TECHNICAL SPECIFICATION

ISO/TS 16610-28

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Geometrical product specifications (GPS) — Filtration —

Part 28:
Profile filters: End effects

Spécification géométrique des produits (GPS) — Filtrage —

Partie 28: Filtres de profil: Effets de bords

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Foreword

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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.

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

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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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.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 16610-28 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

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

— *Part 1: Overview and basic concepts* [Technical Specification]

— *Part 20: Linear profile filters: Basic concepts* [Technical Specification]

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

— *Part 22: Linear profile filters: Spline filters* [Technical Specification]

— *Part 28: Profile filters: End effects* [Technical Specification]

— *Part 29: Linear profile filters: Spline wavelets* [Technical Specification]

— *Part 30: Robust profile filters: Basic concepts* [Technical Specification]

— *Part 31: Robust profile filters: Gaussian regression filters* [Technical Specification]

— *Part 32: Robust profile filters: Spline filters* [Technical Specification]

— *Part 40: Morphological profile filters: Basic concepts* [Technical Specification]

— *Part 41: Morphological profile filters: Disk and horizontal line-segment filters* [Technical Specification]

— *Part 49: Morphological profile filters: Scale space techniques* [Technical Specification]

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 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 16610 is a geometrical product specification (GPS) standard and is to be regarded as a global GPS standard (see ISO/TR 14638). It influences the chain link 3 of all chains of standards.

For more detailed information of the relation of this part of ISO 16610 to the GPS matrix model, see Annex C.

This part of ISO 16610 develops the concept of handling end effects in the case of linear profile filters.

Geometrical product specifications (GPS) — Filtration —

Part 28:
Profile filters: End effects

1 Scope

This part of ISO 16610 provides methods for treating the end effects of linear profile filters where such effects occur.

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, *Geometrical product specifications (GPS) — Filtration — Part 1: Overview and basic concepts*

ISO/TS 16610-20, *Geometrical product specifications (GPS) — Filtration — Part 20: Linear profile filters: Basic concepts*

ISO 16610-21, *Geometrical product specifications (GPS) — Filtration — Part 21: Linear profile filters: Gaussian filters*

ISO/TS 16610-22, *Geometrical product specifications (GPS) — Filtration — Part 22: Linear profile filters: Spline filters*

ISO/TS 16610-31, *Geometrical product specifications (GPS) — Filtration — Part 31: Robust profile filters: Gaussian regression filters*

ISO/TS 16610-32, *Geometrical product specifications (GPS) — Filtration — Part 32: Robust profile filters: Spline filters*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99, ISO/TS 16610-1, ISO/TS 16610-20, ISO 16610-21, ISO/TS 16610-22, ISO/TS 16610-31, ISO/TS 16610-32 and the following apply.

3.1
end effect
unintentional changes in the filtration response in the end portions of an open profile

3.2
end effect region
end portion of an open profile where end effects are significant

3.3
moment
nth moment, μ_n, of a real valued function $f(x)$, defined by

$$\mu_n = \int_{-\infty}^{\infty} x^n \times f(x) \times \mathrm{d}x \quad (1)$$

3.4
moment criterion
criterion applying to the shift invariant filter class of a linear profile filter where the weighting function of the filtration operation has vanishing moments up to the nth order, as expressed by

$$\int_{\Omega} x^p \times s(x) \times \mathrm{d}x = 0, \quad p = 1, \ldots, n \quad (2)$$

where $s(x)$ is the weighting function of the filter and Ω the definition area of the weighting function

4 End effect correction methods

4.1 General

A linear shift invariant profile filter can be implemented as a weighted moving average with a constant weighting function, $s(x)$, e.g. the Gaussian bell curve according to ISO 16610-21. Because the measured profile, $z(x)$, is always finite, $s(x)$ must have a local support, $-l_1 \leqslant x \leqslant l_2$, which is normally much smaller than the traversing length. Therefore, the filter equation for the low-pass filter based on the convolution is defined as

$$w(x) = \int_{-l_1}^{l_2} z(x-u) \times s(u) \times \mathrm{d}u = \int_{x-l_2}^{x+l_1} z(u) \times s(x-u) \times \mathrm{d}u, \quad l_2 \leqslant x \leqslant lt - l_1 \quad (3)$$

where

$w(x)$ is the reference line;

$z(x)$ is the measured profile;

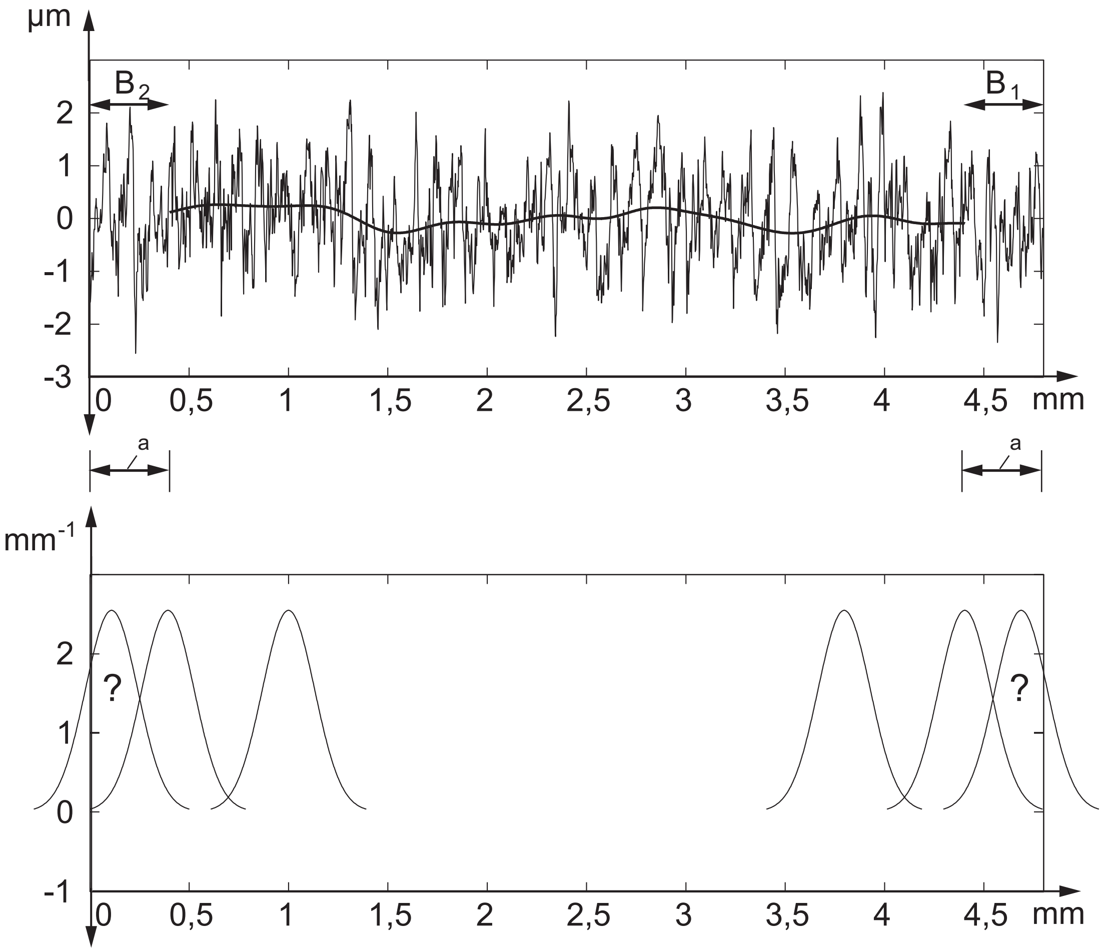
lt is the measuring length.

In contrast to profile $z(x)$, reference line $w(x)$ is only valid for $l_2 \leqslant x \leqslant lt - l_1$. The end effect regions are $B_2 = [0, l_2]$ and $B_1 = [lt - l_1, lt]$.

NOTE 1 For simplicity, only continuous weighting functions $s(x)$ are considered in this part of ISO 16610. The methods are also valid for discrete weighting functions.

NOTE 2 The procedure can be applied directly to the profile or can modify the filtration operation.

EXAMPLE In the case of the standardized Gaussian filter (see ISO 16610-21), the weighting function has a local support, e.g. $l_1 = l_2 = \lambda_c/2$. As shown in Figure 1, the filter equation cannot be applied over the whole traversing length. In the end effect region, either the left side or the right side of the bell curve lies outside the profile.



[a] End effect region.

Figure 1 — End effects using standardized Gaussian filter

Due to their mathematical definition, the filters specified in ISO/TS 16610-22, ISO/TS 16610-29, ISO/TS 16610-32 (spline filter) and ISO/TS 16610-31 (Gaussian regression filter) have an automatic end effect correction. Annex A presents the corresponding weighting function for different positions of the linear spline filter and the linear Gaussian regression filter.

4.2 Extrapolation of the profile — Methods

4.2.1 Zero padding

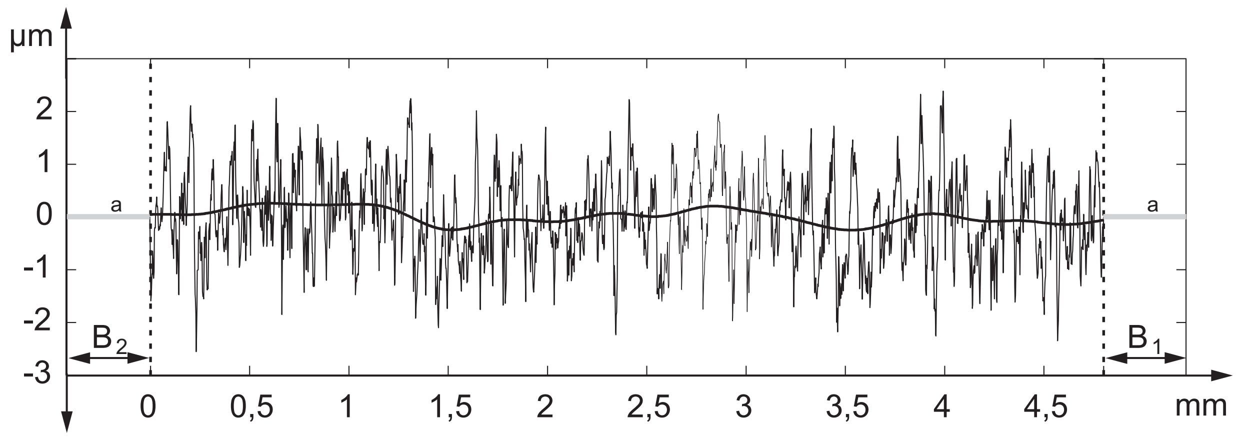
Zero padding is a simple method for retaining the traversing length after filtering the profile. Profile $z(x)$ is padded with zeros over length l_2 at the left side and over length l_1 at the right side of the profile:

$$\tilde{z}(x) = \begin{cases} 0 & \text{for} \quad -l_2 \leqslant x < 0 \\ z(x) & \text{for} \quad 0 \leqslant x \leqslant lt \\ 0 & \text{for} \quad lt < x \leqslant lt + l_1 \end{cases} \tag{4}$$

The Equation (2) filter can be rewritten as

$$w(x) = \int_{-l_1}^{l_2} \tilde{z}(x-u) \times s(u) \times \mathrm{d}u = \int_{x-l_2}^{x+l_1} \tilde{z}(u) \times s(x-u) \times \mathrm{d}u, \quad 0 \leqslant x \leqslant lt \tag{5}$$

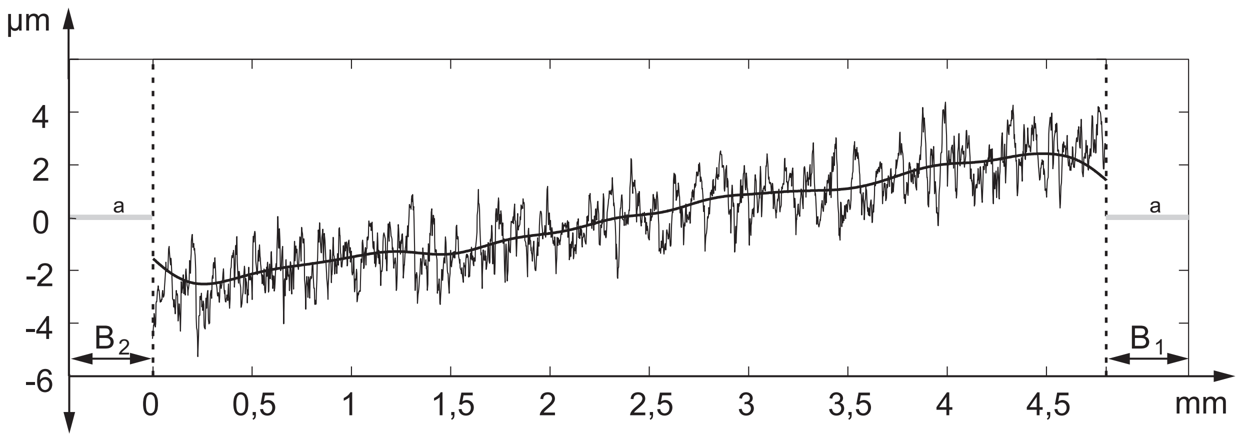
EXAMPLE 1 Figure 2 shows zero padding using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$ and a profile without a slope.



a Zero.

Figure 2 — Zero padding using standardized Gaussian filter and profile without slope

EXAMPLE 2 Figure 3 shows zero padding using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$ and a profile with a slope.



NOTE In Example 2, the end effects have not been eliminated.

a Zero.

Figure 3 — Zero padding using standardized Gaussian filter and profile with slope

4.2.2 Linear extrapolation

In the case of linear extrapolation, a least-squares line is fitted to the profile within the left and right end effect regions:

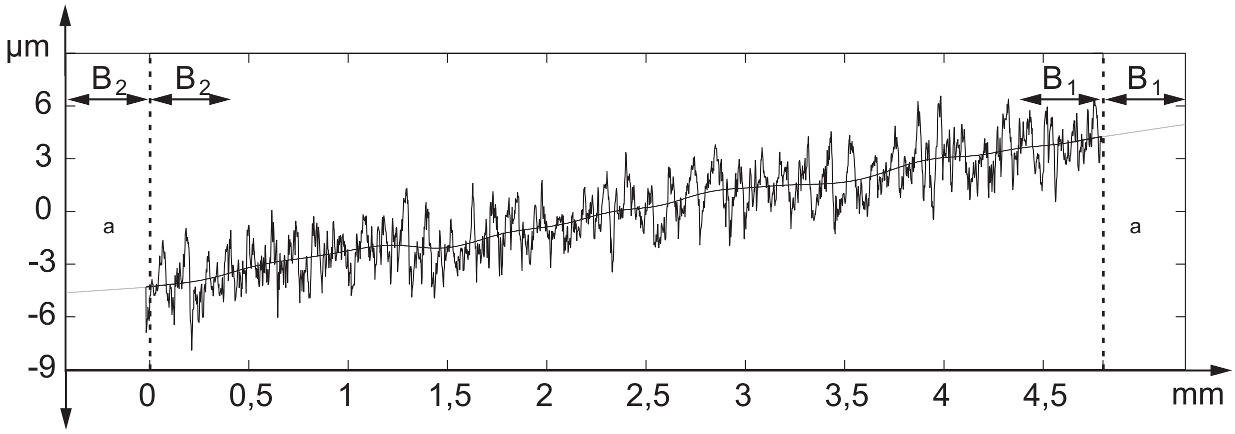
$$\int_0^{l_2} \left[z(x) - m_l \times x - t_l \right]^2 \times \mathrm{d}x \;\rightarrow\; \underset{m_l, t_l}{\mathrm{Min}} \quad \text{and} \quad \int_{lt-l_1}^{lt} \left[z(x) - m_r \times x - t_r \right]^2 \times \mathrm{d}x \;\rightarrow\; \underset{m_r, t_r}{\mathrm{Min}} \qquad (6)$$

The profile is now extended to

$$\tilde{z}(x) = \begin{cases} m_l \times x + t_l & \text{for} \quad -l_2 \leqslant x < 0 \\ z(x) & \text{for} \quad 0 \leqslant x \leqslant lt \\ m_r \times x + t_r & \text{for} \quad lt < x \leqslant lt + l_1 \end{cases} \tag{7}$$

Inserting $\tilde{z}(x)$ in Equation (5) yields the reference line.

EXAMPLE Figure 4 shows the linear extrapolation method using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$ and a profile with a slope.



NOTE In cases where more information with regard to the shape of the profile is known, more sophisticated approximation methods can be used, e.g. higher-order polynomials.

[a] Linear extrapolation.

Figure 4 — Linear extrapolation using standardized Gaussian filter and profile with slope

4.2.3 Symmetric extension

4.2.3.1 General

A measured profile is extended by symmetric extension on the left hand and right hand respectively.

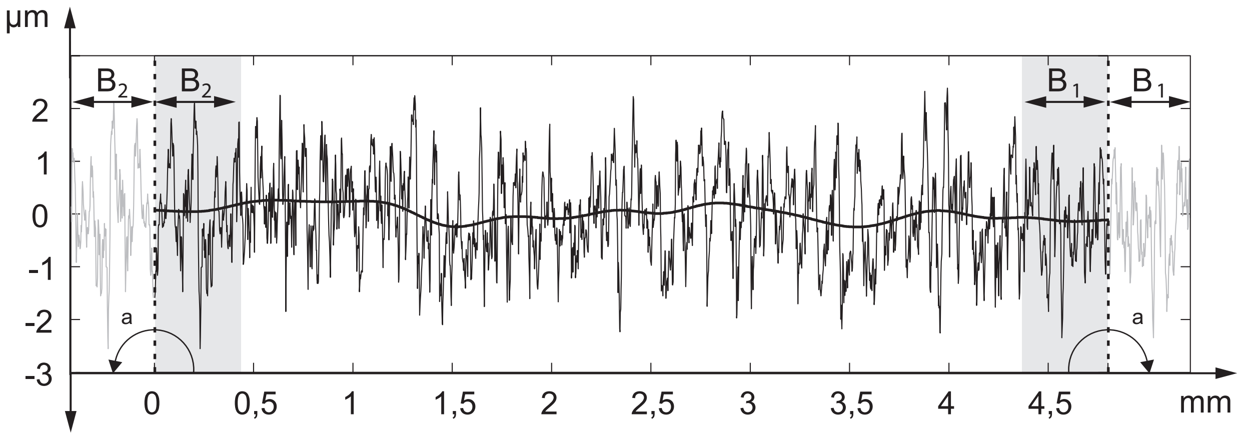
4.2.3.2 Line symmetrical reflection

A measured profile is extended by horizontal reflection on the left hand and right hand, respectively, and is defined by

$$\tilde{z}(x) = \begin{cases} z(-x) & \text{for} \quad -l_2 \leqslant x < 0 \\ z(x) & \text{for} \quad 0 \leqslant x \leqslant lt \\ z(2 \times lt - x) & \text{for} \quad lt < x \leqslant lt + l_1 \end{cases} \tag{8}$$

Inserting $\tilde{z}(x)$ in Equation (5) yields the reference line.

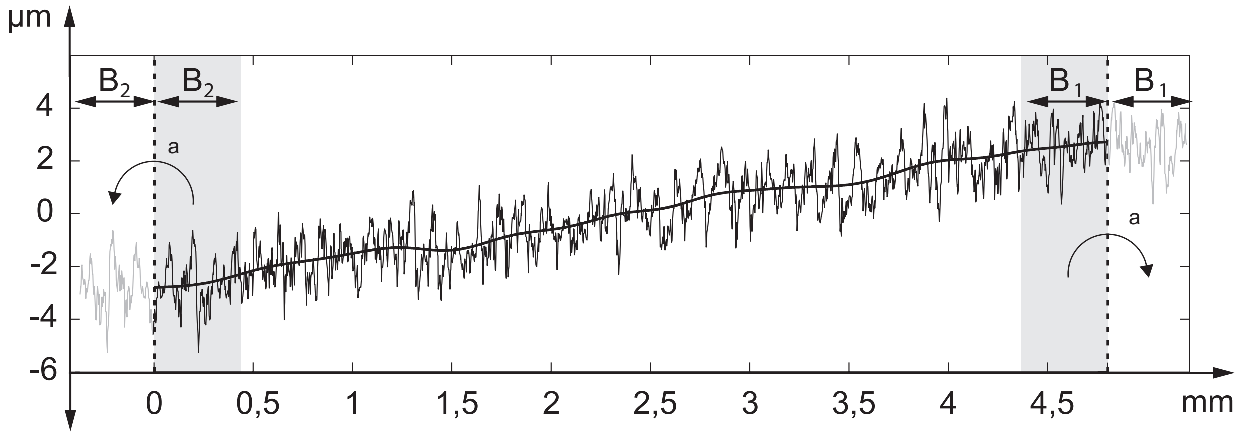
EXAMPLE 1 Figure 5 shows the line symmetrical reflection method using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$.



a Reflected.

Figure 5 — Line symmetrical profile reflection using standardized Gaussian filter

EXAMPLE 2 Figure 6 shows the line symmetrical reflection method using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$ and a profile with a slope.



a Reflected.

Figure 6 — Line symmetrical profile reflection using standardized Gaussian filter and profile with slope

4.2.3.3 Point symmetrical reflection

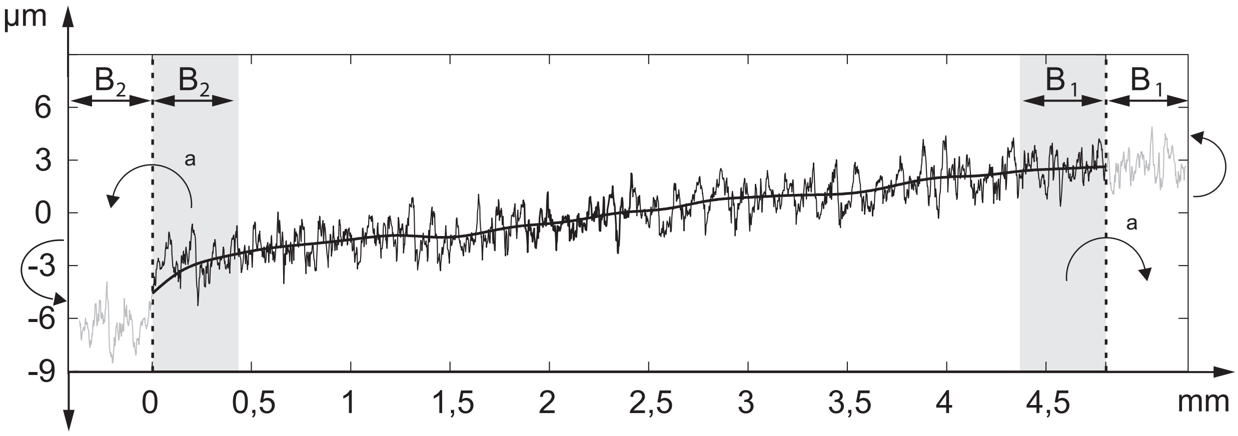
A measured profile is extended by horizontal reflection in conjunction with vertical reflection on the left and right hand respectively. Both reflection lines shall intersect at the respective end point of the profile.

The point symmetrical reflection is defined by

$$\tilde{z}(x) = \begin{cases} 2 \times z(x=0) - z(-x) & \text{for} \quad -l_2 \leqslant x < 0 \\ z(x) & \text{for} \quad 0 \leqslant x \leqslant lt \\ 2 \times z(x=lt) - z(2 \times lt - x) & \text{for} \quad lt < x \leqslant lt + l_1 \end{cases} \tag{9}$$

Inserting $\tilde{z}(x)$ in Equation (5) yields the reference line.

EXAMPLE 1 Figure 7 shows the point symmetrical reflection method using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$.



[a] Reflected.

Figure 7 — Point symmetrical profile reflection using standardized Gaussian filter

4.3 Moment retainment criterion (default case)

In order to retain the moment criterion for a given weighting function, $s(x)$, at the end effect region, the filter equation of Equation (3) must be modified to

$$w(x) = \int_{\max(x-l_2,0)}^{\min(x+l_1,lt)} z(\xi)\times\left(\sum_{p=0}^{n} b_p(x)\times(x-u)^p \times s(x-u)\right)\times \mathrm{d}u, \quad 0 \leqslant x \leqslant lt \tag{10}$$

where

n is the last vanishing moment of the weighting function, $s(x)$;

$b_p(x)$ is the shift variant correction function.

In the interior, $-l_2 \leqslant x \leqslant lt - l_1$, the filter equation is equal to Equation (3) and $b_p(x)$ results in

$$b_p(x) = \begin{cases} 1 & \text{for} \quad p = 0 \\ 0 & \text{for} \quad p > 0' \end{cases} \quad l_2 \leqslant x \leqslant lt - l_1 \tag{11}$$

At the end effect region, $0 \leqslant x < l_2$ and $lt - l_1 < x \leqslant lt$, $b_p(x)$ can be calculated by solving the matrix equation:

$$\begin{bmatrix} \mu_0(x) & \mu_1(x) & \cdots & \mu_n(x) \\ \mu_1(x) & \mu_2(x) & \cdots & \mu_{n+1}(x) \\ \vdots & \vdots & \ddots & \vdots \\ \mu_n(x) & \mu_{n+1}(x) & \cdots & \mu_{2n}(x) \end{bmatrix} \cdot \begin{bmatrix} b_0(x) \\ b_1(x) \\ \vdots \\ b_n(x) \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{12}$$

with

$$\mu_p(x) = \int_{\max(x-l_2,0)}^{\min(x+l_1,lt)} (x-u)^p \times s(x-u)\times \mathrm{d}u, \quad p = 0,..,2n \tag{13}$$

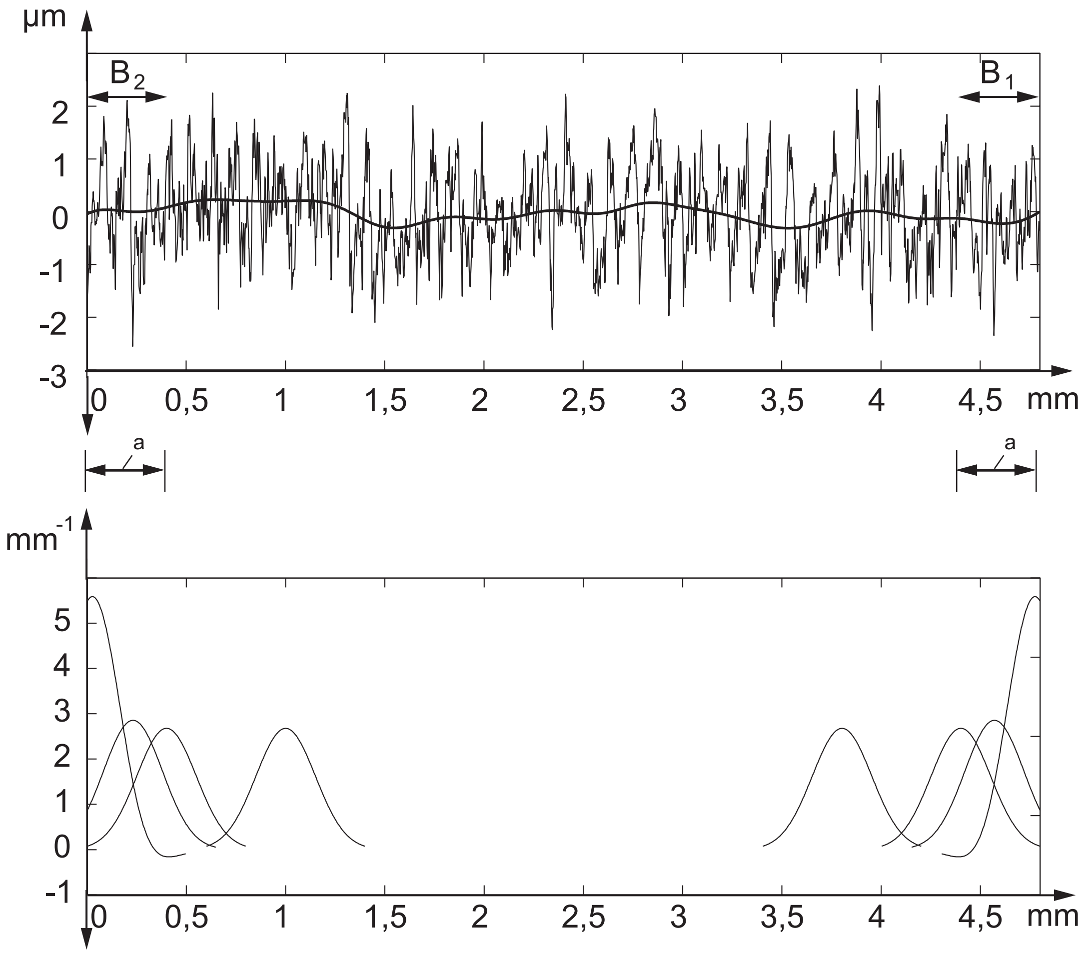
EXAMPLE 1 Due to its symmetrical weighting function, the standardized Gaussian filter has one vanishing moment, p = 1. When solving Equation (12), correction function $b_p(x)$ at the end effect region results in

$$b_0(x) = \mu_2(x) / \det(x), \quad b_1(x) = -\mu_1(x) / \det(x) \tag{14}$$

with

$$\det(x) = \mu_2(x) \times \mu_0(x) - \mu_1(x)^2$$

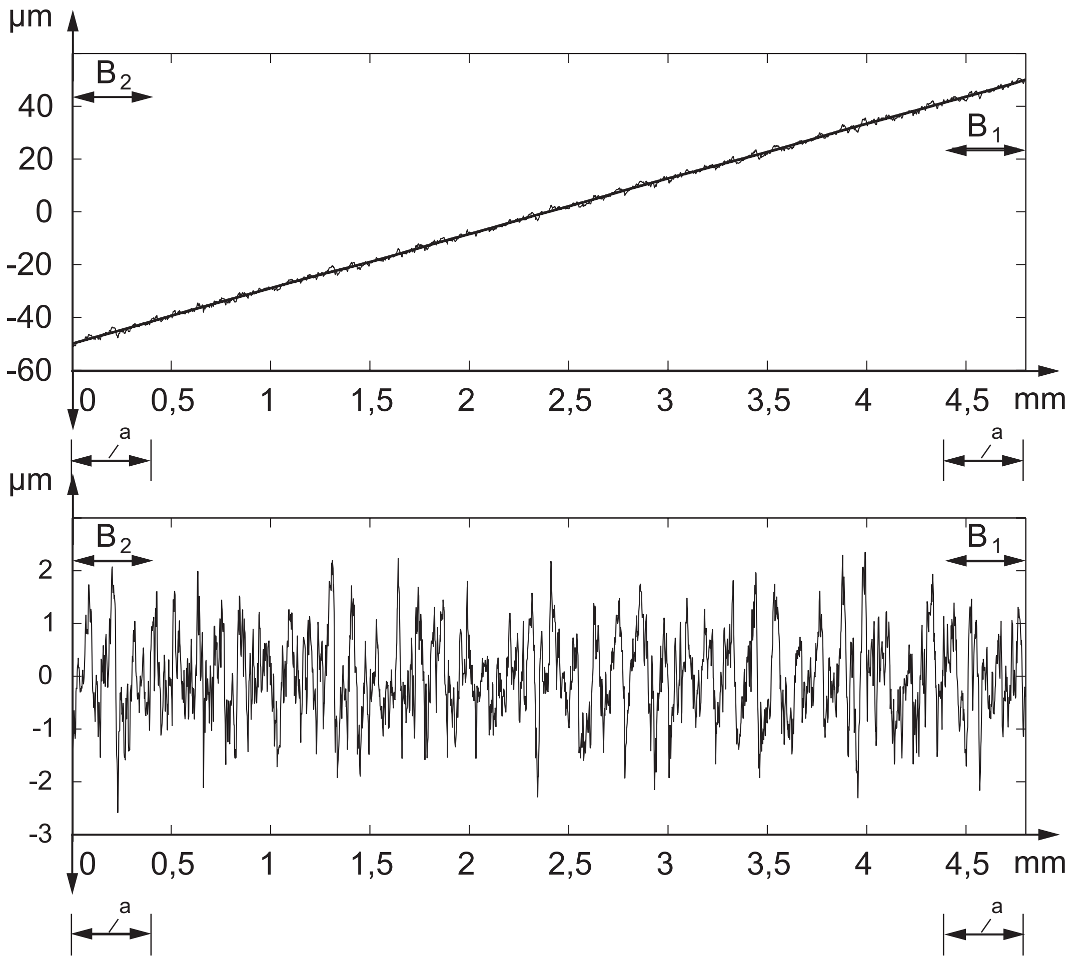
The corresponding weighting function for $l_1 = l_2 = \lambda_c/2$ at different positions is shown in Figure 8. For further information, see Reference [6].



a End effect region.

Figure 8 — Retained moment condition $n = 1$, using standardized Gaussian filter

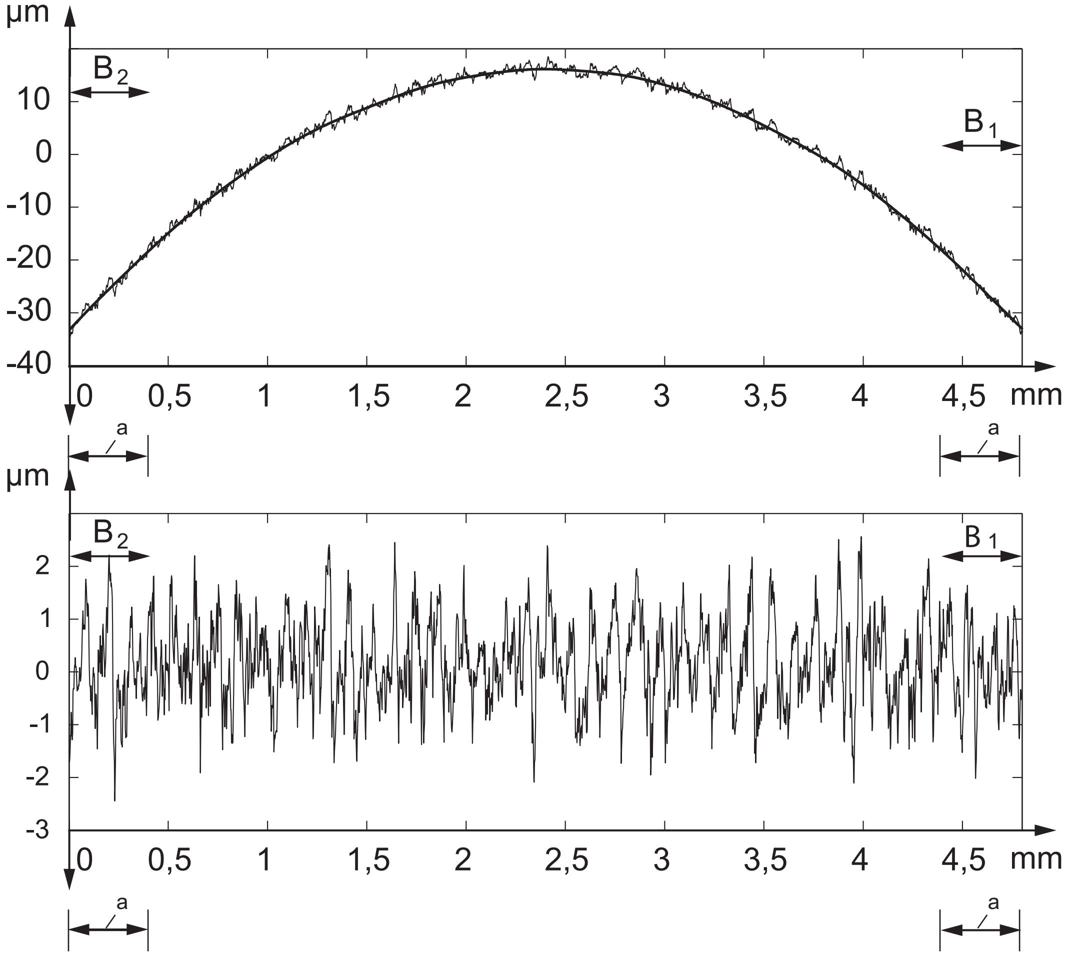
Due to the chosen moment condition, $n = 1$, the filter can exactly approximate a tilted profile as shown in Figure 9.



[a] End effect region.

Figure 9 — Retained moment condition $n = 1$, using standardized Gaussian filter and tilted profile

As shown in Figure 10, moment condition $n = 1$ leads also to a good approximation of a profile with an arc.



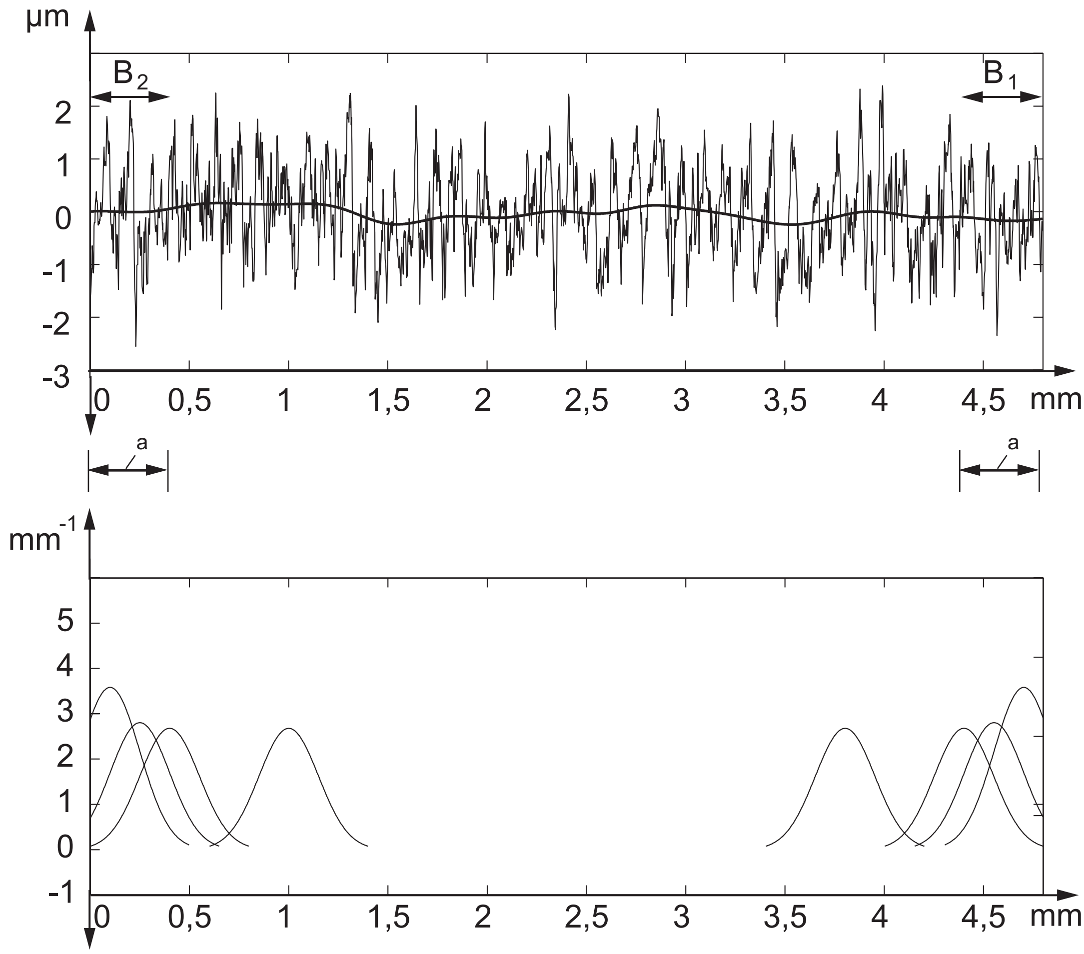
[a] End effect region.

Figure 10 — Retained moment condition $n = 1$, using standardized Gaussian filter and profile with arc

EXAMPLE 2 Retaining only the 0th moment leads to a very simple expression for the correction function:

$$b_0(x) = 1/\mu_0(x) \tag{15}$$

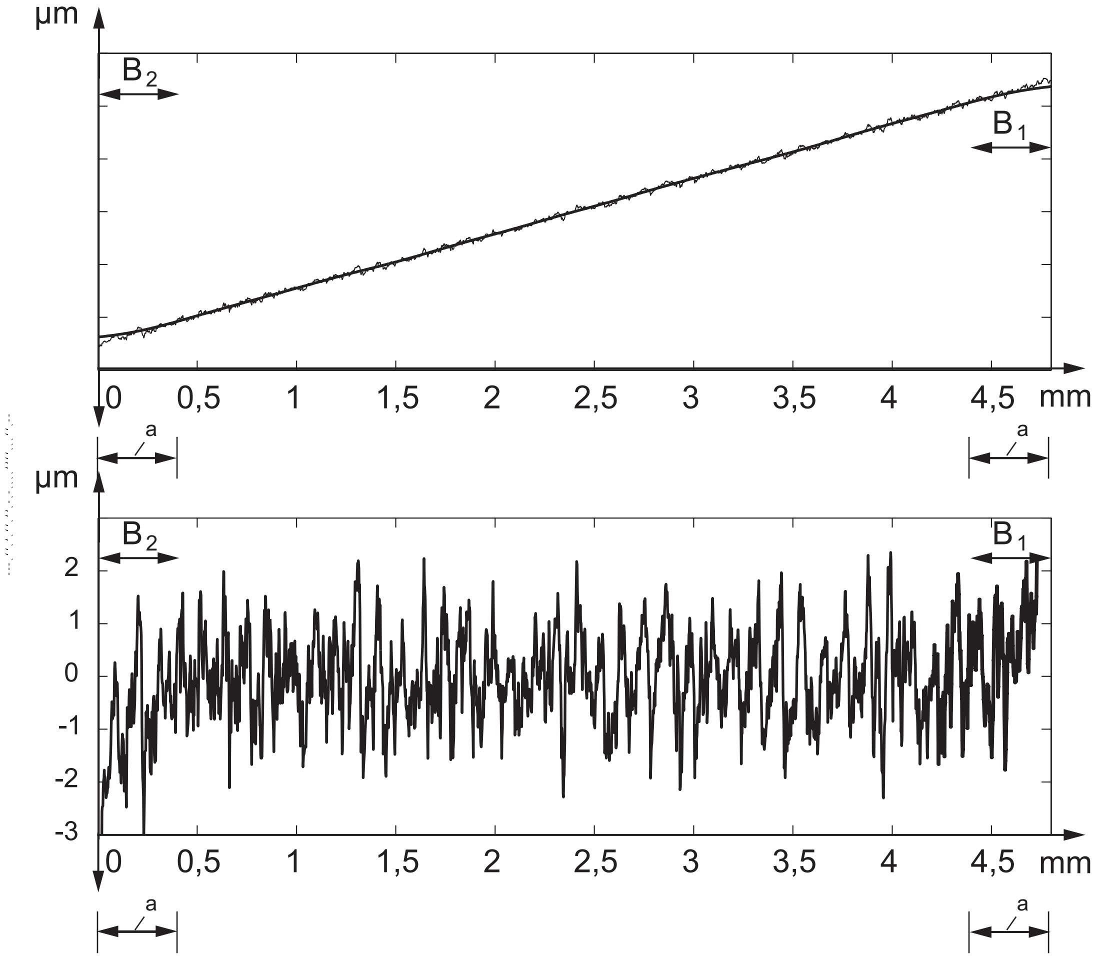
The result is shown in Figure 11 for $l_1 = l_2 = \lambda_c/2$.



[a] End effect region.

Figure 11 — Retained moment condition $n = 0$, **using standardized Gaussian filter and** $n = 0$

In contrast to Example 1, the filter has no vanishing moment and leads to a distorted roughness profile at the end effect region when filtering a highly tilted profile (see Figure 12).



[a] End effect region.

Figure 12 — Retained moment condition $n = 0$, using standardized Gaussian filter and tilted profile

Annex A
(normative)

Filters according to ISO 16610 with automatic correction of end effects

Figures A.1 and A.2 show the mean line and weighting function of filters according to ISO/TS 16610-22 (spline filter) and ISO/TS 16610-31 (Gaussian regression filter) with an automatic correction of end effects.

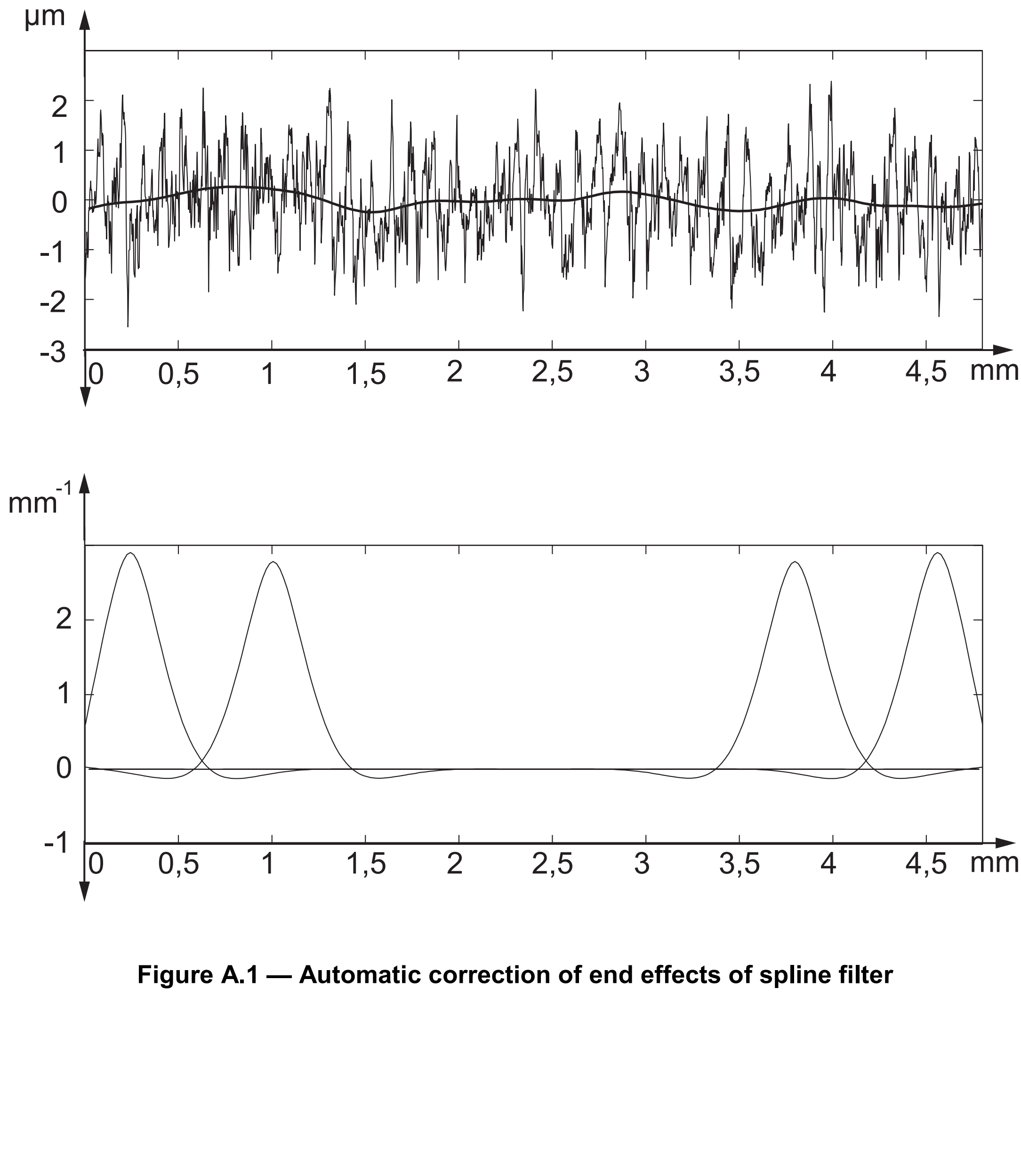


Figure A.1 — Automatic correction of end effects of spline filter

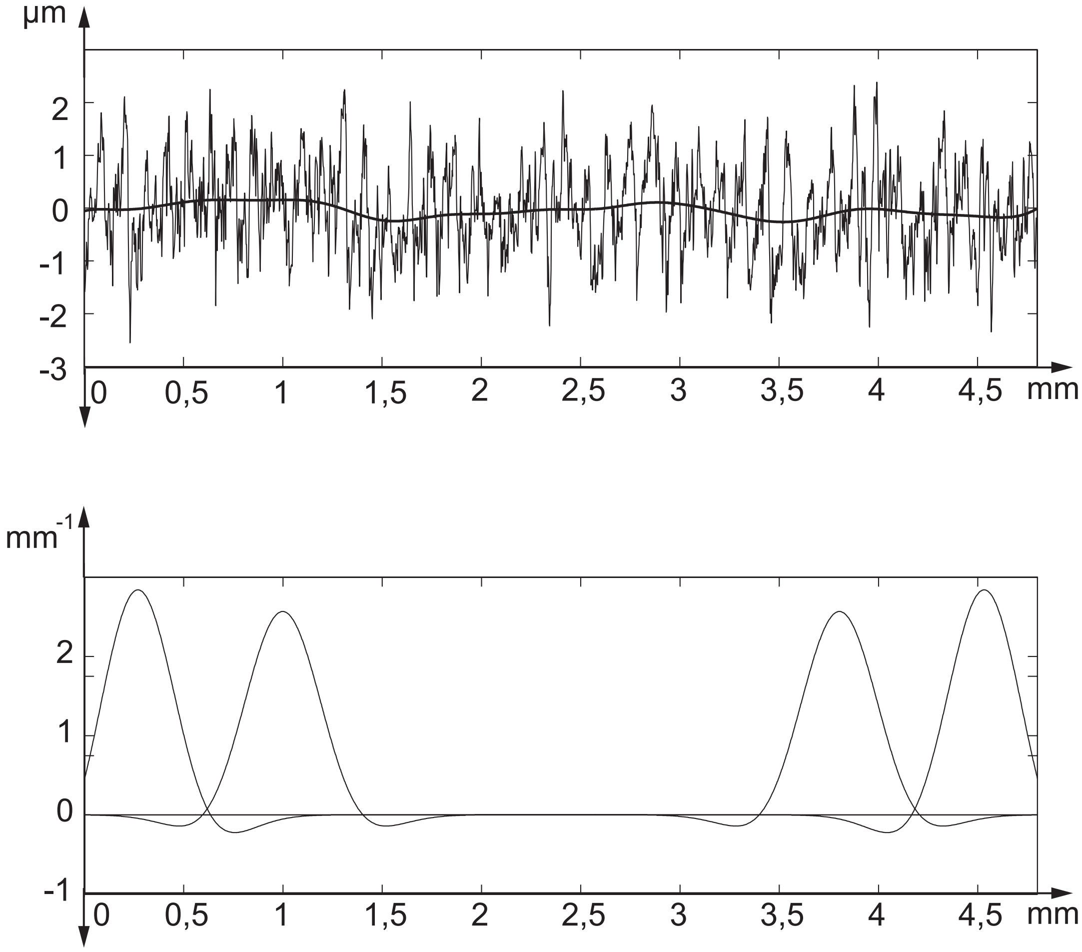


Figure A.2 — Automatic correction of end effects of Gaussian regression filter ($p = 2$)

Annex B
(informative)

Relationship to the filtration matrix model

B.1 General

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

B.2 Position in the filtration matrix model

This part of ISO 16610 is a particular filter document in the column "Profile filters, Linear" (see Figure B.1).

General	Filters: ISO 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 B.1 — Relationship to the filtration matrix model

Annex C
(informative)

Relationship to the GPS matrix model

C.1 General

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

C.2 Information on this Technical Specification and its application

This part of ISO 16610 defines the characteristics of the robust Gaussian regression filter. In particular, the robust separation of long- and short-wave components of surface profiles is defined.

C.3 Position in the GPS matrix model

This part of ISO 16610 is a global GPS Technical Specification that influences the chain link 3 of all chains of standards, as graphically illustrated on Figure C.1.

Fundamental GPS standards

Global GPS standards

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

Figure C.1 — Position in the GPS matrix model

C.4 Related International Standards

The related International Standards are those of the chain of standards indicated in Figure C.1.

Bibliography

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

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

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