It is important to consider which of these harmonics are present on a feature of flatness when specifying an appropriate sampling strategy for assessment.

A.2 Aliasing and the Nyquist criterion

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

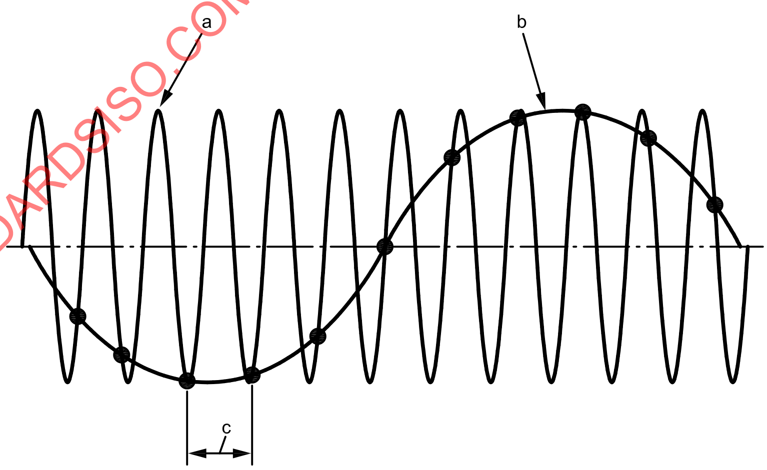
If the original signal is bandwidth limited, in that there is a shortest wavelength present (highest harmonic) in the signal, then the Nyquist theorem imposes a limitation on the maximum sampling interval possible. The Nyquist theorem states:

> *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.

The surface of a plane is an area and so the sampling intervals along the two defined orthogonal directions need to be specified. Again, the Nyquist criterion can be used to specify the sampling intervals in the two directions by considering the highest harmonic present in each direction.



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. Common approaches include “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 can be used to impose a theoretical maximum sampling interval as in the following:

> 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.

A.3 Harmonic content of a feature of flatness

An indication of the ability of each of the extraction strategies to assess harmonics as given in a) to f).

a) Rectangular grid extraction method

The main characteristic of the rectangular grid extraction strategy is a high density of points along both the orthogonal profiles. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in both directions relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness.

b) Polar grid extraction strategy

The main characteristic of the polar grid extraction strategy is a high density of points along both the radial and roundness profiles. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in both the radial and circumferential directions relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness that is nominally a disk.

c) Specified grid extraction strategy “triangular grid extraction strategy”

The main characteristic of the triangular grid extraction strategy is a high density of points along the profiles which define the “triangular grid”. Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy the ability to assess the harmonic content in the directions defining the triangular grid relative to the form content. Hence, this extraction strategy is recommended as the sampling strategy for the assessment of the total feature of flatness as an alternative to the rectangular grid and polar grid extraction strategies.

d) Specified grid extraction strategy “Union Jack extraction strategy”

Although this is not a full high-density coverage of the feature of flatness, it does give the extraction strategy a limited ability to assess the harmonic content in the directions defined by the “Union Jack” relative to the form content. This extraction strategy is limited by the small number of profiles used and the large areas not sampled. Hence, this extraction strategy should be used only if the longer wavelength content of the feature of flatness is negligible, where it is a quick extraction strategy. The rectangular, polar and triangular extraction strategies are recommended, before the Union Jack extraction strategy, as the sampling strategies for the assessment of the total flatness if the wavelength content of the surface is not known *a priori*.

e) Parallel extraction strategy

The main characteristic of the parallel extraction strategy is a higher density of points in the direction of the profile relative to the density of points orthogonal to the profile. This gives the extraction strategy the ability to assess very much higher harmonic information in the direction of the profile in comparison to harmonic information orthogonal to the profile. Hence, this extraction strategy is recommended only if high harmonic information is of interest in one direction compared to the direction orthogonal to it.

f) Points extraction strategy

The density of points is typically lower than with the other extraction strategies listed above. This restricts the ability to assess the harmonic content of a feature of flatness. The lower number of points also presents problems when filtering. It is for this reason that the points extraction strategy is not recommended unless only approximate estimates of the flatness parameters are required.

Annex B
(informative)

Extraction strategies

B.1 General

In order to obtain a reliable assessment of flatness form, an appropriate extraction strategy for obtaining a representative set of points on the workpiece is required. Of prime importance in determining an appropriate strategy is the harmonic content of the workpiece. This determines the theoretical minimum density of points to cover the workpiece.

In practice, it is often difficult to achieve a complete covering of the feature of flatness given by the theoretical minimum density of points. In these situations, more limited extraction strategies are employed that give specific rather than general information concerning the assessment of flatness form. These include the

— rectangular grid extraction strategy,

— polar grid extraction strategy,

— specified grid, e.g. “Union Jack” and triangular extraction strategies,

— parallel extraction strategy, and

— points extraction strategy.

When extraction is made by any of the above strategies, only a small number of sample points of the feature of flatness are considered. For this reason, and because of different instrument designs and specific implementations of the strategies, differences can occur in the measurement results unless care is taken to select a set of points which, for the purpose of the specific assessment, is adequate to represent the feature of flatness. A.3 describes the harmonic content of each sampling strategy, together with some recommendations on possible use, taking the harmonic content into account.

B.2 Rectangular grid extraction strategy

The extraction strategy consists of equally spaced straightness profiles in two orthogonal directions to form a grid (see Figure B.1).

B.3 Polar grid extraction strategy

The extraction strategy consists of equally spaced concentric circular profiles about a defined centre together with equally angled radial straightness profiles through the defined centre to form a polar grid (see Figure B.2).

B.4 Specified grid — Triangular grid extraction strategy

The extraction strategy consists of equally spaced straightness profiles in three directions 60° apart from each other to form a triangular grid (see Figure B.3).

B.5 Specific grid — Union Jack extraction strategy

The extraction strategy consists of a series of grids with three profiles in each direction together with two straightness profiles across the main diagonals of the grid to form a “Union Jack” (see Figure B.4).

NOTE This method can lead to disputes due to the lack of points on large surfaces.

B.6 Parallel profile extraction strategy

The extraction strategy consists of equally spaced straightness profiles in one specified direction to form a series of parallel profiles (see Figure B.5).

B.7 Points extraction strategy

The extraction strategy consists of points taken at random or patterned on the flatness surface (see Figure B.6).

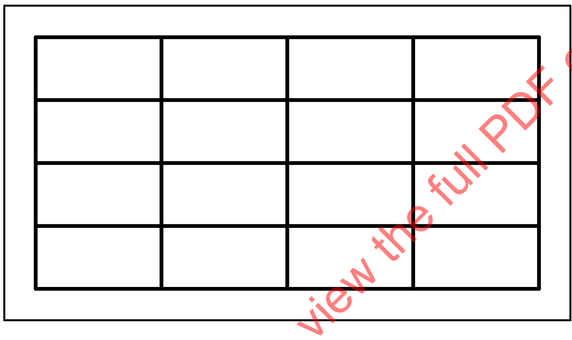


Figure B.1 — Rectangular grid extraction strategy

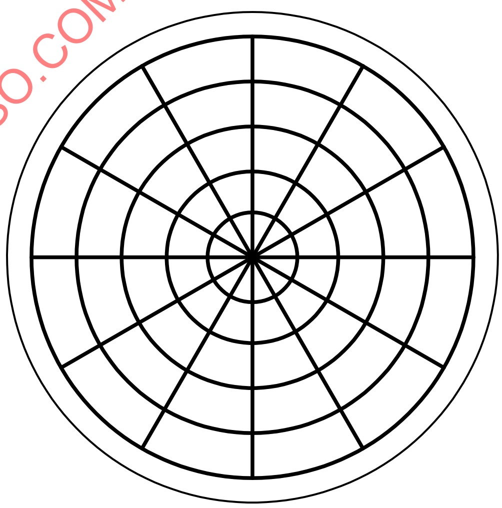


Figure B.2 — Polar grid extraction strategy

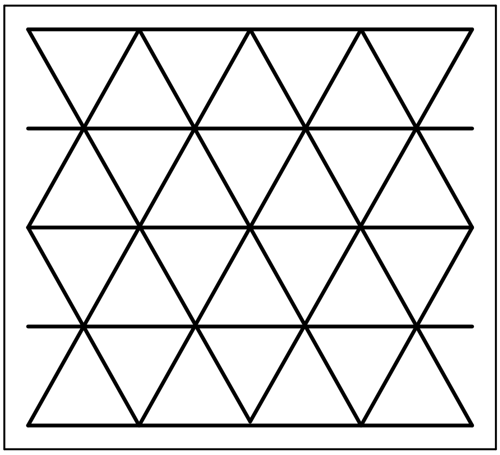


Figure B.3 — Triangular grid extraction strategy

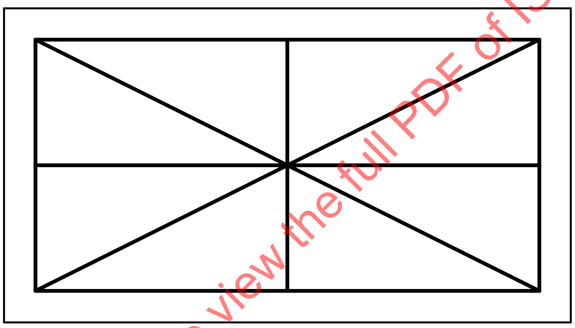


Figure B.4 — "Union Jack" extraction strategy

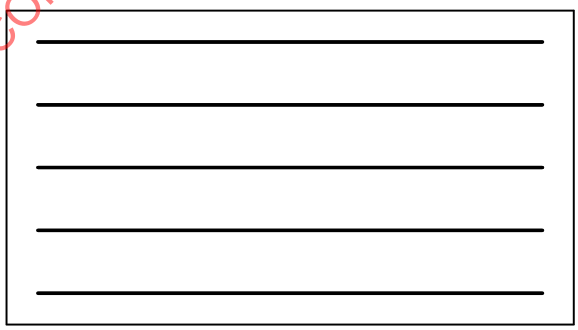


Figure B.5 — Parallel profile extraction strategy

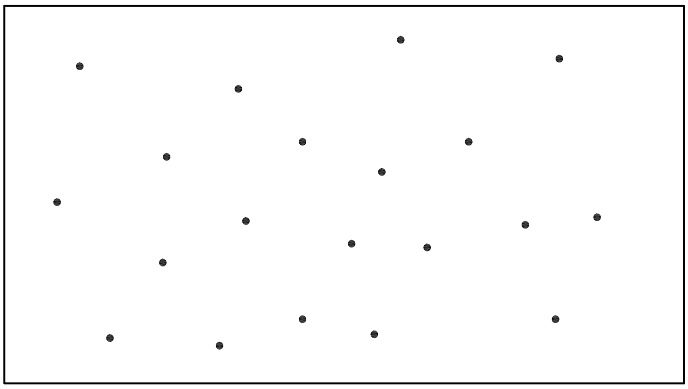


Figure B.6 — Points extraction strategy