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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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## 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](http://www.iso.org/directives)).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This first edition cancels and replaces ISO/TS 16610-49:2006 which has been technically revised.

ISO 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 21: Linear profile filters: Gaussian filters
- Part 22: Linear profile filters: Spline filters
- Part 28: Profile filters: End effects
- Part 29: Linear profile filters: Spline wavelets
- Part 30: Robust profile filters: Basic concepts
- 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
- Part 60: Linear areal filters: Basic concepts
- Part 61: Linear areal filters: Gaussian filters

- Part 71: Robust areal filters: Gaussian regression filters
- Part 85: Morphological areal filters: Segmentation

The following parts are planned:

- 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 45: Morphological profile filters: Segmentation
- Part 62: Linear areal filters: Spline filters
- Part 69: Linear areal filters: Spline wavelets
- Part 70: Robust areal filters: Basic concepts
- 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 89: Morphological areal filters: Scale space techniques

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## Introduction

This part of ISO 16610 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences chain links 3 and 5 in the GPS matrix structure.

The ISO/GPS Masterplan given in ISO 14638 gives an overview of the ISO/GPS system of which this part of ISO 16610 is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this part of ISO 16610 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 16610, unless otherwise indicated.

For more detailed information of the relation about this part of ISO 16610 to the GPS matrix model, see [Annex D](#).

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

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# Geometrical product specifications (GPS) — Filtration —

## Part 49:

# Morphological profile filters: Scale space techniques

## 1 Scope

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

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16610-1:2015, *Geometrical product specification (GPS) — Filtration — Part 1: Overview and basic terminology*

ISO 16610-40:2015, *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 16610-1, ISO 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 1 to entry: An opening is both a morphological filter and one of the two basic building blocks for other morphological filters.

[SOURCE: ISO 16610-40:2015]

### 3.2

#### anti-size distribution

indexed family of *closings* (3.2.1) which satisfies the *sieve criterion* (3.3)

#### 3.2.1

##### closing

(morphological filters) morphological operation obtained by applying the dilation followed by the erosion

Note 1 to entry: A closing is both a morphological filter and one of the two basic building blocks for other morphological filters.

[SOURCE: ISO 16610-40:2015]

### 3.3 sieve criterion

criterion where two primary mappings applied one after another to a surface portion 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

[SOURCE: ISO 16610-1:2015]

### 3.4 scale

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

Note 1 to entry: 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 to entry: 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 shall 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 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, shall persist all the way through scale space to zero scale. This is often called the monotone property, since the number of objects shall 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.

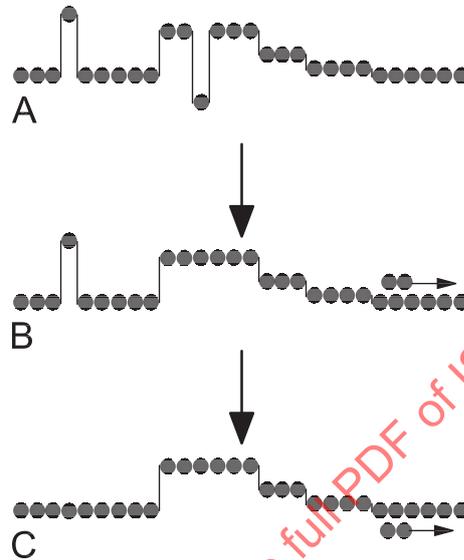
### 4.2 Size and anti-size distributions

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<sup>[4]</sup> 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 peaks 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  $O_j()$  and a closing  $C_j()$  with a given scale  $j$ , as follows:

- a)  $m_j = O_j [C_j ()]$ ;
- b)  $n_j = C_j [O_j ()]$ ;
- c)  $r_j = C_j \{O_j [C_j ()]\}$ ;
- d)  $s_j = O_j \{C_j [O_j ()]\}$ .

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

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

- N-sieve:  $N_i = n_1 n_2 n_3 \dots n_{i-1} n_i n_{i-1} \dots n_3 n_2 n_1$
- R-sieve:  $R_i = r_1 r_2 r_3 \dots r_{i-1} r_i r_{i-1} \dots r_3 r_2 r_1$
- S-sieve:  $S_i = s_1 s_2 s_3 \dots s_{i-1} s_i s_{i-1} \dots s_3 s_2 s_1$

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][7][8] 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  $M_{i+1}$ , 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  $(d^1, d^2, d^3, \dots, d^n, S^n)$  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  $i$ th model, say model $^i$ , reconstructed from  $(d^i, d^{i+1}, \dots, d^n, S^n)$ . The scale of the model is equivalent to a cut-off value  $\lambda_s$ .

A “transmission bandwidth” can be defined using the nested mathematical models by calculating the height difference between two specified models, e.g. 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  $\lambda_s$  and scale  $j$  is equivalent to cut-off value  $\lambda_c$ .

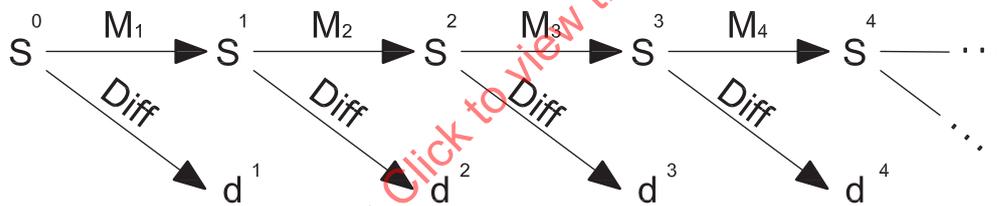


Figure 2 — Schematic representation of the ladder structure of scale space

### 5 Recommendations

#### 5.1 Circular disk structuring element

The definitions for openings and closings with a circular disk structural element are given in ISO 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, while 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  $\mu\text{m}$ , 2  $\mu\text{m}$ , 5  $\mu\text{m}$ , 10  $\mu\text{m}$ , 20  $\mu\text{m}$ , 50  $\mu\text{m}$ , 100  $\mu\text{m}$ , 200  $\mu\text{m}$ , 500  $\mu\text{m}$ , 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 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, while 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  $\mu\text{m}$ , 2  $\mu\text{m}$ , 5  $\mu\text{m}$ , 10  $\mu\text{m}$ , 20  $\mu\text{m}$ , 50  $\mu\text{m}$ , 100  $\mu\text{m}$ , 200  $\mu\text{m}$ , 500  $\mu\text{m}$ , 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 an M-sieve with a circular disk structuring element.

## 6 Filter designation

Morphological profile filters according to this part of ISO 16610 are designated as follows:

	Filter designation
Alternating series Disk	<b>FPMAD</b>
Alternating series Horizontal segment	<b>FMAH</b>

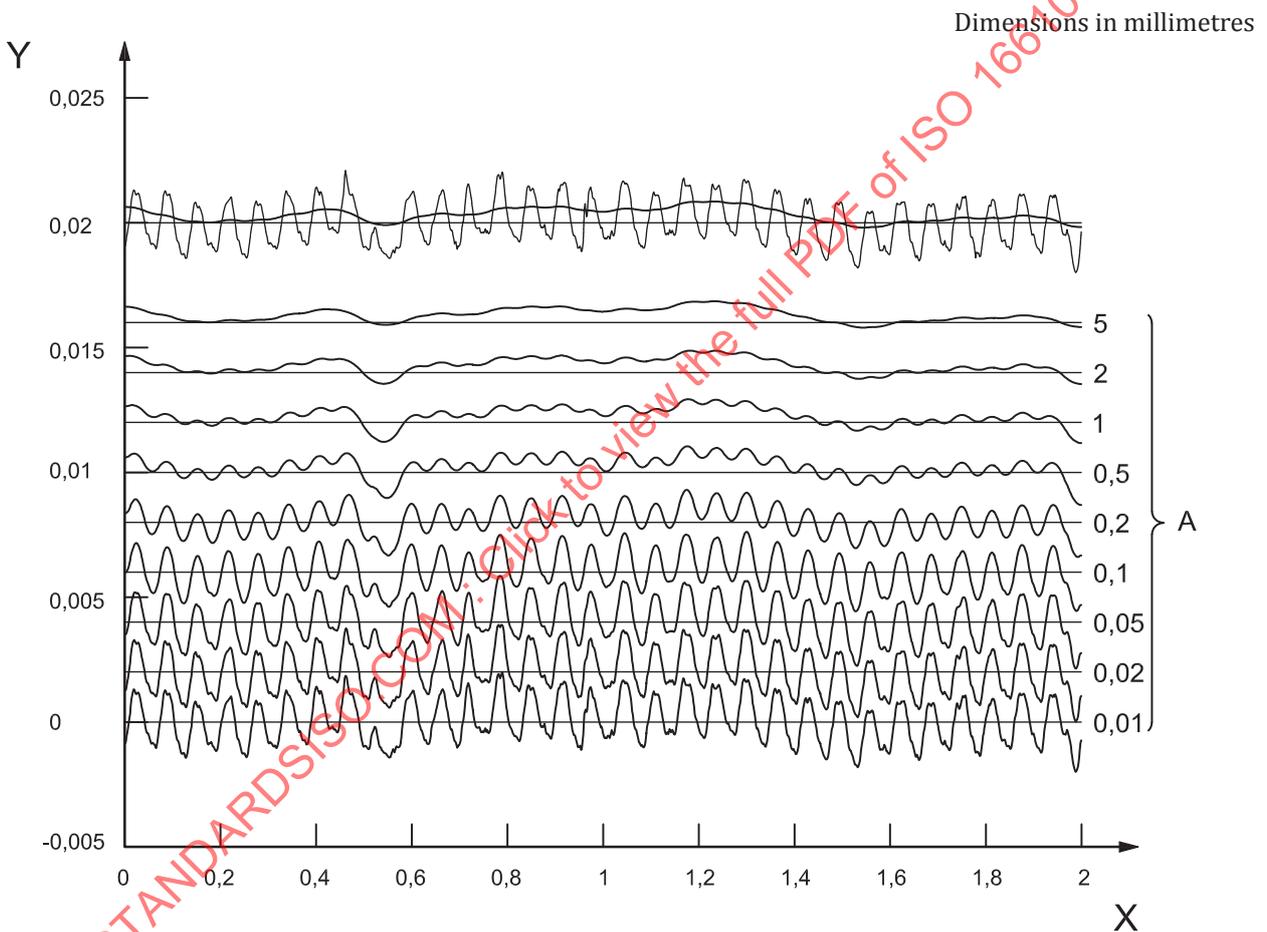
See also ISO 16610-1:2015, Clause 5.

## Annex A (informative)

### Illustrative examples of scale space

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

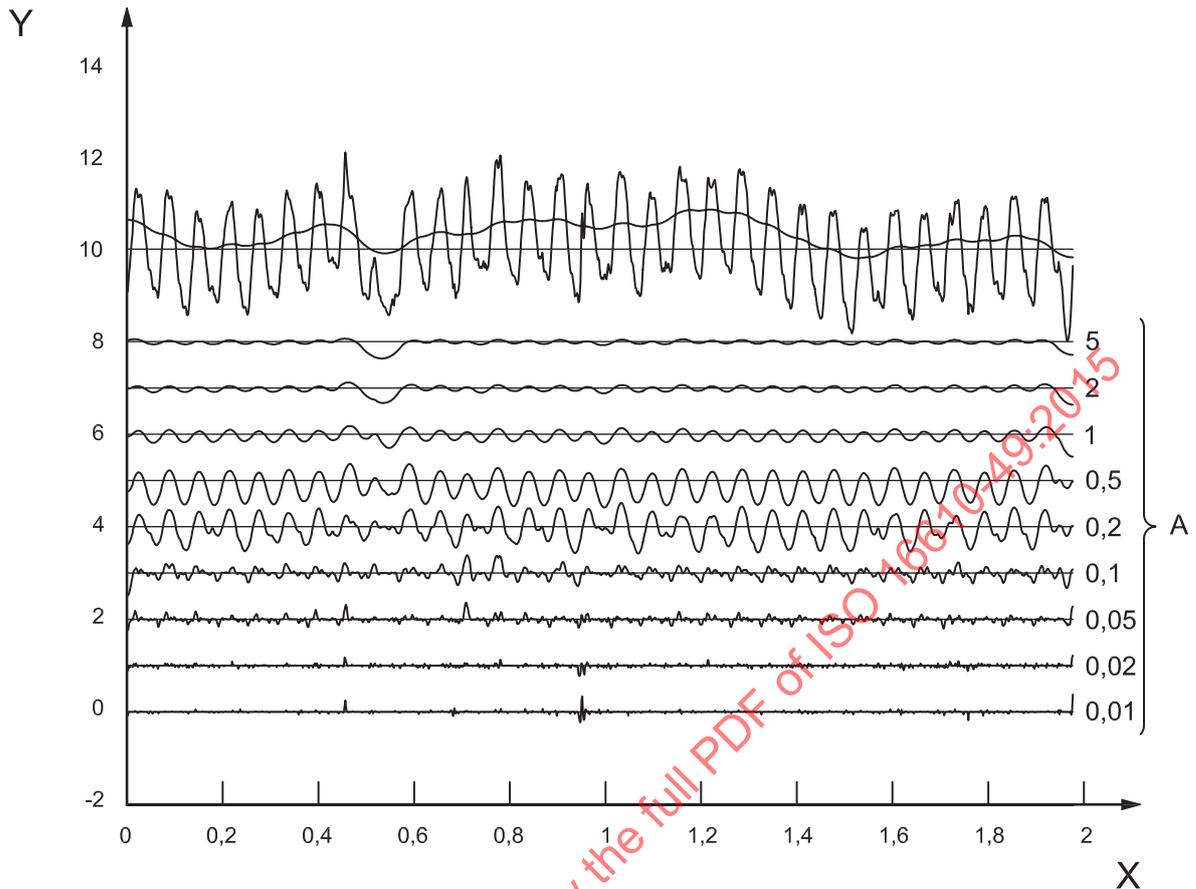
The profile is taken from a milled surface, measured with a 5 mm tip stylus. The series of scale values given in [Clause 4](#) is used, starting with the first value larger than the stylus tip radius. [Figure A.1](#) shows the successively smoothed profiles, together with the original profile at the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



Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 A scale, mm

**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 defective 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

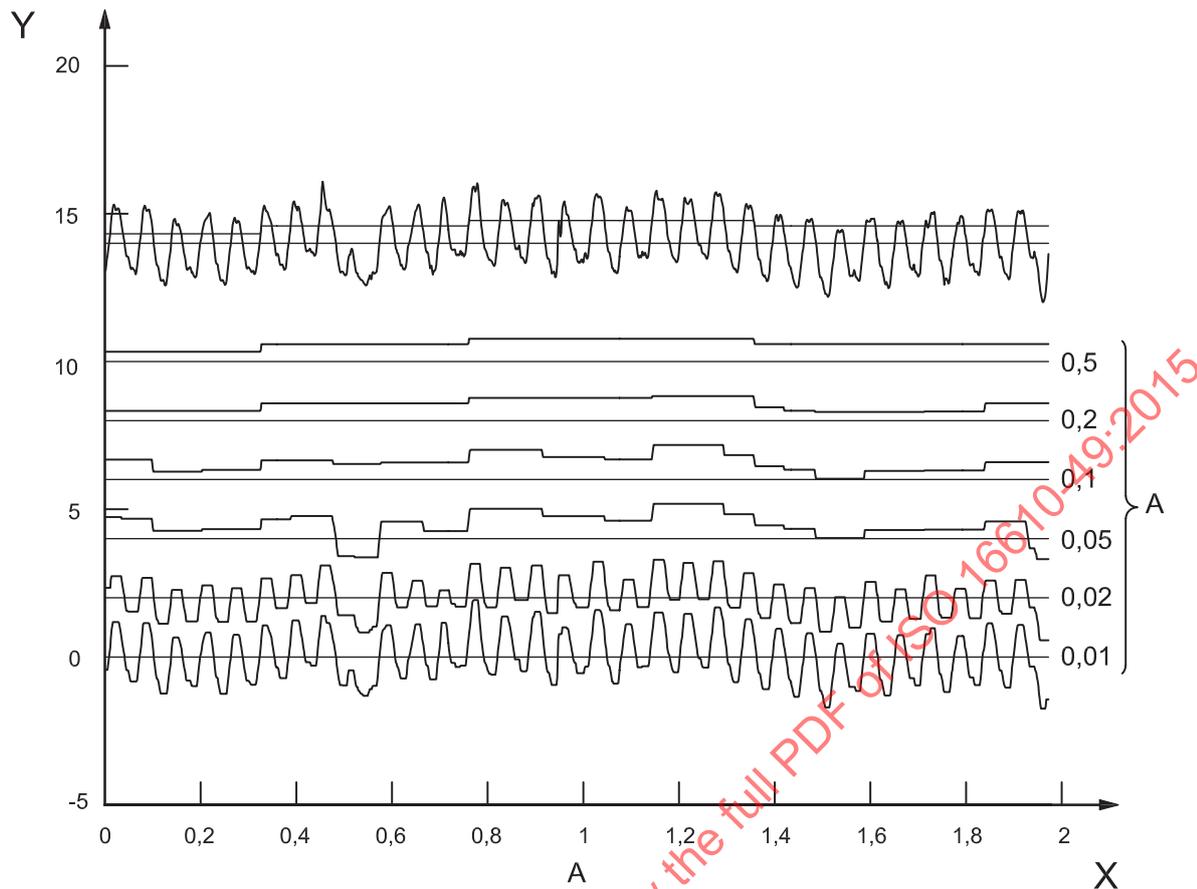
Y height,  $\mu\text{m}$ 

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

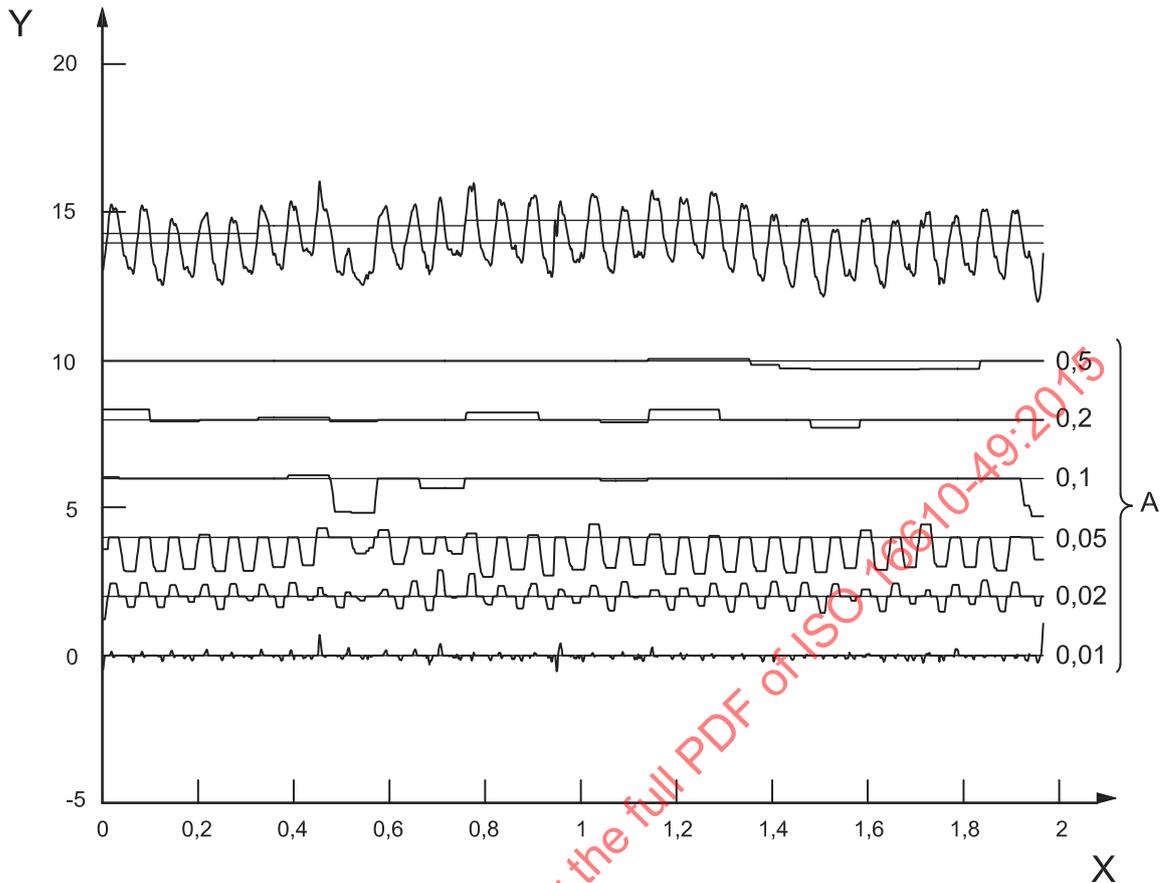
This is the same profile from a milled surface as in [A.1](#). Again, the series of scale values given in [Clause 4](#) is used, starting with the first value larger than the stylus tip radius. [Figure A.3](#) shows the successively smoothed profiles, together with the original profile at the top.



Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 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,  $\mu\text{m}$

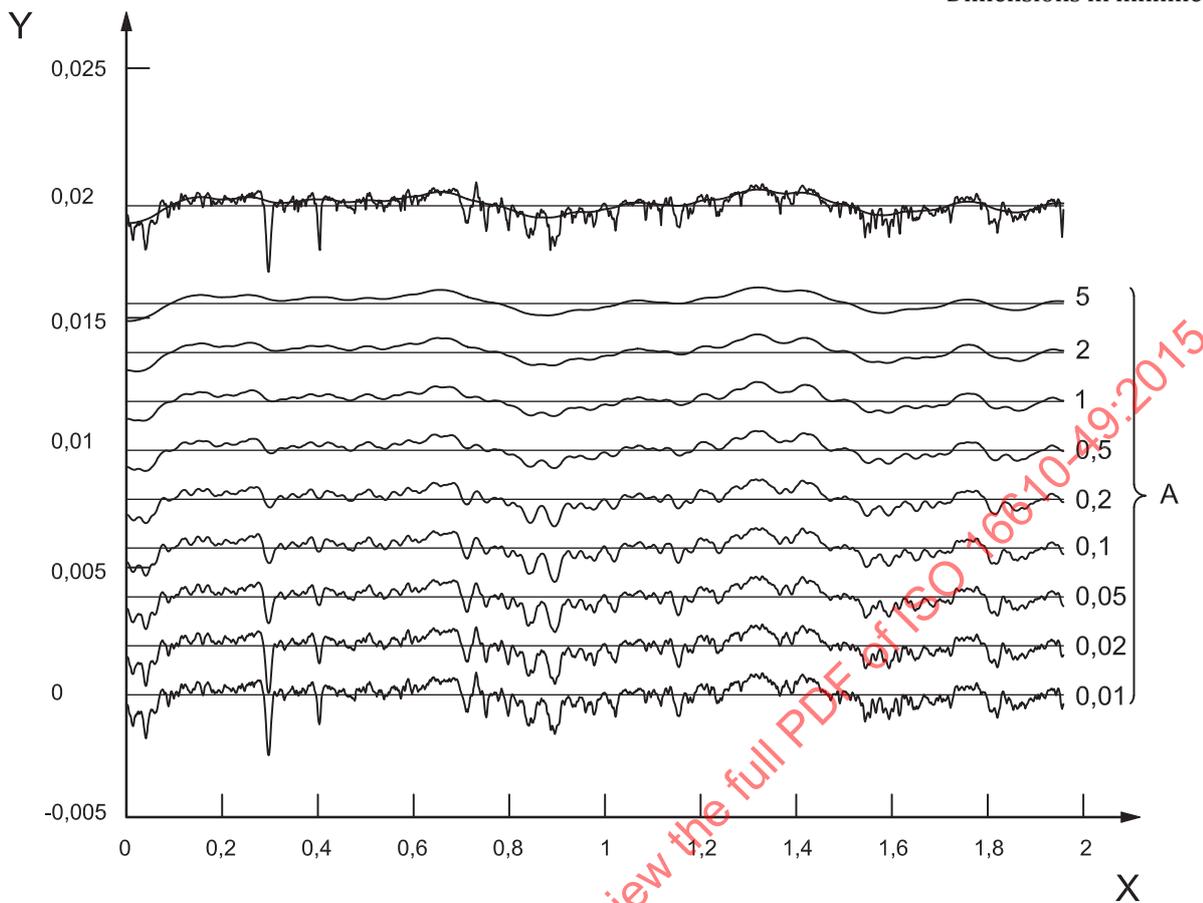
A scale, mm

**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.

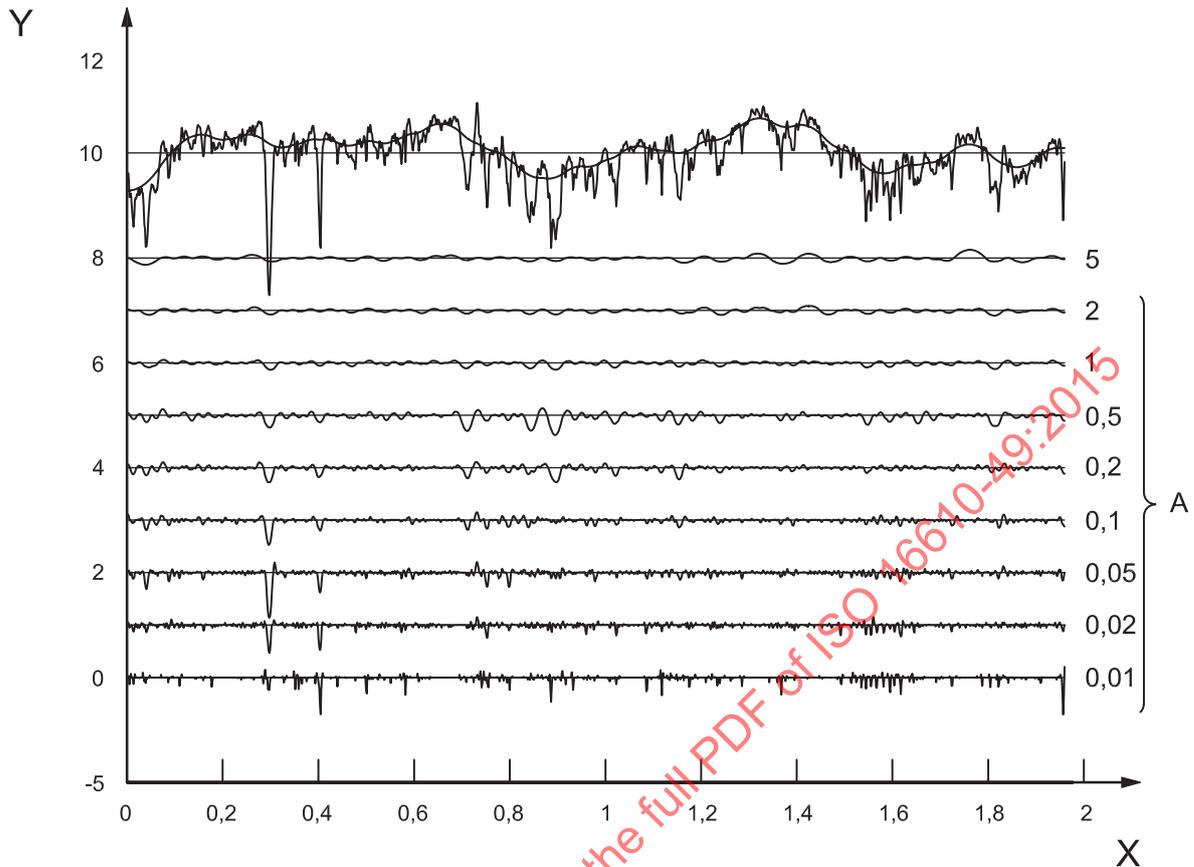
Dimensions in millimetres



Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 A scale, mm

**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.

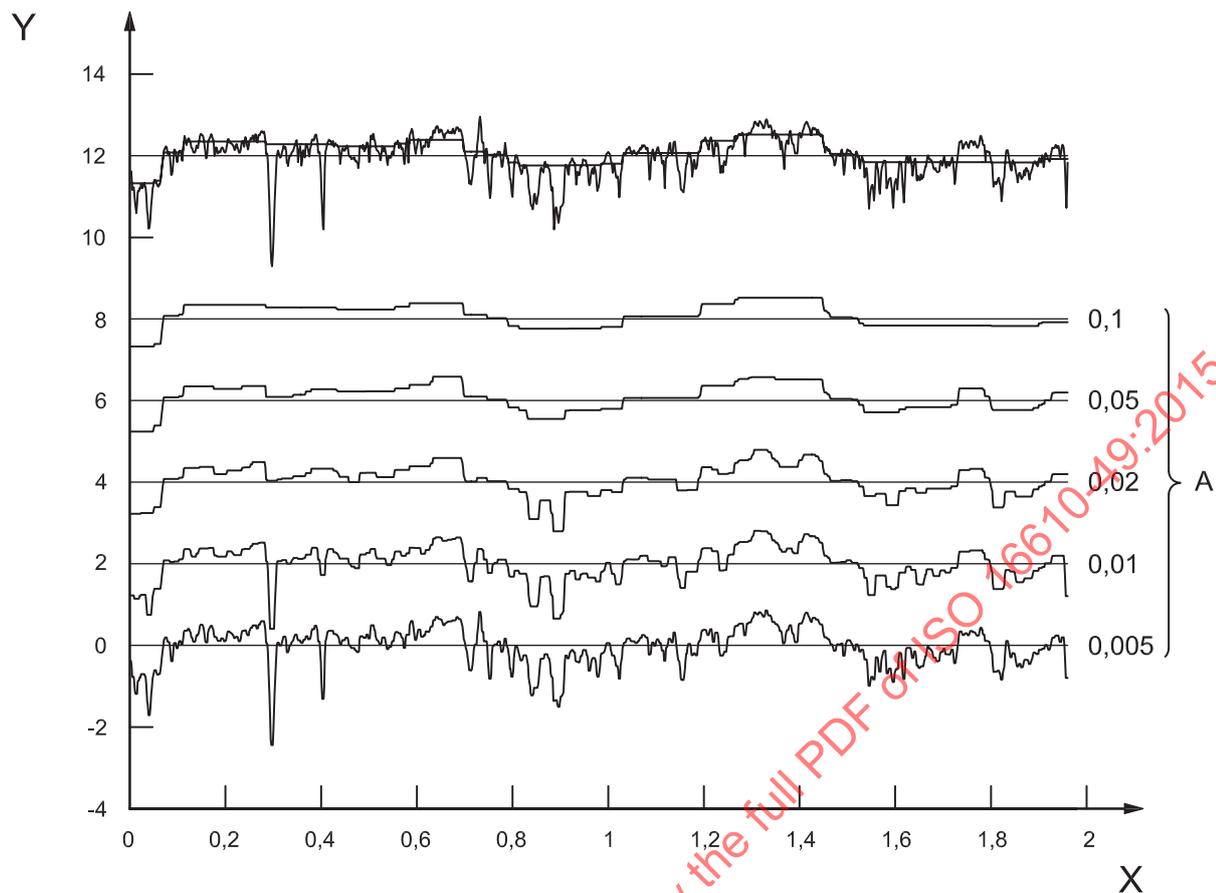


Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 A scale, mm

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

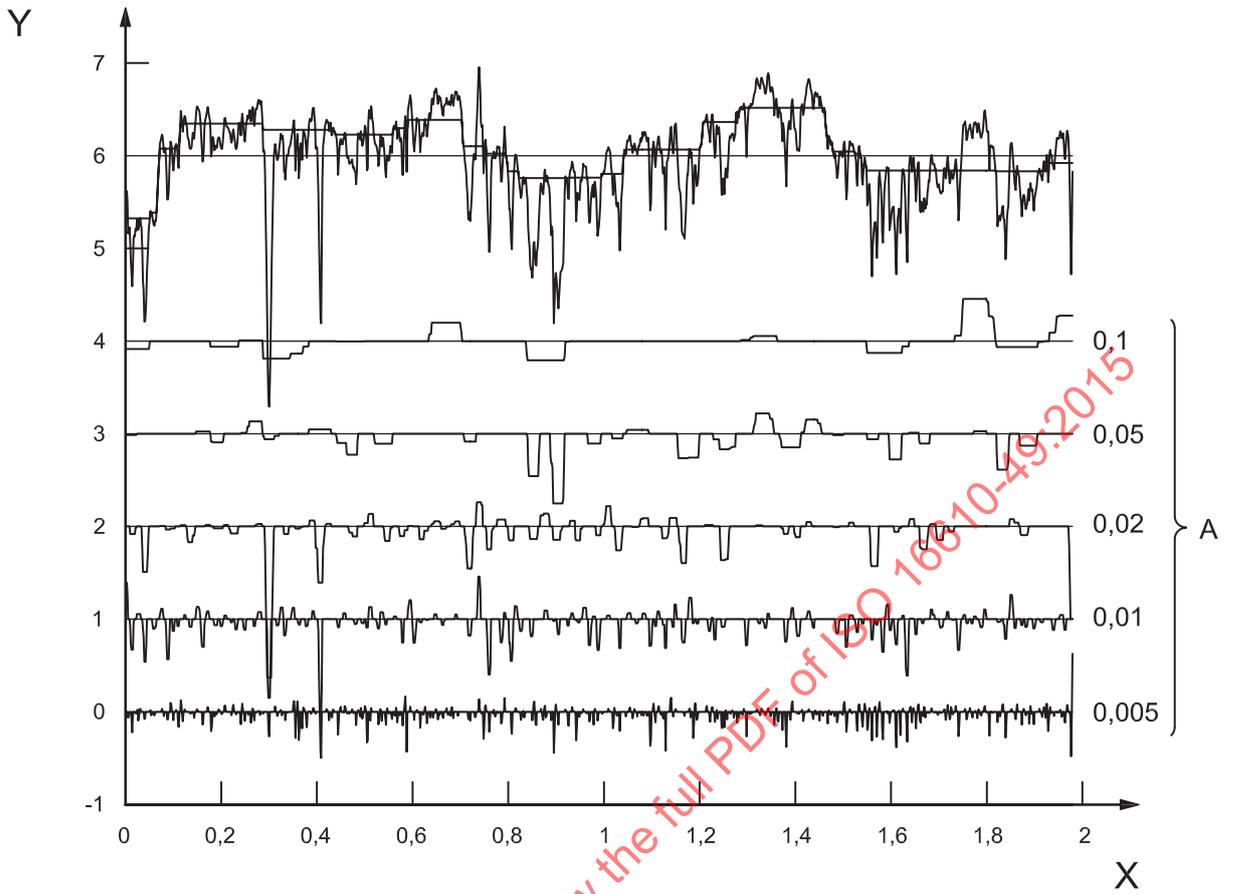
This is the same rough ceramic surface as in [A.3](#). The series of scale values given in [Clause 4](#) is used, starting with the first value larger than the stylus tip radius. [Figure A.7](#) shows the successively smoothed profiles, together with the original profile at the top. Notice how the smoothed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



Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 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 0,01 mm, reflecting the width of these features.



Key  
 X distance, mm  
 Y height,  $\mu\text{m}$   
 A scale, mm

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