TECHNICAL SPECIFICATION

ISO/TS 16610-28

First edition
2010-08-15

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

Reference number
ISO/TS 16610-28:2010(E)

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Published in Switzerland

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Foreword

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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

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

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

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

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

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

where

$w(x)$ is the reference line;

$z(x)$ is the measured profile;

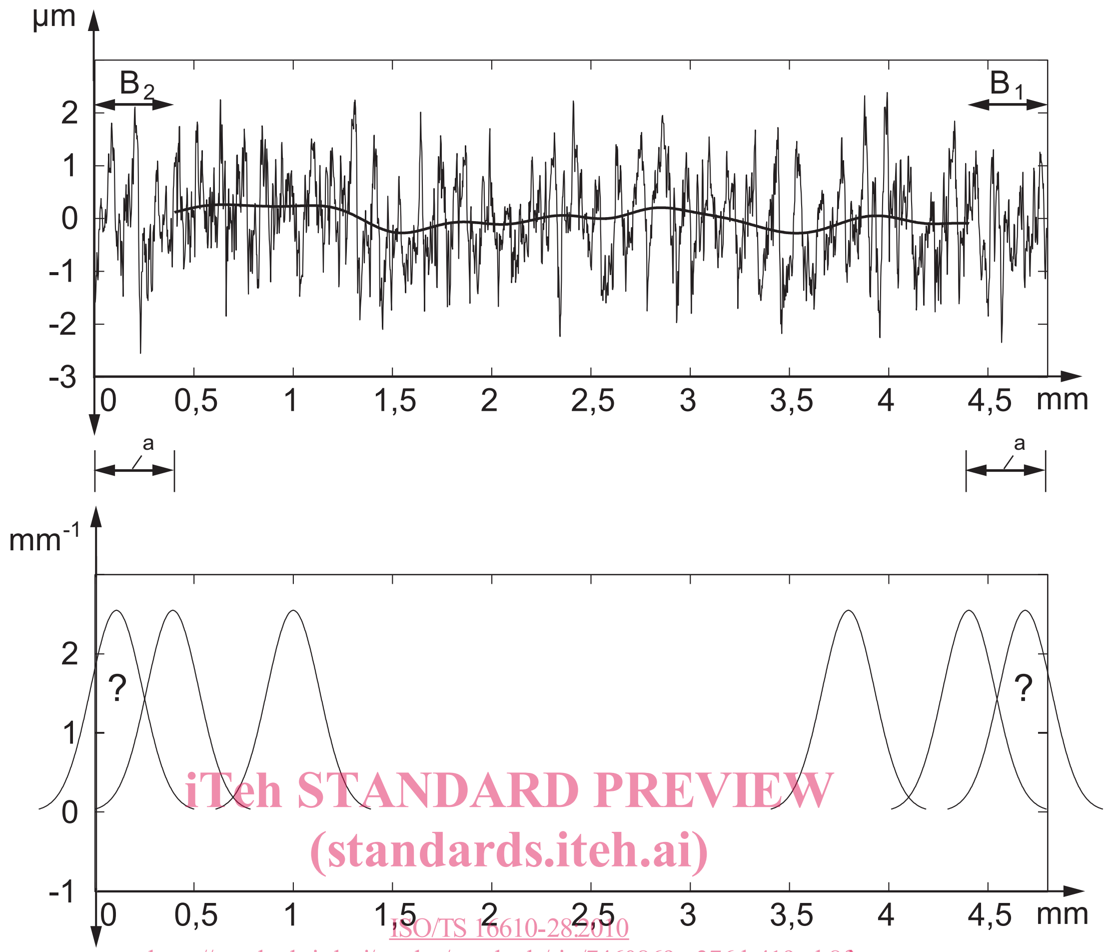
lt is the measuring length.

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

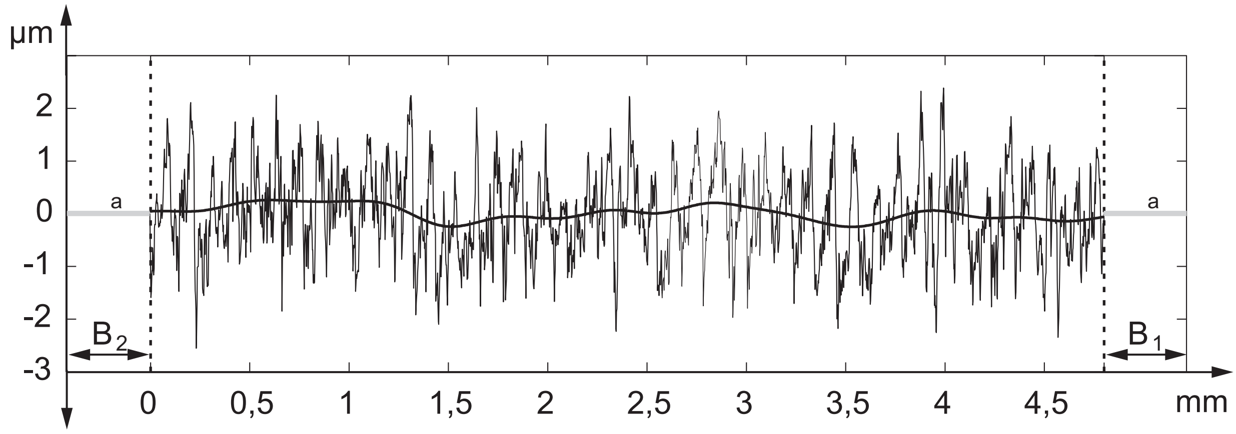
Zero padding is a simple method for retaining the traversing length after filtering the profile. Profile $z(x)$ is padded with zeros over length l_2 at the left side and over length l_1 at the right side of the profile:

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

The Equation (2) filter can be rewritten as

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

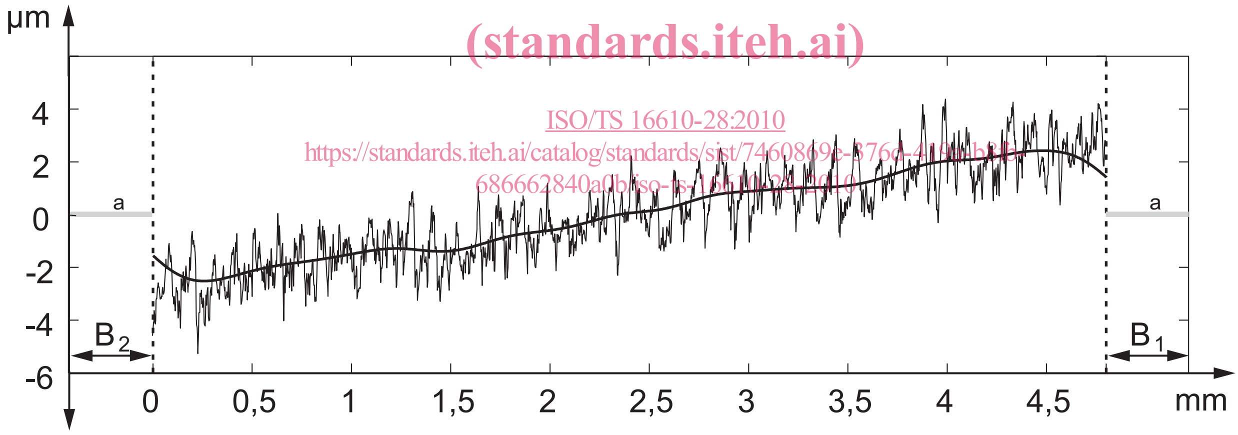
EXAMPLE 1 Figure 2 shows zero padding using the Gaussian weighting function with $l_1 = l_2 = \lambda_c/2$ and a profile without a slope.



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:

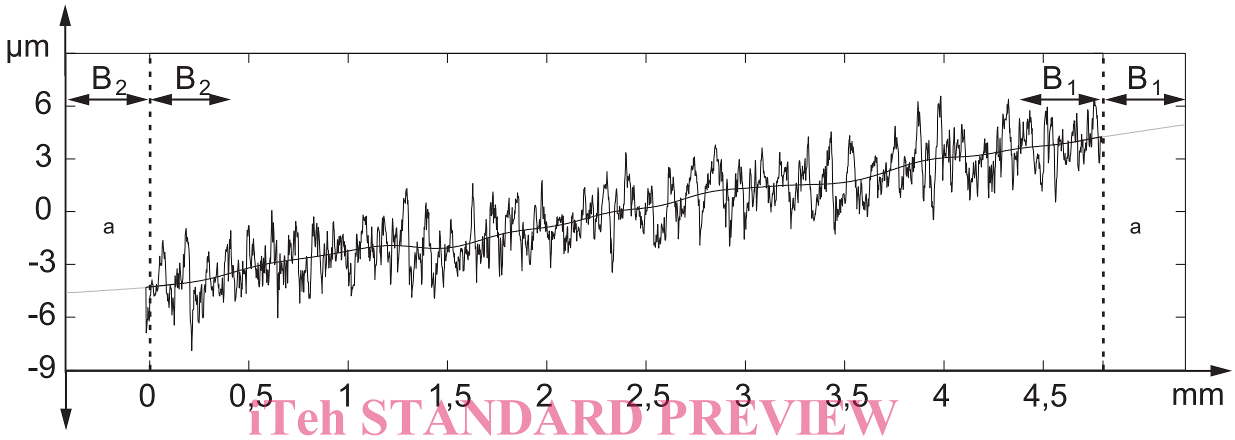
$$\int_{0}^{l_2} \left[z(x) - m_l \times x - t_l \right]^2 \times \mathrm{d}x \rightarrow \underset{m_l, t_l}{\text{Min}} \quad \text{and} \quad \int_{lt - l_1}^{lt} \left[z(x) - m_r \times x - t_r \right]^2 \times \mathrm{d}x \rightarrow \underset{m_r, t_r}{\text{Min}} \tag{6}$$

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 $l_1 = l_2 = \lambda_c/2$.