TECHNICAL SPECIFICATION

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Geometrical product specifications (GPS) — Filtration —

Part 49:
Morphological profile filters: Scale space techniques

Spécification géométrique des produits (GPS) — Filtrage —

Partie 49: Filtres de profil morphologiques: Techniques d'analyse par espace d'échelle

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Contents

Page

Foreword

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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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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/TS 16610-49 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO/TS 16610 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Filtration*:

— *Part 1: Overview and basic concepts*

— *Part 20: Linear profile filters: Basic concepts*

— *Part 22: Linear profile filters: Spline filters*

— *Part 29: Linear profile filters: Spline wavelets*

— *Part 31: Robust profile filters: Gaussian regression filters*

— *Part 32: Robust profile filters: Spline filters*

— *Part 40: Morphological profile filters: Basic concepts*

— *Part 41: Morphological profile filters: Disk and horizontal line-segment filters*

— *Part 49: Morphological profile filters: Scale space techniques*

The following parts are under preparation:

— *Part 21: Linear profile filters: Gaussian filters*

— *Part 26: Linear profile filters: Filtration on nominally orthogonal grid planar data sets*

— *Part 27: Linear profile filters: Filtration on nominally orthogonal grid cylindrical data sets*

— *Part 30: Robust profile filters: Basic concepts*

— *Part 42: Morphological profile filters: Motif filters*

— *Part 60: Linear areal filters: Basic concepts*

— *Part 61: Linear areal filters: Gaussian filters*

— *Part 62: Linear areal filters: Spline filters*

— *Part 69: Linear areal filters: Spline wavelets*

— *Part 70: Robust areal filters: Basic concepts*

— *Part 71: Robust areal filters: Gaussian regression filters*

— *Part 72: Robust areal filters: Spline filters*

— *Part 80: Morphological areal filters: Basic concepts*

— *Part 81: Morphological areal filters: Sphere and horizontal planar segment filters*

— *Part 82: Morphological areal filters: Motif filters*

— *Part 89: Morphological areal filters: Scale space techniques*

Introduction

This part of ISO/TS 16610 is a geometrical product specification (GPS) Technical Specification and is to be regarded as a global GPS Technical Specification (see ISO/TR 14638). It influences the chain links 3 and 5 of all chains of standards

For more detailed information of the relation about this part of ISO/TS 16610 to the GPS matrix model, see Annex D.

This part of ISO/TS 16610 develops the terminology and concepts for morphological scale space techniques.

Geometrical product specifications (GPS) — Filtration —

Part 49: Morphological profile filters: Scale space techniques

1 Scope

This part of ISO/TS 16610 specifies morphological scale space techniques. The basic terminology for scale space techniques is given together with their usage.

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/TS 16610-1:2006, *Geometrical Product Specification (GPS) — Filtration — Part 1: Overview and basic terminology*

ISO/TS 16610-40:2006, *Geometrical product specifications (GPS) — Filtration — Part 40: Morphological profile filters: Basic concepts*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 16610-1 and ISO/TS 16610-40 and the following apply.

3.1
size distribution
indexed family of **openings** (3.1.1) which satisfies the **sieve criterion** (3.3)

3.1.1
opening
⟨morphological filters⟩ morphological operation obtained by applying the erosion followed by the dilation

NOTE An opening is both a morphological filter and one of the two basic building blocks for other morphological filters.

[ISO/TS 16610-40:2006]

3.2
anti-size distribution
indexed family of **closings** (3.2.1) which satisfies the **sieve criterion** (3.3)

[ISO/TS 16610-1:2006]

3.2.1
closing
⟨morphological filters⟩ morphological operation obtained by applying the dilation followed by the erosion

NOTE A closing is both a morphological filter and one of the two basic building blocks for other morphological filters.

[ISO/TS 16610-40:2006]

3.3
sieve criterion
criterion where two primary mappings (PM) applied one after another to a surface portion (SP) is entirely equivalent to only applying one of these two primary mappings to the surface portion, namely that primary mapping with the highest nesting index (NI)

NOTE The sieve criterion is defined in terms of mathematical mappings as

$$PM[PM(SP \mid NI_1) \mid NI_2] = PM(SP \mid NI) \text{ with } NI = \max(NI_1, NI_2) \tag{1}$$

where

SP is the surface portion.

3.4
scale
indexing parameter in a **size distribution** (3.1) or **anti-size distribution** (3.2)

NOTE 1 A size and an anti-size distribution are often combined to create a continuous real scale, where the positive scale uses the size distribution and the negative scale uses the anti-size distribution with minus scale values.

NOTE 2 Scale is a nesting index.

3.5
scale space
size distribution (3.1) or **anti-size distribution** (3.2) with the **monotone property** (3.5.1)

3.5.1
monotone property
property that once an object in a signal (profile/surface) is present at some **scale** (3.4), it must persist all the way through **scale space** (3.5) to zero scale.

3.6
alternating symmetrical filter
morphological filter satisfying the **sieve criterion** (3.3) which can eliminate peaks and valleys below a given **scale** (3.4)

4 General scale space background

4.1 General

A scale space technique conforming to this part of ISO/TS 16610 shall exhibit the characteristics described in 4.2, 4.3, 4.4, 5.1, 5.2 and 5.3.

Scale space is a way of decomposing a signal (profile/surface) into objects of different scales. A defining feature of scale space is the property that an object, once present at some scale in a signal, must persist all the way through scale space to zero scale. This is often called the monotone property, since the number of objects must necessarily be a monotone decreasing function of scale.

To define scale space, we need to define the size of objects in a signal (profile/surface). The concept of the size and anti-size distribution is a mathematical generic approach to the definition of size of objects in a signal (profile/surface).

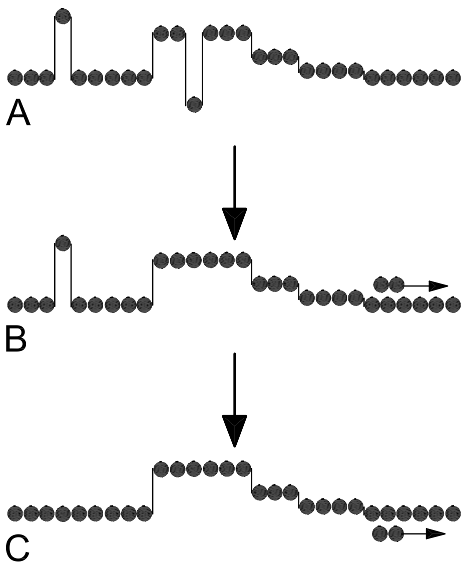
NOTE Examples of scale space are given in Annex A. A concept diagram for the concepts for morphological profile filters: scale space techniques is given in Annex B. The relationship to the filtration matrix model is given in Annex C.

4.2 Size and anti-size distributions

Sieving is a commonly used sizing technique. In physical terms, sieving involves classifying small solid particles according to a series of sieves with decreasing mesh openings. In the first place, the population of different sized grains are allowed to work their way through the sieves (a transformation) in order to classify the different sizes of grains. The contents of each sieve are then either counted or weighed to obtain a histogram of the size distribution of the original population of particles.

Matheron[4] was the first to define mathematically the concept of size. He demonstrated that a family of morphological openings, satisfying the sieve criterion and indexed by a positive number called the scale, could be used to define the concept of size and size distributions, analogous to physically sieving a population of particles as described above.

Since size distributions are based on a family of opening filters, the size distribution measures the width of peaks on the signal/image. Using the opening filter of a particular scale eliminates peaks whose widths are less than this given scale (see Figure 1). The dual concept of anti-size distributions based on a family of closing filters measures the width of valleys on the signal/image. Using the closing filter of a particular scale eliminates valleys whose widths are less than this given scale (see Figure 1).



Key

A original profile

B profile after closing with a horizontal line

C profile after opening with a horizontal line

NOTE The process illustrated in Figure 1 eliminates features whose widths are less than the size of the structural element, i.e. size 2.

Figure 1 — Closing and opening with a horizontal line structural element of size 2

4.3 Alternating symmetrical filters

An opening filter of a particular scale from a size distribution removes peaks whose widths are less than this given scale, while a closing filter of the same scale from an anti-size distribution removes valleys whose widths are less than this given scale. To eliminate both peaks and valleys whose widths are less than this given scale at the same time, alternating symmetrical filters are required.

To eliminate both peak and valleys at the same time, we need to combine openings and closings from a size and anti-size distribution respectively. It can be shown that there are only four possibilities for composing an opening $Oj( )$ and a closing $Cj( )$ with a given scale j, as follows:

a) $mj = Oj\ [Cj\ ( )]$;

b) $nj = Cj\ [Oj\ ( )]$;

c) $rj = Cj\ \{Oj\ [Cj\ ( )]\}$;

d) $sj = Oj\ \{Cj\ [Oj\ ( )]\}$.

We can define the following four alternating symmetrical filters with a given scale i

— M-sieve: $Mi = m_1 m_2 m_3 \ldots m_{i-1}\ m_i m_{i-1} \ldots m_3 m_2 m_1$

— N-sieve: $Ni = n_1 n_2 n_3 \ldots n_{i-1}\ n_i n_{i-1} \ldots n_3 n_2 n_1$

— R-sieve: $Ri = r_1 r_2 r_3 \ldots r_{i-1}\ r_i r_{i-1} \ldots r_3 r_2 r_1$

— S-sieve: $s_1 s_2 s_3 \ldots s_{i-1}\ s_i s_{i-1} \ldots s_3 s_2 s_1$

where the increasing number of the indices represents increasing scale (i.e. if $u < v$, then the scale of m_u is less than the scale of m_v).

It can be shown[5][6] that these alternating symmetrical filters are morphological filters which satisfy the sieve criterion and which eliminate peaks and valleys whose widths are less than the scale i.

Alternating symmetrical filters allow the construction of a ladder structure of higher order scale space representations of the original signal/image (see Figure 2). The first rung is the original signal (profile/surface). At each rung in the ladder, the signal S^i is filtered by an alternating symmetrical filter of order i+1, say Mi+1, in order to obtain the next order scale space representation of the signal/image S^{i+1}, which becomes the next rung, and a component that is the difference between the two rungs d^{i+1}. The original signal can be reconstructed from $(d^1,d^2,d^3,\ldots,d^n,S^n)$ by reversing the ladder structure.

4.4 Nested mathematical models

The ladder structure lends itself naturally to a set of nested mathematical models of the surface, with the ith model, say model^i, reconstructed from $(d^i,d^{i+1},\ldots,d^n,s^n)$. The scale of the model is equivalent to a cut-off value λ_s.

A “transmission bandwidth” can be defined using the nested mathematical models by calculating the height difference between two specified models, e.g. $\text{model}^{i,j} = \text{model}^i - \text{model}^j$ with $i < j$. Thus, in this particular example, scale i is equivalent to cut-off value λ_s and scale j is equivalent to cut-off value λ_c.

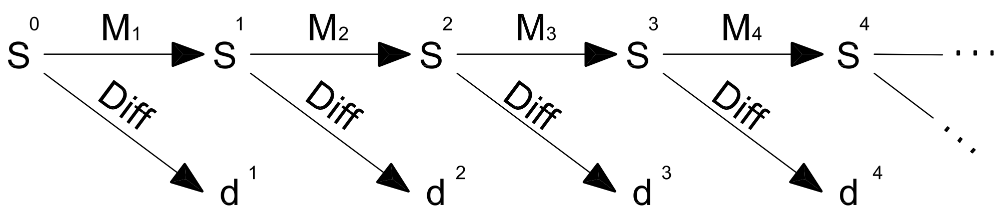


Figure 2 — Schematic representation of the ladder structure of scale space

5 Recommendations

5.1 Circular disk structuring element

The definitions for openings and closings with a circular disk structural element are given in ISO/TS 16610-41. To implement the alternating symmetrical filters, it is recommended to use the M-sieve with a logarithmic series (constant ratio) of scale values (the radius of the circular disk of the structural element). Experience has shown that a constant ratio of around two between successive scale values is optimal. This value is sufficiently large to distinguish and interpret the details in the ladder structure, whilst remaining sufficiently small that the partition of scale space can still be considered diagnostic. To start the alternating series filter, a scale value not less than the stylus tip radius should be selected in order that each successive level of the ladder has approximately the same ratio of scale values.

The following series of scale values has a ratio of around 2:

...1 mm, 2 mm, 5 mm, 10 mm, 20 mm, 50 mm, 100 mm, 200 mm, 500 mm, 1 mm, 2 mm, 5 mm, 10 mm, ...

This series has an additional advantage that it is consistent with the recommended stylus tip radii for surface texture (see ISO 3274). Hence, surfaces measured with different styli have an overlap of scale values and so are directly comparable.

5.2 Horizontal line structuring element

The definitions for openings and closings with a horizontal line structural element are given in ISO/TS 16610-41. To implement the alternating symmetrical filters, it is recommended to use the M-sieve with a logarithmic series (constant ratio) of scale values (the length of the horizontal line of the structural element). Experience has shown that a constant ratio of around two between successive scale values is optimal. This value is sufficiently large to distinguish and interpret the details in the ladder structure, whilst remaining sufficiently small that the partition of scale space can still be considered diagnostic. To start the alternating series filter, a scale value not less than the stylus tip diameter should be selected in order that each successive level of the ladder has approximately the same ratio of scale values.

The following series of scale values has a ratio of around 2:

...1 mm, 2 mm, 5 mm, 10 mm, 20 mm, 50 mm, 100 mm, 200 mm, 500 mm, 1 mm, 2 mm, 5 mm, 10 mm, ...

This series has the additional advantage that it is consistent with the recommended stylus tip radii for surface texture (see ISO 3274). Hence, surfaces measured with different styli have an overlap of scale values and so are directly comparable.

5.3 Default scale space technique

If not otherwise specified, the default scale space technique shall be a M-sieve with a circular disk structuring element.

6 Filter designation

Morphological profile filters according to this part of ISO/TS 16610 are designated

	Filter designation
Alternating series Disk	**FPMAD**
Alternating series Horizontal segment	**FPMAH**

See also ISO/TS 16610-1:2006, Clause 5.

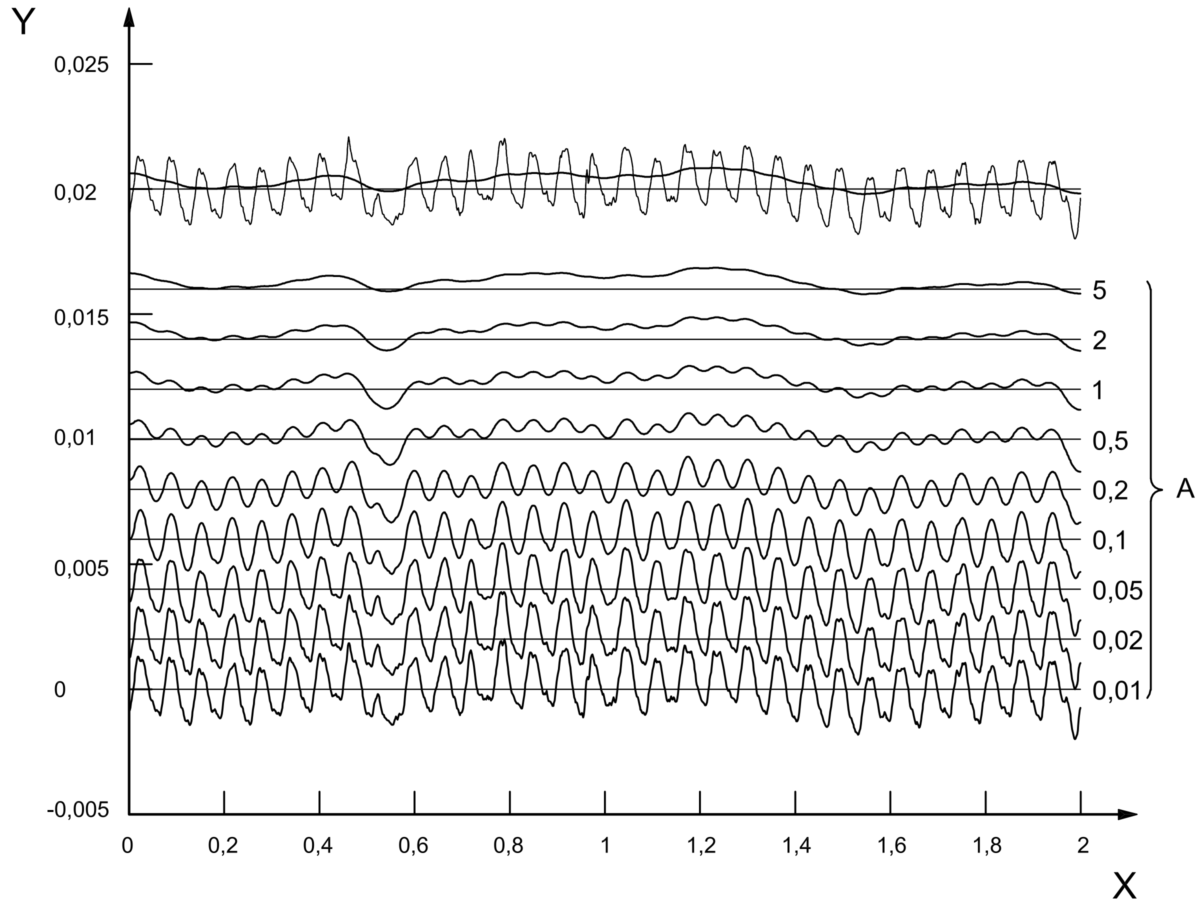
Annex A
(informative)

Illustrative examples of scale space

A.1 Circular disk on a profile from a milled surface

The profile is taken from a milled surface, measured with a 5 mm tip stylus. The series of scale values given in Clause 4 is used, starting with the first value larger than the stylus tip radius. Figure A.1 shows the successively smoothed profiles, together with the original profile at the top.

Dimensions in millimetres



Key

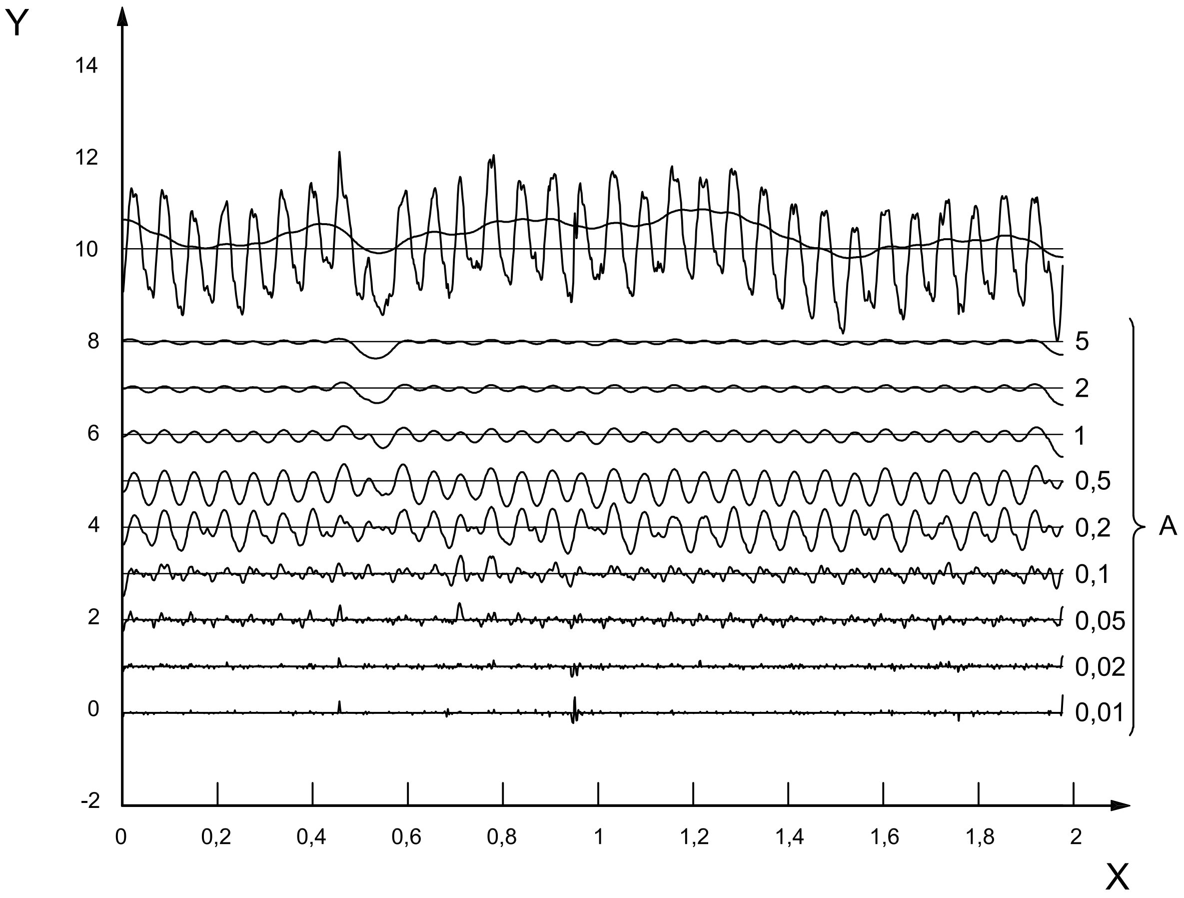
X distance

Y height

A scale

Figure A.1 — Successively smoothed profiles of a profile from a milled surface using a circular disk

Figure A.2 shows the differences between successive smoothings. Notice how the deflective milling mark has been easily identified at scales 2 mm and 5 mm, and the milling marks at scales 0,5 mm and 0,2 mm.



Key

X distance, mm

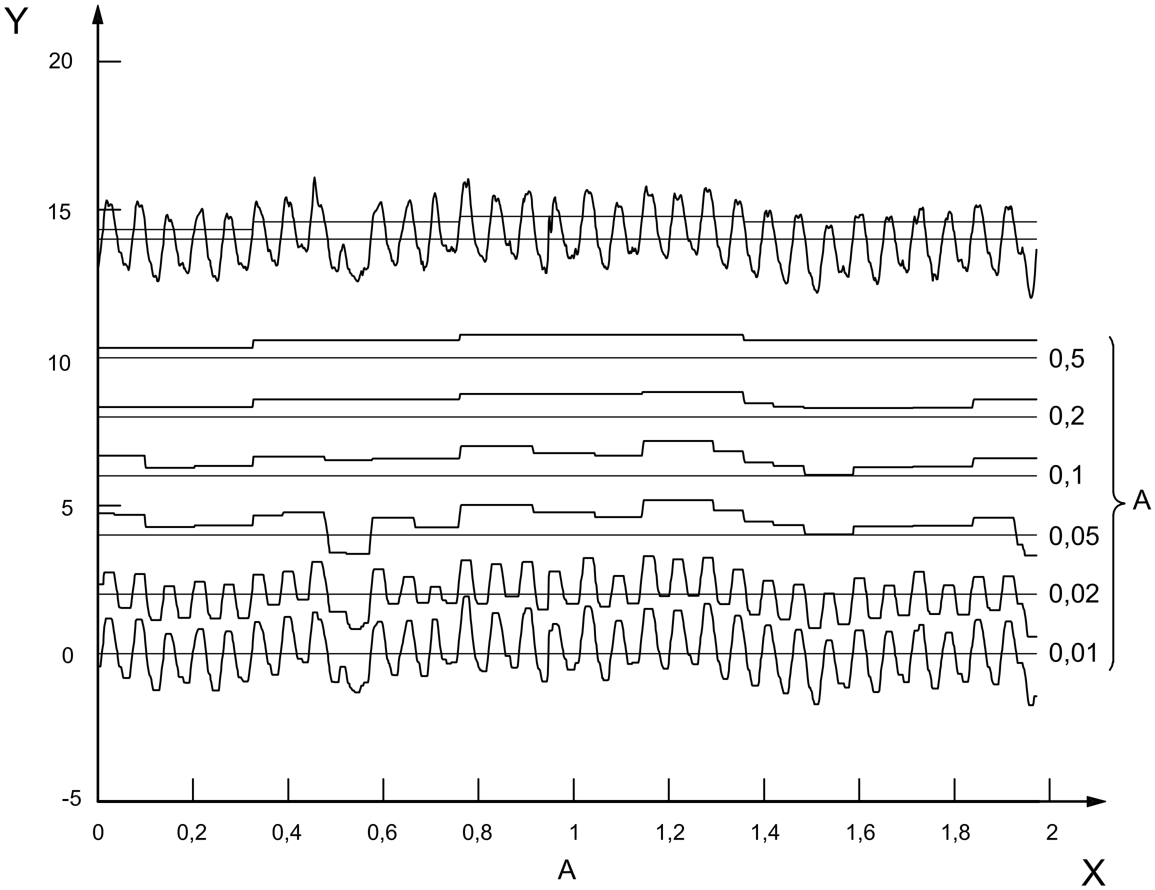
Y height, µm

A scale, mm

Figure A.2 — Differences on a profile from a milled surface using a circular disk

A.2 Horizontal line on a profile from a milled surface

This is the same profile from a milled surface as in A.1. Again the series of scale values given in Clause 4 is used, starting with the first value larger than the stylus tip radius. Figure A.3 shows the successively smoothed profiles, together with the original profile at the top.



Key

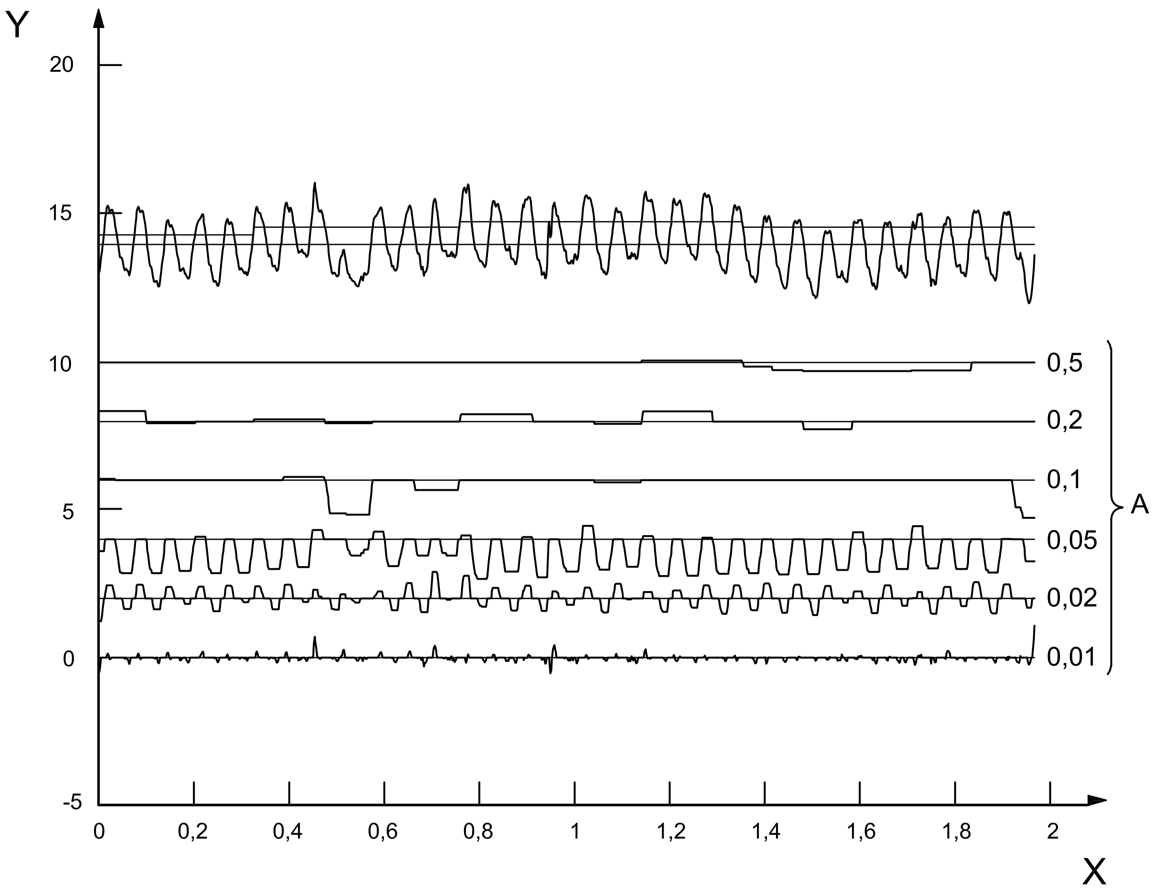
X distance, mm

Y height, µm

A scale, mm

Figure A.3 — Successively smoothed profiles of a profile from a milled surface using a horizontal line segment

Figure A.4 shows the differences between successive smoothings. Notice how the defective milling mark has been easily identified at scale 0,1 mm and the milling marks at scale 0,05 mm, reflecting the width of these features.



Key

X distance, mm

Y height, µm

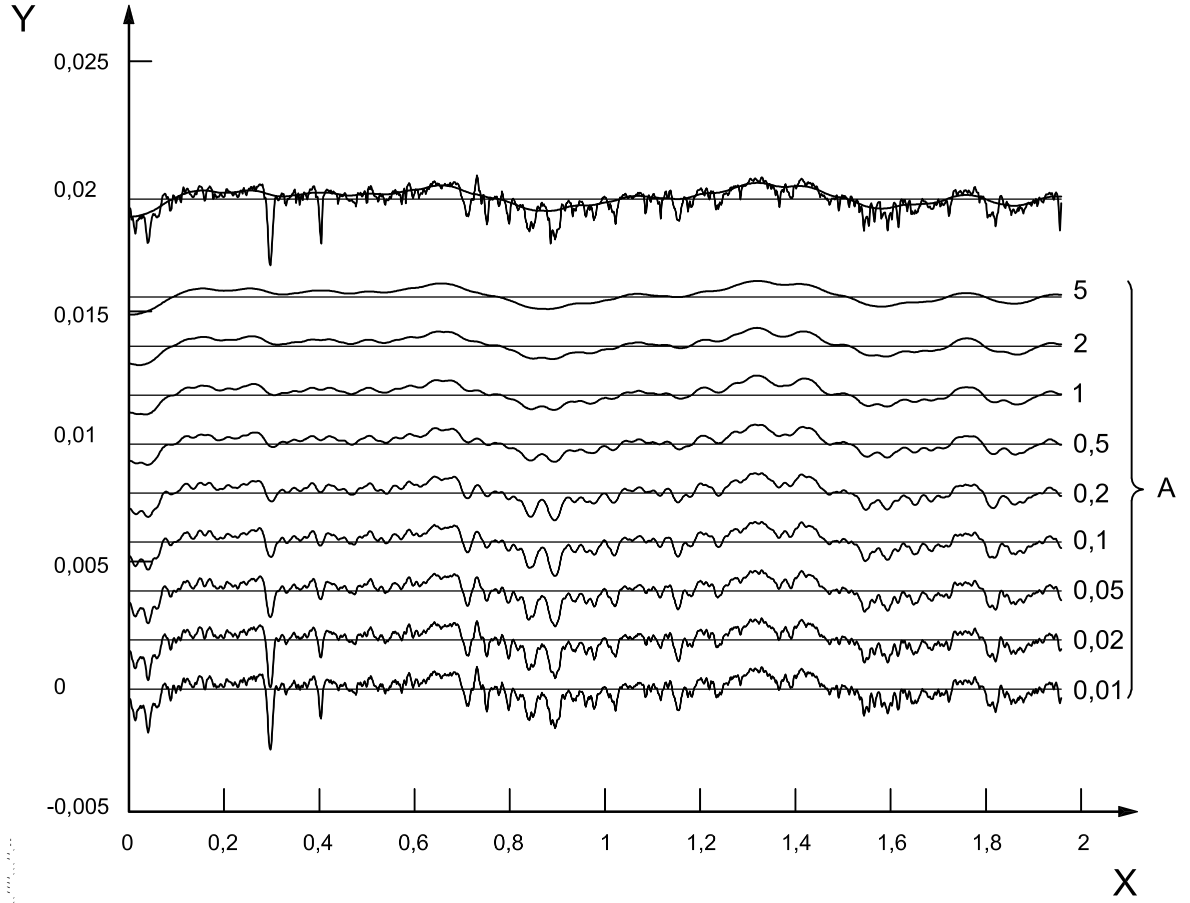
A scale, mm

Figure A.4 — Differences on a profile from a milled surface using a horizontal line segment

A.3 Circular disk on a profile from a ceramic surface

The profile is taken from a rough ceramic surface, measured with a 5 mm tip stylus. The series of scale values given in Clause 4 is used, starting with the first value larger than the stylus tip radius. Figure A.5 shows the successively smoothed profiles, together with the original profile at the top. Notice how the smoothed profiles at larger scales are robust against the deep valleys.

Dimensions in millimetres



Key

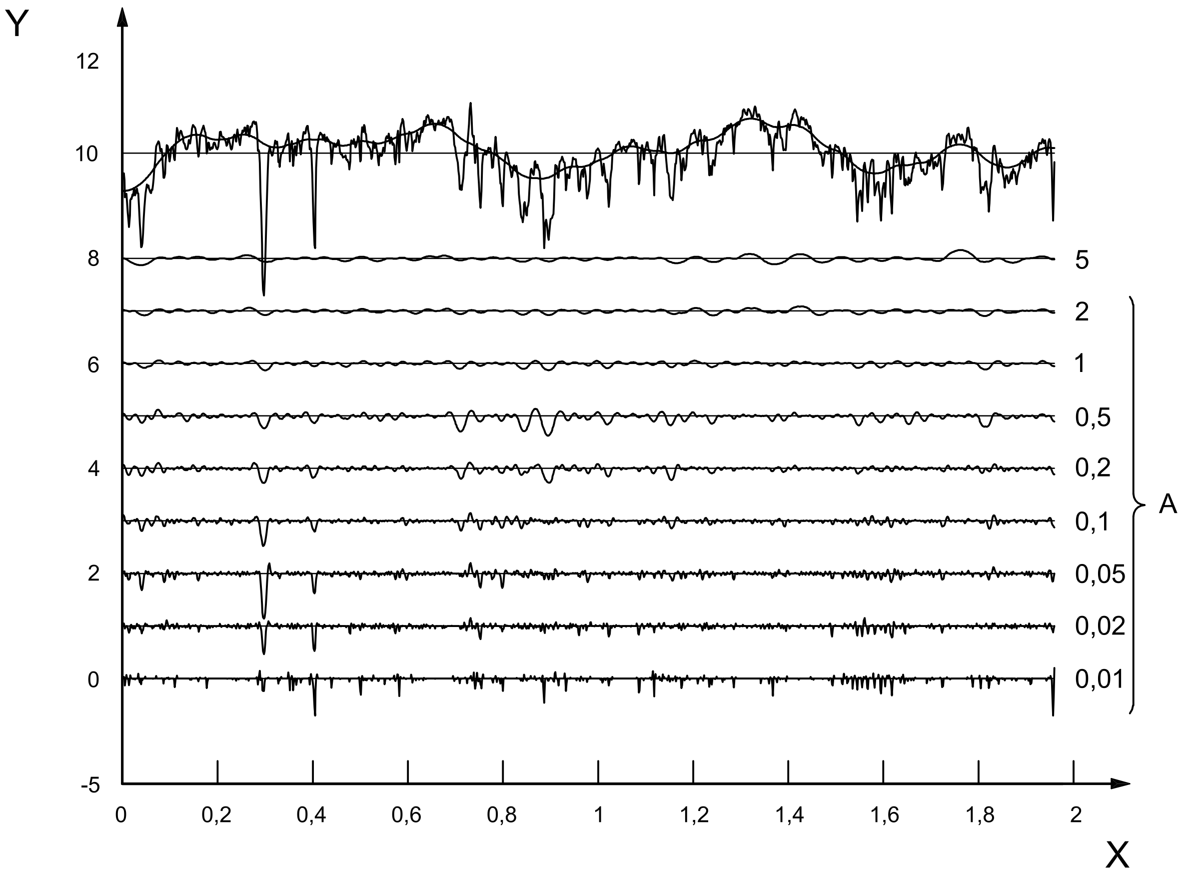
X distance

Y height

A scale

Figure A.5 — Successively smoothed profiles of a profile from a ceramic surface using a circular disk

Figure A.6 shows the differences between successive smoothings. Notice how the deep valleys are easily identified at scales 0,2 mm to 0,01 mm.



Key

X distance, mm

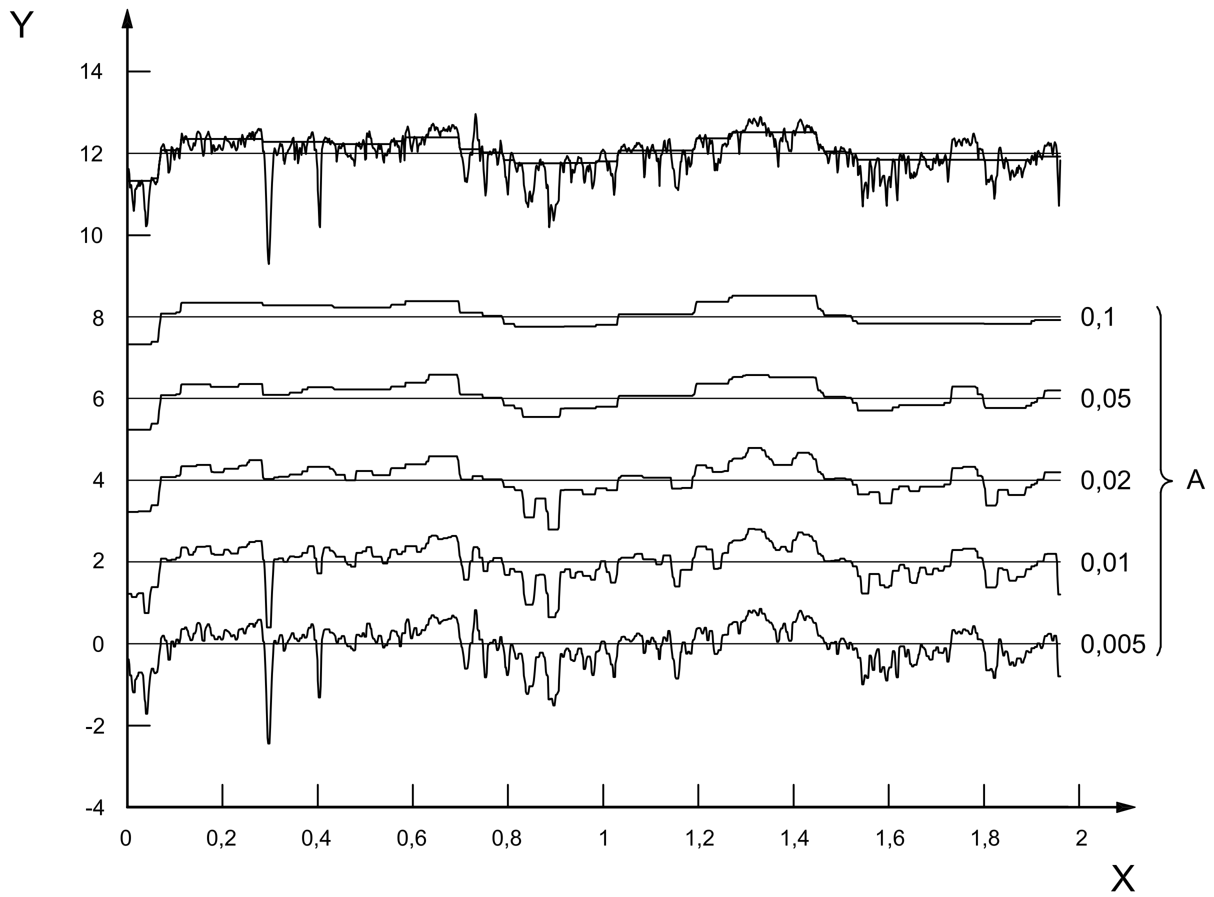
Y height, µm

A scale, mm

Figure A.6 — Differences on a profile from a ceramic surface using a circular disk

A.4 Horizontal line on a profile from a ceramic surface

This is the same rough ceramic surface as in A.3. The series of scale values given in Clause 4 is used, starting with the first value larger than the stylus tip radius. Figure A.7 shows the successively smoothed profiles, together with the original profile at the top. Notice how the smoothed profiles at larger scales are robust against the deep valleys.



Key

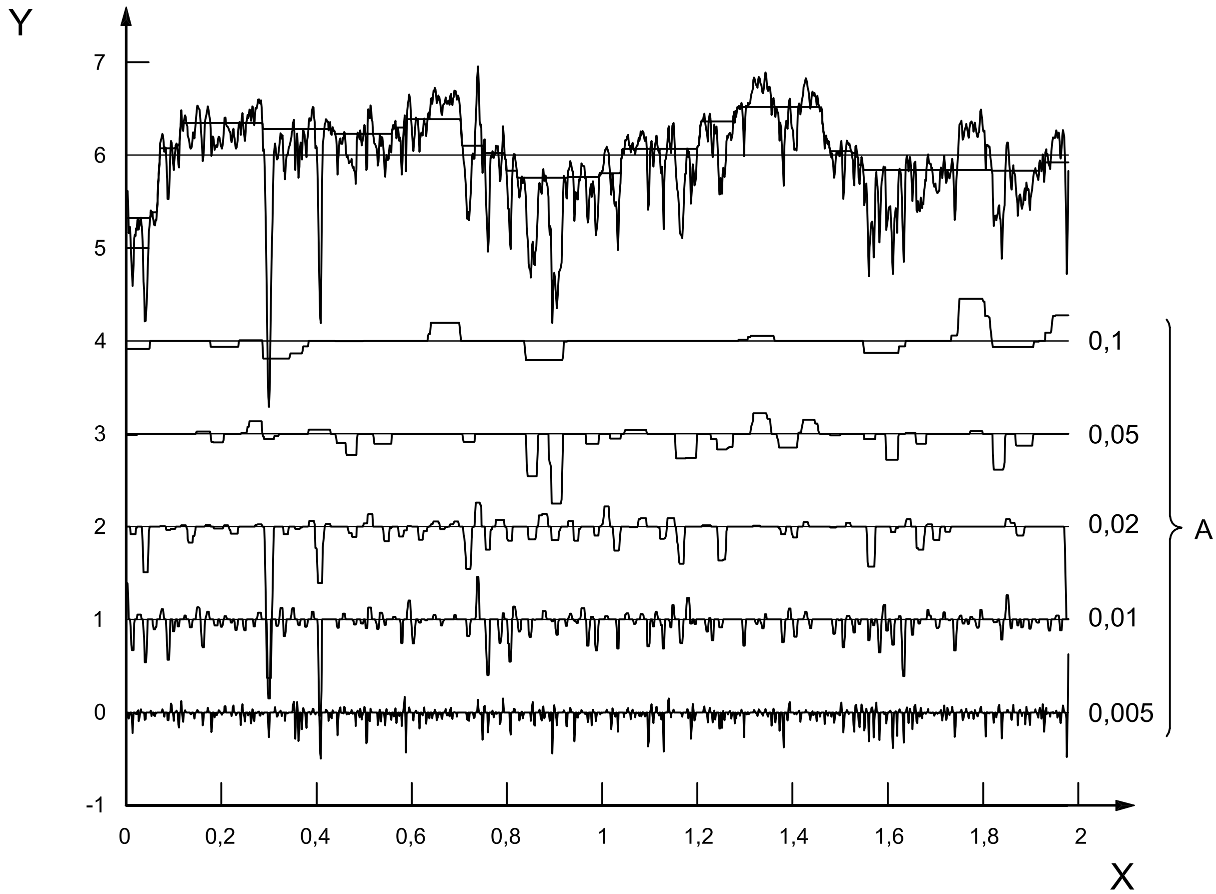
X distance, mm

Y height, µm

A scale, mm

Figure A.7 — Successively smoothed profiles of a profile from a ceramic surface using a horizontal line

Figure A.8 shows the differences between successive smoothings. Notice how the deep valleys are easily identified at scales 0,05 to 0,01mm reflecting the width of these features.



Key

X distance, mm

Y height, µm

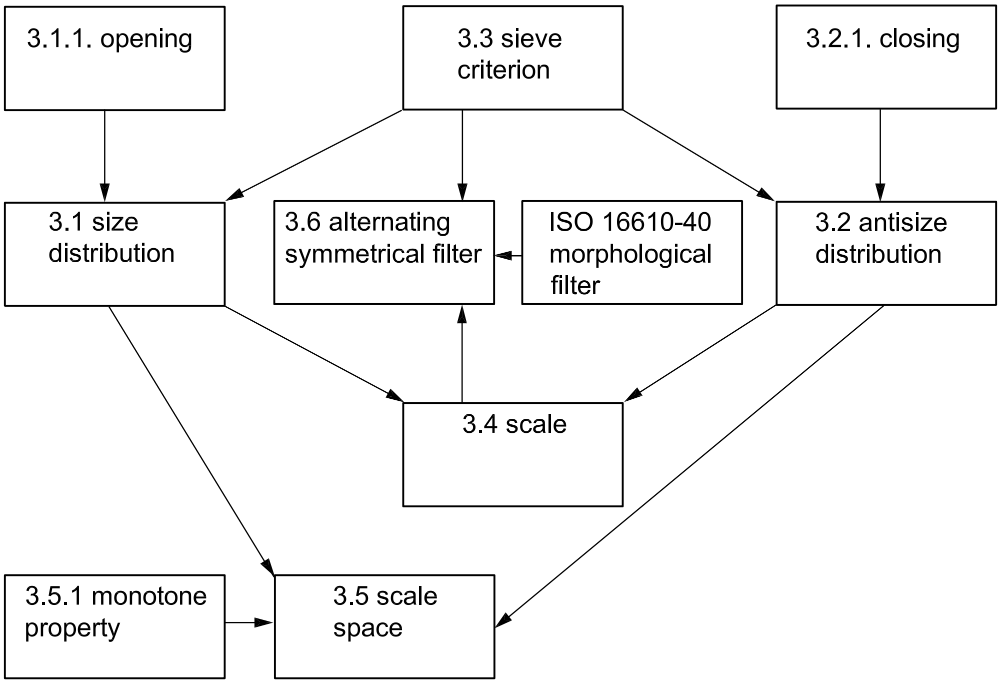
A scale, mm

Figure A.8 — Differences on a profile from a ceramic profile using a horizontal line

Annex B
(informative)

Concept diagram

The following is a concept diagram for this part of ISO/TS 16610.



Annex C
(informative)

Relationship to the filtration matrix model

For full details about the filtration matrix model see ISO/TS 16610-1.

C.1 Position in the filtration matrix model

This part of ISO/TS 16610 is a specific document that influences particular filters in the column: Profile filters, Morphological (see Figure C.1).

General	Filters: ISO/TS 16610 series					
	Part 1					
Fundamental	Profile filters			Areal filters		
	Part 11[a]			Part 12[a]		
	Linear	Robust	Morphological	Linear	Robust	Morphological
Basic concepts	Part 20	Part 30	Part 40	Part 60	Part 70	Part 80
Particular filters	Parts 21-25	Parts 31-35	Parts 41-45	Parts 61-65	Parts 71-75	Parts 81-85
How to filter	Parts 26-28	Parts 36-38	Parts 46-48	Parts 66-68	Parts 76-78	Parts 86-88
Multiresolution	Part 29	Part 39	Part 49	Part 69	Part 79	Part 89

[a] At present included in Part 1.

Figure C.1 — Relationship to the filtration matrix model

Annex D
(informative)

Relationship to the GPS matrix model

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

D.1 Information about this Technical Specification and its use

This part of ISO/TS 16610 defines the basic terminology for envelope scale space techniques.

D.2 Position in the GPS matrix model

This part of ISO/TS 16610 is a global GPS Technical Specification, which influences chain links 3 and 5 of all chains of standards in the GPS matrix structure, as graphically illustrated in Figure D.1.

Fundamental GPS standards

Global GPS standards

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

Figure D.1 — Position in the GPS matrix model

D.3 Related International Standards

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

Bibliography

[1] ISO 3274:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments*

[2] ISO/TR 14638:1995, *Geometrical Product Specifications (GPS) — Masterplan*

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