International Standard

ISO 25178-605

Geometrical product specifications (GPS) — Surface texture: Areal —

Part 605: **Design and characteristics of non-contact (point autofocus probe) instruments**

Spécification géométrique des produits (GPS) — État de surface: Surfacique —

Partie 605: Conception et caractéristiques des instruments sans contact (capteur autofocus à point)

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 290, *Dimensional and geometrical product specification and verification,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 25178-605:2014), which has been technically revised.

The main changes are as follows:

— removal of the terms and definitions now specified in ISO 25178-600;

— revision of all terms and definitions for clarity and consistency with other ISO standards documents;

— addition of Clause 4 for instrument requirements, which summarizes normative features and characteristics;

— addition of Clause 5 on metrological characteristics;

— addition of Clause 6 on design features, which clarifies the types of instruments relevant to this document;

— addition of an information flow concept diagram in Clause 4;

— revision of Annex A describing the principles of instruments addressed by this document;

— addition of Annex B on metrological characteristics and influence quantities; replacement of the normative table of influence quantities with an informative description of common error sources and how these relate the metrological characteristics in ISO 25178-600.

A list of all parts in the ISO 25178 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO 14638). It influences chain link F of the chains of standards on profile and areal surface texture.

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

For more detailed information on the relation of this document to other standards and the GPS matrix model, see Annex C.

This document includes terms and definitions relevant to the point autofocus probe (PAP) instruments for the measurement of areal surface topography. Annex A briefly summarizes PAP instruments and methods to clarify the definitions and to provide a foundation for Annex B, which describes common sources of uncertainty and their relation to the metrological characteristics of PAP.

NOTE Portions of this document, particularly the informative sections, describe patented systems and methods. This information is provided only to assist users in understanding the operating principles of PAP instruments. This document is not intended to establish priority for any intellectual property, nor does it imply a license to proprietary technologies described herein.

Geometrical product specifications (GPS) — Surface texture: Areal —

Part 605:
Design and characteristics of non-contact (point autofocus probe) instruments

1 Scope

This document specifies the design and metrological characteristics of point autofocus probe (PAP) instruments for the areal measurement of surface topography. Because surface profiles can be extracted from areal surface topography data, the methods described in this document are also applicable to profiling measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 25178-600:2019, *Geometrical product specifications (GPS) — Surface texture: Areal — Part 600: Metrological characteristics for areal topography measuring methods*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 25178-600 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
probing system
<point autofocus probe> component of the instrument consisting of an autofocus optical system, an *autofocus mechanism* (3.6) and an electronic controller

3.2
point autofocus probe
PAP
device that converts the height of a point on a surface into a signal during measurement using the autofocus function

3.3
point autofocus profiling
surface topography measurement method whereby the local surface height is measured by automatically centring a focused light beam reflected from the sample on a position sensitive detector as a function of surface height

[SOURCE: ISO 25178-6:2010, 3.3.11]

3.4
objective
lens that focuses the light source image on the workpiece surface

3.5
autofocus sensor
optical sensor that detects a focal position using the light reflected from the workpiece surface

3.6
autofocus mechanism
autofocus driving mechanism that positions optical elements or the whole optical system

3.7
***z*-position sensor**
sensor that measures the vertical position of the measured point

3.8
working distance
<point autofocus probe> distance along the optical axis between the element closest to the surface and the focus point on the surface

Note 1 to entry: Maximum measurable step height is related to working distance.

3.9
spot size
W_{SPOT}
<point autofocus probe> size of the light source image focused on the workpiece surface

Note 1 to entry: See Clause B.2.

3.10
focus range
range of z heights, within which it is possible to achieve adequate focus

3.11
vertical range
R_{VERT}
<point autofocus probe> measuring range of the autofocus probe in z heights within which it is possible to output reliable data

3.12
measurable minimum reflection ratio
M_{REF}
minimum ratio of the reflected light intensity to the incident light intensity for a measurable workpiece surface

3.13
autofocus repeatability
R_{AF}
measurement repeatability of the autofocus function, excluding the effect of environmental noise

3.14
speckle noise
N_{SPC}
noise due to non-uniform intensity of reflected light generated by irregular micro-scale geometry of the workpiece surface within the *spot size* (3.9)

Note 1 to entry: Refer to Reference [10].

3.15
temperature drift deviation
$D_{\text{TEM}x}$, $D_{\text{TEM}y}$, $D_{\text{TEM}z}$
form deviation caused by changes in temperature

Note 1 to entry: This deviation is typically managed by increasing measurement speed and reducing the rate or range of temperature variation.

Note 2 to entry: Refer to Reference [14].

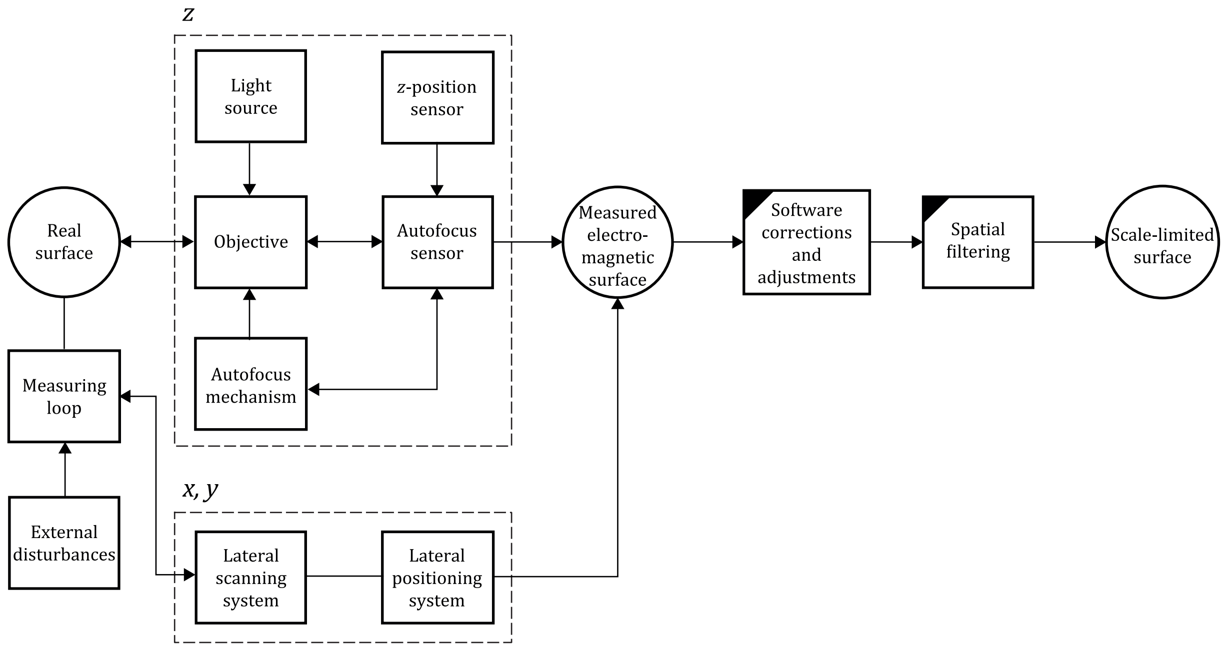
3.16
beam offset direction
direction of the offset of the light source optical axis from the optical axis of the *objective* (3.4)

Note 1 to entry: See Clause B.4.

4 Instrument requirements

An instrument according to this document shall perform an areal surface topography measurement of a surface using point autofocus profiling. The instrument shall comprise a PAP and a lateral scanning system. The PAP instrument shall comprise an objective, an autofocus sensor, a *z*-position sensor and an autofocus mechanism for automatically measuring a local height of the surface. The instrument shall acquire data by scanning the surface in *x*- and *y*-directions while autofocusing on it. The instrument shall save acquired point cloud data in order to generate an areal topography.

Figure 1 shows the information flow between these elements for a PAP instrument, flowing from a workpiece surface to a primary surface. Examples of PAP instrument hardware, techniques and error sources are given in Annexes A and B.



Key

x, *y*	scanning systems
z	probing system
(circle)	measurand
(box with marked corner)	operator with intended modification
(box)	operator without intended modification

Figure 1 — Information flow concept diagram for a PAP instrument

5 Metrological characteristics

The standard metrological characteristics for areal surface texture measuring instruments specified in ISO 25178-600 shall be considered when designing and calibrating the instrument. Additional metrological characteristics or error sources, or both, for an instrument according to this document consist of working distance, spot size, focus range, vertical range, measurable minimum reflection ratio, autofocus repeatability, speckle noise, temperature drift deviation and beam offset direction. All shall be considered when designing and calibrating the instrument.

Annex B describes sources of measurement error that can influence the calibration result.

6 Design features

Standard design features described in ISO 25178-600 shall be considered in the design.

Annex A provides examples of specific design features of PAP instruments.

7 General information

The relationship between this document and the GPS matrix model is given in Annex C.

Annex A
(informative)

Principles of PAP instruments for areal surface topography measurement

A.1 General

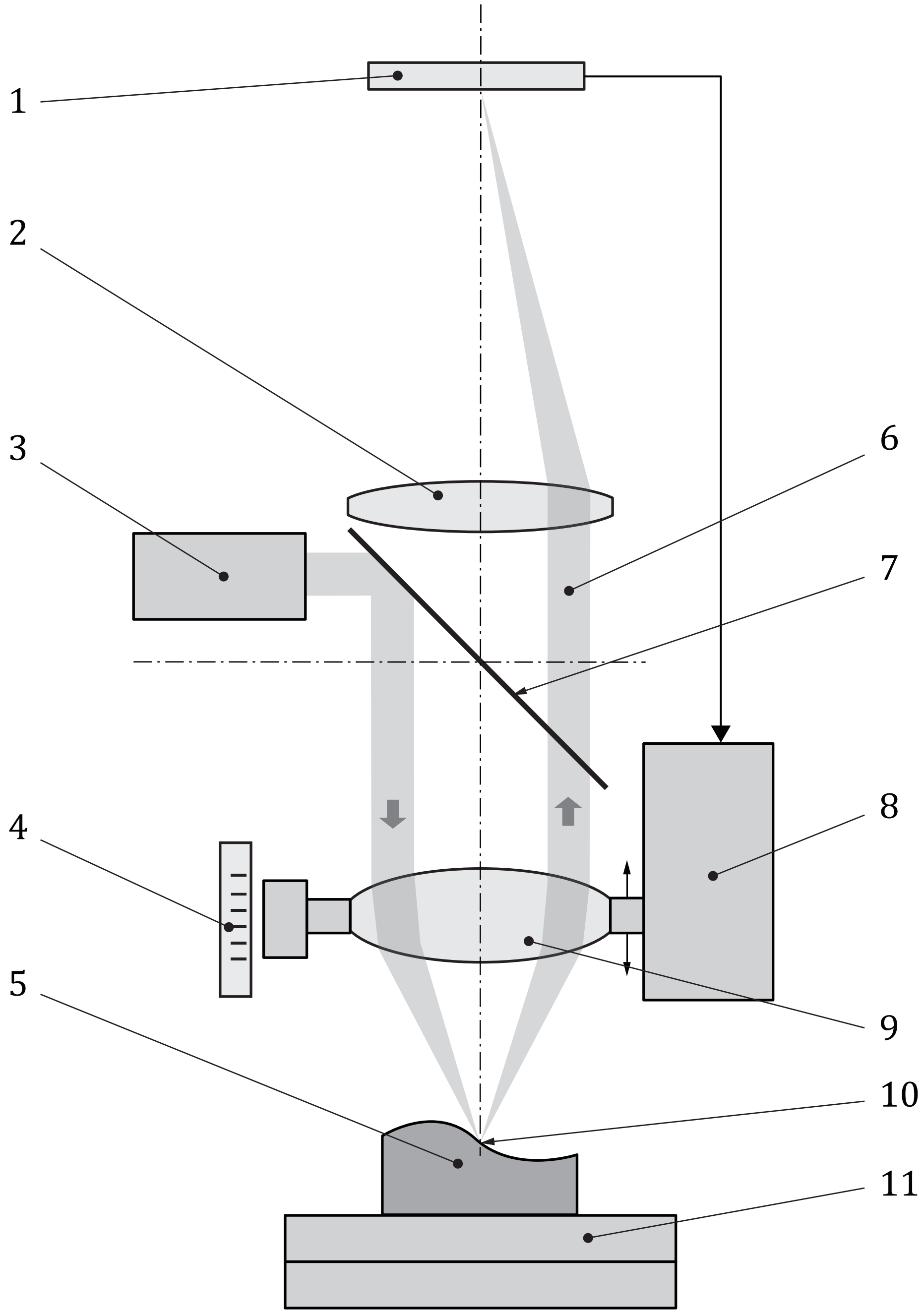
PAP instruments measure surface texture by automatically focusing a laser beam on to a point on the workpiece surface, moving the workpiece surface with fixed sampling intervals using an x-y scanning stage, and measuring the workpiece surface height at each focused point.

A.2 Instrument design

Figure A.1 illustrates a typical optical system for PAP instruments. A laser beam that can be focused to a small spot is generally used for the light source. The optical axis of the laser beam passes through the left-hand side of the objective and focuses on to the workpiece surface at the centre of the optical axis. The reflected laser beam passes through the right-hand side of the objective and forms an image on the autofocus sensor after passing through the imaging lens. Figure A.1 shows the "in-focus" state.

Figure A.2 shows the principle of the autofocus operation. Figure A.2 a) shows the in-focus state. Figure A.2 b) shows the defocused state. When the workpiece surface is displaced downward (Δz), the laser beam position on the autofocus sensor changes accordingly. The autofocus sensor detects the laser spot position; hence, the sensor detects the laser spot displacement (W) and feeds this information back to the autofocus mechanism in order to adjust the objective to the in-focus position. Figure A.2 c) shows the refocus state. The displacement of the workpiece surface (z_1) is equal to the moving distance of the objective (z_2), and the z-position sensor (typically, a linear position scale is used) acquires the height information on the workpiece. A distinctive feature of PAP instruments is that they are not influenced by the colour or reflection coefficients of workpiece surfaces since the autofocus sensor detects the position of the laser spot, not the intensity. Also, PAP instruments have a wide measuring range and high resolution in the z-coordinate, which is equivalent to the movable range, and repeatability of the autofocus mechanism.

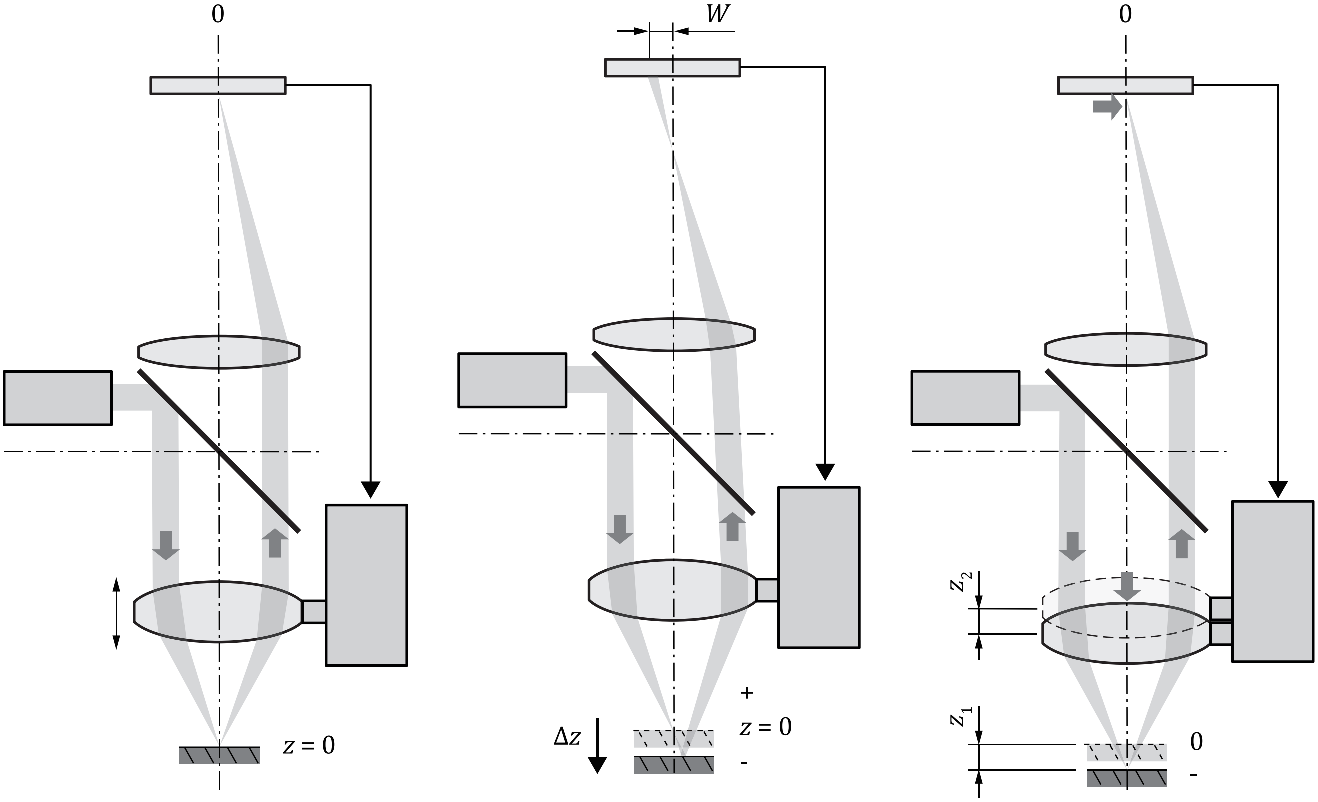
NOTE Refer to References [8], [9], [12], [13], [15], [16], [17] for further details.



Key

1	autofocus sensor
2	image lens
3	light source
4	*z*-position sensor
5	workpiece
6	laser beam
7	half mirror
8	autofocus mechanism
9	objective
10	measurement point
11	*x*- and *y*- scanning stage

Figure A.1 — Schematic diagram of a typical PAP instrument



a) In-focus state **b) Defocused state** **c) Refocus state**

Key

W	laser spot displacement on the detector	z_1	displacement of the workpiece surface
z	workpiece surface height	z_2	moving distance of the objective
Δz	downward displacement of the workpiece surface		

Figure A.2 — Principle of a typical PAP operation

A.3 PAP instrument

A typical PAP instrument is composed of a lateral scanning system and a PAP.

This type of instrument is also able to perform profile measurements.

The range of height measurement is determined by the movable range of the autofocus mechanism and the working distance of the objective. A typical measuring range is from a few millimetres to several tens of millimetres.

A.4 Measurement process

A typical PAP instrument uses the following measurement process.

— The probing system performs profile acquisition through continuous measurement along the *x*-axis over measuring length.

— After the profile has been measured, the probing system returns to its starting position of each profile.

— The perpendicular drive unit along the *y*-axis steps by one sampling interval along the *y*-axis.

— These operations are repeated until the measurement is completed.

— The raw surface is then obtained. It contains *n* profiles separated from each other by the *y*-sampling interval, each profile containing *m* points separated by the *x*-sampling interval.

It is also possible to perform the measurement without returning to the starting position after acquiring each profile. The next profile can be scanned in the opposite direction compared to the previous scan. In this case, it is recommended to check that the repositioning hysteresis is compatible with the intended measurement uncertainty. Nevertheless, a typical probing system is generally designed for measuring in only one direction.

Recommendations for choosing measuring area and sampling intervals are found in ISO 25178-3.

Annex B
(informative)

Sources of measurement error for PAP instruments

B.1 Metrological characteristics and influence quantities

ISO 25178-600:2019, 3.1.28 defines a specific set of metrological characteristics for areal surface topography measuring instruments. These metrological characteristics capture influence quantities, factors that can influence a measurement result and can be propagated through an appropriate measurement model to evaluate measurement uncertainty. See ISO 25178-700 and ISO 12179 for methods for calibration, adjustment and verification of the metrological characteristics.

In this annex, influence quantities are described that affect the metrological characteristics. Knowledge of these influence quantities is not needed for uncertainty analysis if it is feasible to perform a direct calibration of the corresponding metrological characteristics. However, knowledge of influence quantities can be useful for optimizing measurements and minimizing sources of error.

Table B.1 summarizes the influence quantities discussed in this annex.

Table B.1 — Summary of influence quantities and related metrological characteristics

Item	Influence quantity	Relevant metrological characteristic	
B.2	Spot size	N_M D_x, D_y W_R D_LIM R_l W_l	measurement noise sampling interval topographic special resolution lateral period limit lateral resolution width limit for full height transmission
B.3	Focal shift error	N_M N_SPC	measurement noise speckle noise
B.4	Beam offset direction and maximum measurable local slope	Φ_MS	maximum measurable local slope
B.5	Autofocus repeatability	D_z W_R	digitization in step in z topographic special resolution
B.6	Measurement of a surface covered with a thick transparent film	α_z	amplification coefficient
B.7	Non-measured points (autofocus errors)	N_M	measurement noise
B.8	Linearity of z-axis	F_z l_z	response function linearity deviation

B.2 Spot size

The spot size not only determines the lateral resolution, but also provides the focal shift parameter for surface measurement. When a parallel beam with a uniform intensity distribution enters from the back of the objective, the spot size (W_SPOT) at its focal plane is generally given by Formula (B.1).

$$W_\mathrm{SPOT} = \frac{1{,}22\lambda_0}{A_N} \tag{B.1}$$

where

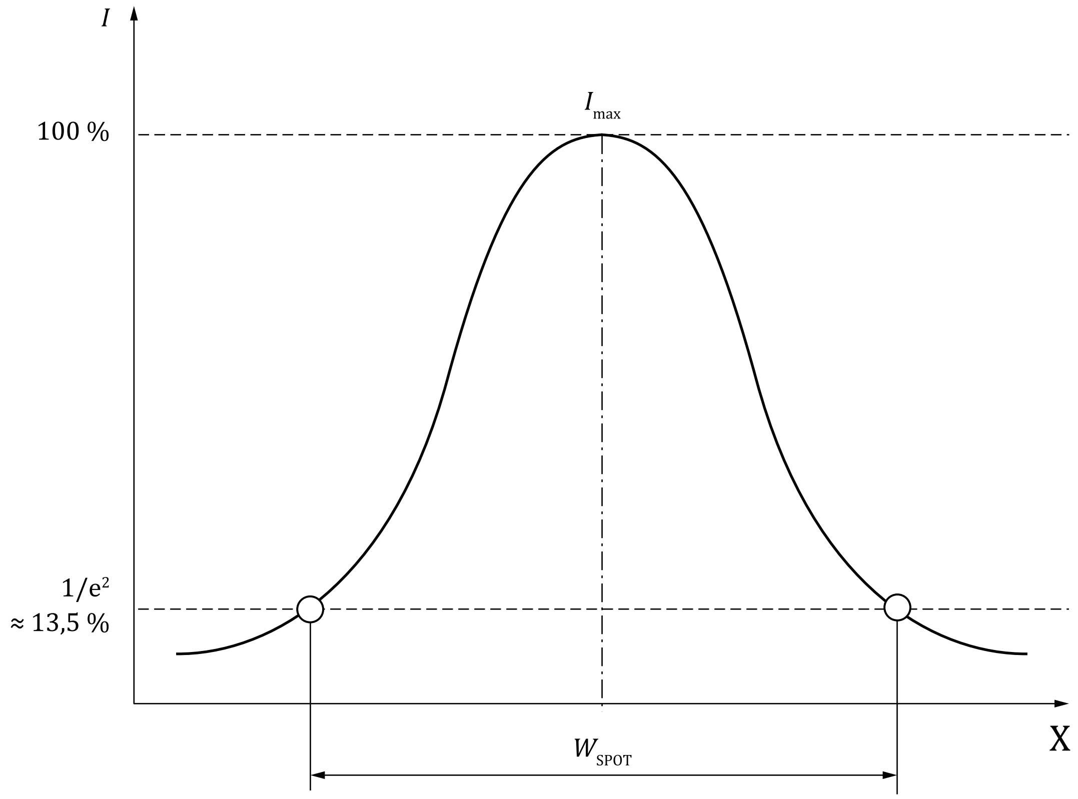
λ_0 is wavelength of the light source;

A_N is the numerical aperture.

However, in the case of a light source with a Gaussian intensity distribution, such as a laser, the spot size is expressed as a diameter, where the intensity is a specified fraction of the maximum intensity. A commonly used fraction is $1/e^2$ (≈ 13,5 %) of the maximum intensity (see Figure B.1). The associated spot size is given by Formula (B.2).

$$W_{SPOT} = \frac{0{,}61\lambda_0}{A_N} \tag{B.2}$$

Spot size is an influence quantity for the lateral period limit D_{LIM} and the lateral resolution R_l and the width limit for full height transmission W_l, defined in ISO 25178-600:2019, 3.1.21, 3.1.22 and 3.1.23, respectively.



Key

X x (µm)

I intensity

I_{max} maximum intensity

W_{spot} spot size

Figure B.1 — Spot size

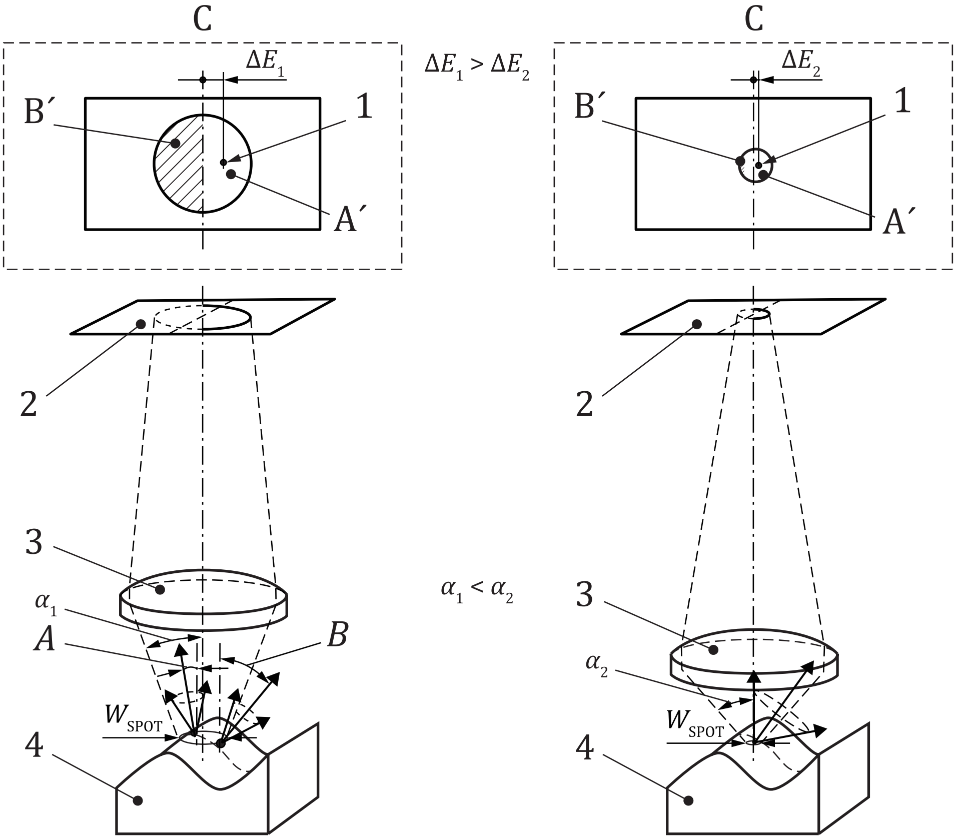
B.3 Focal shift error

Figure B.2 shows an example of focal shift errors caused by different spot sizes.

Figure B.2 a) shows a large spot image on the autofocus sensor resulting from reflection of the incident laser beam from an irregular workpiece surface. In this case the reflecting angle of ray (A) at the peak of the convex workpiece surface is less than the half aperture angle (α_1) and forms the image on the autofocus sensor that results in a bright area (A′). Conversely, the reflecting angle of ray (B) on the slope of the convex workpiece surface is greater than α_1, which causes the reflected ray (B) to miss the objective and thus forms no image on the autofocus sensor resulting in the dark area (B′). This is how non-uniform optical intensity can occur within the spot area on the autofocus sensor. When the autofocus sensor detects the geometrical centre of the spot area, the focus position shifts to ΔE_1. This is one of a source of measurement error (speckle noise N_{SPC}).

The half aperture angle (α_2) in the optical system in Figure B.2 b) is greater than α_1 in Figure B.2 a). Therefore, the autofocus sensor detects the ray on the slope of the convex workpiece surface, resulting in a smaller dark area and less variation of optical intensity in the spot area. In addition, a smaller spot size generates a smaller focus position shift, ΔE_2.

Focal shift error is an influence quantity for the measurement noise N_M defined in ISO 25178-600:2019, 3.1.15.



a) Large spot size **b) Small spot size**

Key

1	geometrical centre of spot	ΔE_1, ΔE_2	focus position shift
2	autofocus sensor	A	reflecting angle of ray
3	objective	A′	bright area
4	workpiece	B	reflecting angle of ray
α_1, α_2	half aperture angle	B′	dark area
W_{SPOT}	spot size	C	spot image on the sensor

Figure B.2 — Focal shift error with different spot sizes

B.4 Beam offset direction and maximum measurable local slope

The maximum local slope measurable with a point autofocus sensor depends on the slope orientation with respect to the laser beam offset direction. Figure B.3 shows the laser beam path offset along the y coordinate direction. The maximum measurable local slope angles in the cross-section parallel to the offset direction are

A_1 and A_2 [see Figure B.3 a)]. The maximum measurable local slope angle in the cross-section perpendicular to the offset direction is A_3 [see Figure B.3 b)]. The angles A_1, A_2 and A_3 are given by Formulae (B.3) to (B.5).

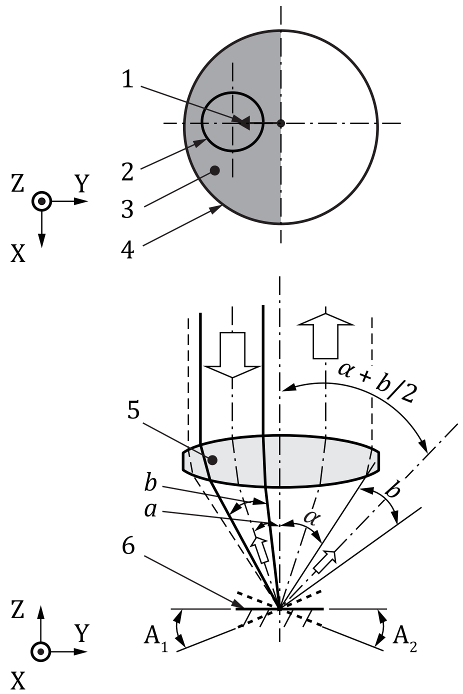
$$A_1 < \alpha \tag{B.3}$$

$$A_2 < \frac{\left(\alpha + \frac{b}{2} - a\right)}{2} \tag{B.4}$$

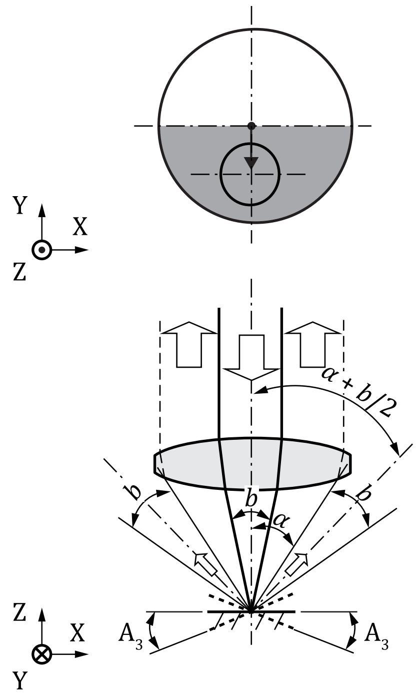
$$A_3 < \frac{\alpha}{2} + \frac{b}{4} \tag{B.5}$$

NOTE Maximum measurable local slope angles can be increased beyond these limits provided the surface returns sufficiently intense, diffusely-scattered light (e.g. due to sufficient surface roughness)[11] (see ISO 25178-600:2019, Annex A).

Beam offset direction is an influence quantity for the maximum measurable local slope Φ_{MS} defined in ISO 25178-600:2019, 3.1.24.



a) Parallel to the offset direction



b) Perpendicular to the offset direction

Key

1	offset direction	a	angle of incidence
2	light beam	b	collection angle
3	offset area	α	half aperture angle
4	aperture	A_1	maximum measurable local slope angle
5	objective	A_2	maximum measurable local slope angle
6	plane mirror	A_3	maximum measurable local slope angle

Figure B.3 — Maximum measurable local slope depending on offset direction

B.5 Autofocus repeatability

Factors that degrade the autofocus repeatability include:

— repeatability of the autofocus mechanism;

— digitization in step in z, D;

— stability of the light source;

— disturbances from the environmental such as temperature drift and vibration.

Autofocus repeatability is an influence quantity for the topographic spatial resolution W_R defined in ISO 25178-600:2019, 3.1.20.

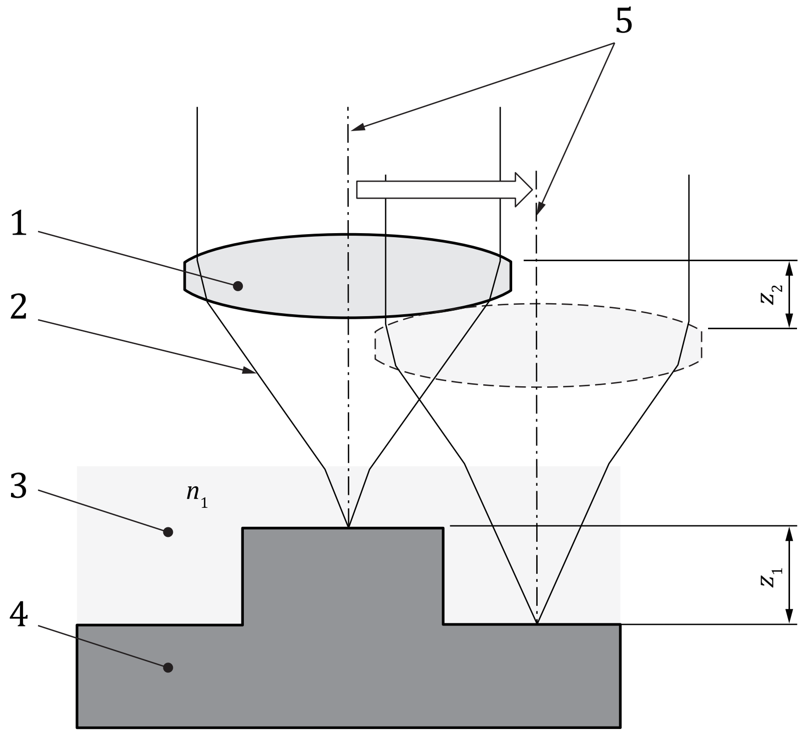
B.6 Measurement of a surface covered with a thick transparent film

When measuring the surface texture of a workpiece covered with a thick transparent film, the z-axis value is affected by the refractive index of the thick film and is given by Formula (B.6).

$$z_1 = \mathrm{Re}(n_1) \times z_2 \tag{B.6}$$

NOTE See Figure B.4.

Refractive index is an influence quantity for the amplification coefficient α_Z defined in ISO 25178-600:2019, 3.1.10.



Key

1 objective

2 light beam

3 thick film

4 base material

5 optical axis

n_1 complex index of refraction

z_1 step height of workpiece surface

z_2 objective displacement

Figure B.4 — Surface measurement covered with a transparent film

B.7 Non-measured points (autofocus errors)

When the sensor is not able to assess the *z*-position of a point on the surface, the point is marked as non-measured (i.e. no valid information is available for this point). For this class of instruments, non-measured points are informally referred to as “autofocus errors” or “autofocus error points”.

An autofocus error point is usually generated when the PAP cannot identify any spots on the autofocus sensor, generally due to one of the conditions given in Table B.2.

NOTE Non-measured points can be reconstructed by an interpolation technique.

Table B.2 — Causes of non-measured points

Autofocus error	Condition	Cause	Solution
Dim	Insufficient reflected optical intensity	— Low reflection coefficient for the workpiece surface — Large slope angle — Sudden height transition	— Increase light source power — None — Extend the autofocus range
Hunting	Autofocus mechanism oscillation near the focus position	— High servo-gain of the autofocus mechanism — Secondary reflected ray	— Lower servo-gain — Avoid detection of the secondary reflected ray
Shadowing	The dark area where the laser beam does not fall	Dead angle	None

B.8 Linearity of the *z*-axis

The metrological characteristics F_z and l_z are influenced by the linearity deviations in the *z*-axis that moves the objective combined with the Abbe offset between the *z*-position sensor and the measurement point (see Figure A.1).

Annex C
(informative)

Relationship to the GPS matrix model

C.1 General

The ISO GPS matrix model given in ISO 14638 gives an overview of the ISO GPS system of which this document is a part.

The fundamental rules of ISO GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

C.2 Information about this document and its use

This document specifies the methods, specific terminology and exemplary influence quantities for PAP instruments used to measure profile and areal surface texture.

C.3 Position in the GPS matrix model

This document is a general ISO GPS standard which influences chain link F of the chains of standards on profile and areal surface texture in the GPS matrix model, as shown in Table C.1. The rules and principles given in this document apply to all segments of the ISO GPS matrix which are indicated with a filled dot (•).

Table C.1 — Relationship to the ISO GPS matrix model

	Chain links						
	A	B	C	D	E	F	G
	Symbols and indications	Feature requirements	Feature properties	Conformance and non-conformance	Meas-ure-ment	Measurement equipment	Calibration
Size							
Distance							
Form							
Orientation							
Location							
Run-out							
Profile surface texture						•	
Areal surface texture						•	
Surface imperfections							

C.4 Related International Standards

The related International Standards are those of the chains of standards indicated in Table C.1.

Bibliography

[1] ISO 8015, *Geometrical product specifications (GPS) — Fundamentals — Concepts, principles and rules*

[2] ISO 12179, *Geometrical product specifications (GPS) — Surface texture: Profile method — Calibration of contact (stylus) instruments*

[3] ISO 14253-1, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for verifying conformity or nonconformity with specifications*

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