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

Part 603: **Nominal characteristics of non-contact (phase-shifting interferometric microscopy) instruments**

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

Partie 603: Caractéristiques nominales des instruments sans contact (microscopes interférométriques à glissement de franges)

Reference number
ISO 25178-603:2013(E)

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Foreword

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

ISO 25178 consists of the following parts, under the general title *Geometrical product specification (GPS) — Surface texture: Areal:*

— *Part 1: Areal surface texture drawing indication*

— *Part 2: Terms, definitions and surface texture parameters*

— *Part 3: Specification operators*

— *Part 6: Classification of methods for measuring surface texture*

— *Part 70: Material measures*

— *Part 71: Software measurement standards*

— *Part 601: Nominal characteristics of contact (stylus) instruments*

— *Part 602: Nominal characteristics of non-contact (confocal chromatic probe) instruments*

— *Part 603: Nominal characteristics of non-contact (phase-shifting interferometric microscopy) instruments*

— *Part 604: Nominal characteristics of non-contact (coherence scanning interferometric microscopy) instruments*

— *Part 605: Nominal characteristics of non-contact (point autofocus probe) instruments*

— *Part 606: Nominal characteristics of non-contact (focus variation microscopy) instruments*

— *Part 701: Calibration and measurement standards for contact (stylus) instruments*

— *Part 702 Calibration of non-contact (confocal chromatic probe) instruments*

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— *Part 703: Calibration and measurement standards for non-contact (interferometric) instruments*

The following part is under preparation: *Part 72: XML file format x3p*

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Introduction

This part of ISO 25178 is a Geometrical Product Specification standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences the chain link 5 of the chain of standards on areal surface texture.

This part of ISO 25178 describes the metrological characteristics of phase-shifting interferometric (PSI) profile and areal surface texture measuring microscopes, designed for the measurement of surface topography maps. For more detailed information on the phase-shifting interferometry technique, see Annex A and Annex B.

The ISO/GPS Masterplan given in ISO /TR 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.

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

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

Part 603: Nominal characteristics of non-contact (phase-shifting interferometric microscopy) instruments

1 Scope

This part of ISO 25178 describes the metrological characteristics of phase-shifting interferometric (PSI) profile and areal surface texture measuring microscopes.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1 Terms and definitions related to all areal surface texture measurement methods

2.1.1
areal reference
component of the instrument that generates a reference surface with respect to which the surface topography is measured

2.1.2
coordinate system of the instrument
right hand orthonormal system of axes (x, y, z) where

— (x, y) is the plane established by the areal reference of the instrument (note that there are optical instruments that do not possess a physical areal guide);

— z-axis is mounted parallel to the optical axis and is perpendicular to the (x, y) plane for an optical instrument; the z-axis is in the plane of the stylus trajectory and is perpendicular to the (x, y) plane for a stylus instrument

Note 1 to entry: Normally, the x-axis is the tracing axis and the y-axis is the stepping axis. (This note is valid for instruments that scan in the horizontal plane.)

Note 2 to entry: See also “specification coordinate system” [ISO 25178-2:2012, 3.1.2] and “measurement coordinate system” [ISO 25178-6:2010, 3.1.1].

SEE: Figure 1.

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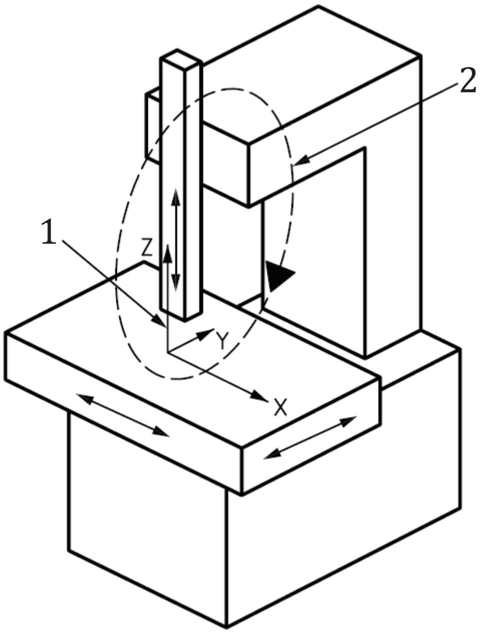

Key

1 coordinate system of the instrument

2 measurement loop

Figure 1 — Coordinate system and measurement loop of the instrument

2.1.3
measurement loop
closed chain which comprises all components connecting the workpiece and the probe, e.g. the means of positioning, the work holding fixture, the measuring stand, the drive unit, the probing system

Note 1 to entry: The measurement loop will be subjected to external and internal disturbances that influence the measurement uncertainty.

SEE: Figure 1.

2.1.4
real surface of a workpiece
set of features which physically exist and separate the entire workpiece from the surrounding medium

Note 1 to entry: The real surface is a mathematical representation of the surface that is independent of the measurement process.

Note 2 to entry: See also “mechanical surface” [ISO 25178-2:2012, 3.1.1.1 or ISO 14406:2010, 3.1.1] and “electromagnetic surface” [ISO 25178-2:2012, 3.1.1.2 or ISO 14406:2010, 3.1.2].

Note 3 to entry: The electromagnetic surface considered for one type of optical instrument may be different from the electromagnetic surface for other types of optical instruments.

2.1.5
surface probe
device that converts the surface height into a signal during measurement

Note 1 to entry: In earlier standards, this was termed “transducer”.

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2.1.6
measuring volume
range of the instrument stated in terms of the limits on all three coordinates measured by the instrument

Note 1 to entry: For areal surface texture measuring instruments, the measuring volume is defined by the measuring range of the x- and y- drive units, and the measuring range of the z-probing system.

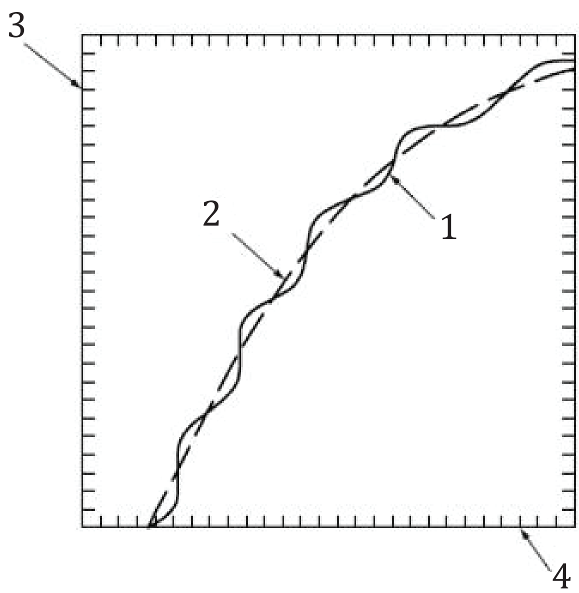
[SOURCE: ISO 25178-601:2010, 3.4.1]

2.1.7
response curve
F_x, F_y, F_z
graphical representation of the function that describes the relation between the actual quantity and the measured quantity

Note 1 to entry: An actual quantity in x (respectively y or z) corresponds to a measured quantity x_M (respectively y_M or z_M).

Note 2 to entry: The response curve can be used for adjustments and error corrections.

SEE: Figure 2



Key

1 response curve
2 assessment of the linearity deviation by polynomial approximation
3 measured quantities
4 input quantities

Figure 2 — Example of a nonlinear response curve

[ISO 25178-601:2010, 3.4.2]

2.1.8
amplification coefficient
α_x, α_y, α_z
slope of the linear regression curve obtained from the *response curve* (2.1.7)

Note 1 to entry: There will be amplification coefficients applicable to the x, y and z quantities.

Note 2 to entry: The ideal response is a straight line with a slope equal to 1 which means that the values of the measurand are equal to the values of the input quantities.

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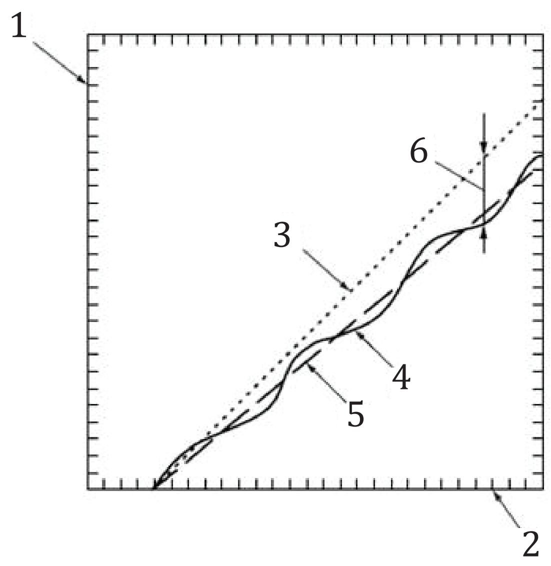
Note 3 to entry: See also "sensitivity of a measuring system" (ISO/IEC Guide 99:2007, 4.12)[1].

SEE: Figure 3



Key

1 measured quantities

2 input quantities

3 ideal response curve

4 linearization of the response curve of Figure 2

5 line from which the amplification coefficient α is derived

6 local residual correction error before adjustment

Figure 3 — Example of the linearization of a response curve

[ISO 25178-601:2010, 3.4.3, modified — Note 3 to entry has been added.]

2.1.9
instrument noise
N_I
internal noise added to the output signal caused by the instrument if ideally placed in a noise-free environment

Note 1 to entry: Internal noise can be due to electronic noise, as e.g. amplifiers, or to optical noise, as e.g. stray light.

Note 2 to entry: This noise typically has high frequencies and it limits the ability of the instrument to detect small scale spatial wavelengths of the surface texture.

Note 3 to entry: The S-filter according ISO 25178-3 may reduce this noise.

Note 4 to entry: For some instruments, instrument noise cannot be estimated because the instrument only takes data while moving.

2.1.10
measurement noise
N_M
noise added to the output signal occurring during the normal use of the instrument

Note 1 to entry: Notes 2 and 3 of 2.1.9 apply as well to this definition.

Note 2 to entry: Measurement noise includes *instrument noise* (2.1.9).

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2.1.11
surface topography repeatability
repeatability of topography map in successive measurements of the same surface under the same conditions of measurement

Note 1 to entry: Surface topography repeatability provides a measure of the likely agreement between repeated measurements normally expressed as a standard deviation.

Note 2 to entry: See ISO/IEC Guide 99:2007[1] , 2.15 and 2.21, for a general discussion of repeatability and related concepts.

Note 3 to entry: Evaluation of surface topography repeatability is a common method for determining the measurement noise.

2.1.12
sampling interval in x
$D_{\boldsymbol{x}}$
distance between two adjacent measured points along the x-axis

Note 1 to entry: In many microscopy systems, the sampling interval is determined by the distance between sensor elements in a camera, called pixels. For such systems, the terms pixel pitch and pixel spacing are often used interchangeably with the term sampling interval. Another term, pixel width, indicates a length associated with one side (x or y) of the sensitive area of a single pixel and is always smaller than the pixel spacing. Yet another term, sampling zone, may be used to indicate the length or region over which a height sample is determined. This quantity could either be larger or smaller than the sampling interval. See also A.3.

2.1.13
sampling interval in y
$D_{\boldsymbol{y}}$
distance between two adjacent measured points along the y-axis

Note 1 to entry: In many microscopy systems the sampling interval is determined by the distance between sensor elements in a camera, called pixels. For such systems, the terms pixel pitch and pixel spacing are often used interchangeably with the term sampling interval. Another term, pixel width, indicates a length associated with one side (x or y) of the sensitive area of a single pixel and is always smaller than the pixel spacing. Yet another term, sampling zone, may be used to indicate the length or region over which a height sample is determined. This quantity could either be larger or smaller than the sampling interval. See also A.3.

2.1.14
digitization step in z
$D_{\boldsymbol{Z}}$
smallest height variation along the z-axis between two ordinates of the extracted surface

2.1.15
lateral resolution
R_{l}
smallest distance between two features which can be detected

[SOURCE: ISO 25178-601:2010, 3.4.10, modified — The word “separation” has been removed before “distance”.]

2.1.16
width limit for full height transmission
W_{l}
width of the narrowest rectangular groove whose measured height remains unchanged by the measurement

Note 1 to entry: Instrument properties (such as the sampling interval in x and y, the digitization step in z, and the short wavelength cutoff filter) should be chosen so that they do not influence the lateral resolution and the width limit for full height transmission.

Note 2 to entry: When determining this parameter by measurement, the depth of the rectangular groove should be close to that of the surface to be measured.

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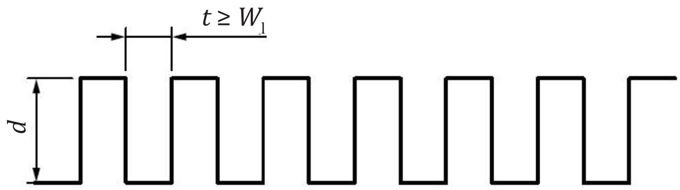
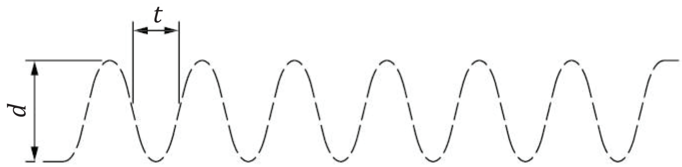
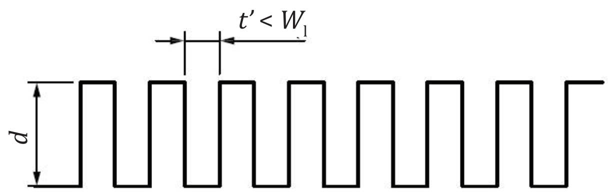


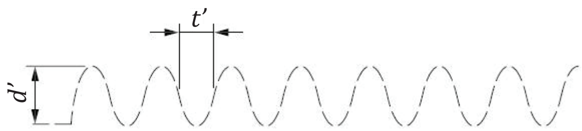
a) Grid with horizontal spacing where t is greater than or equal to W_l



b) Measurement of the grid in a) — The spacing and depth of the grid are measured correctly



c) Grid with horizontal spacing t' smaller than W_l



d) Measurement of the grid in c) — The spacing is measured correctly but the depth is smaller ($d' < d$)

Figure 4 — Examples of grids and their measurements

EXAMPLE 1 Measuring a grid for which the grooves are wider than the width limit for full height transmission leads to a correct measurement of the groove depth [see Figure 4 a) and b)].

EXAMPLE 2 Measuring a grid for which the grooves are narrower than the *width limit for full height transmission* leads to an incorrect groove depth [see Figure 4 c) and d)]. In this situation, the signal is generally disturbed and may contain non-measured points.

[SOURCE: ISO 25178-601:2010, 3.4.11, modified — The definition is identical. The notes, examples and figures are different.]

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2.1.17
lateral period limit
D_{LIM}
spatial period of a sinusoidal profile at which the height response of an instrument falls to 50 %

Note 1 to entry: The lateral period limit is one metric for describing spatial or lateral resolution of a surface topography measuring instrument and its ability to distinguish and measure closely spaced surface features. Its value depends on the heights of surface features and on the method used to probe the surface. Maximum values for this parameter are listed in ISO 25178-3: 2012, Table 3, in comparison with recommended values for short wavelength (s-) filters and sampling intervals.

Note 2 to entry: *Spatial period* is the same concept as *spatial wavelength* and is the inverse of *spatial frequency*.

Note 3 to entry: One factor related to the value of D_{LIM} for optical tools is the Rayleigh criterion (2.3.7). Another is the degree of focus of the objective on the surface.

Note 4 to entry: One factor related to the value of D_{LIM} for contact tools is the stylus tip radius, r_{TIP} (see 25178–601).

Note 5 to entry: Other terms related to *lateral period limit* are *structural resolution* and *topographic spatial resolution*

2.1.18
maximum local slope
greatest local slope of a surface feature that can be assessed by the probing system

Note 1 to entry: The term “local slope” is defined in ISO 4287:1997, 3.2.9.

2.1.19
instrument transfer function
ITF
f_{ITF}
function of spatial frequency describing how a surface topography measuring instrument responds to an object surface topography having a specific spatial frequency

Note 1 to entry: Ideally, the ITF tells us what the measured amplitude of a sinusoidal grating of a specified spatial frequency ν would be relative to the true amplitude of the grating.

Note 2 to entry: For several types of optical instruments, the ITF may be a nonlinear function of height except for heights much smaller than the optical wavelength.

2.1.20
hysteresis
x_{HYS}, y_{HYS}, z_{HYS}
property of measuring equipment or characteristic whereby the indication of the equipment or value of the characteristic depends on the orientation of the preceding stimuli

Note 1 to entry: Hysteresis can also depend, for example, on the distance travelled after the orientation of stimuli has changed.

Note 2 to entry: For lateral scanning systems, the hysteresis is mainly a repositioning error.

[SOURCE: ISO 14978:2006, 3.24, modified — Note 2 to entry and the symbols have been added.]

2.1.21
metrological characteristic
metrological characteristic of a measuring instrument
<measuring equipment> characteristic of measuring equipment, which may influence the results of measurement

Note 1 to entry: Calibration of metrological characteristics may be necessary.

Note 2 to entry: The metrological characteristics have an immediate contribution to measurement uncertainty.

Note 3 to entry: Metrological characteristics for areal surface texture measuring instruments are given in Table 1.

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Table 1 — List of metrological characteristics for surface texture measurement methods

Metrological characteristic	Symbol	Definition	Main potential error along
Amplification coefficient	α_X, α_Y, α_Z	2.1.8 (see Figure 3)	x, y, z
Linearity deviation	l_X, l_Y, l_Z	Maximum local difference between the line from which the amplification coefficient is derived (see Figure 3 – Key 5) and the response curve (see Figure 3 – Key 4)	x, y, z
Residual flatness	z_{FLT}	Flatness of the areal reference	z
Measurement noise	N_M	2.1.10	z
Lateral period limit	D_{LIM}	2.1.17	z
Perpendicularity	Δ_{PERxy}	Deviation from 90° of the angle between the x- and y-axes	x, y

[SOURCE: ISO 14978:2006, 3.12, modified — The notes are different and the table has been added.]

2.2 Terms and definitions related to x- and y-scanning systems

2.2.1
areal reference guide
component(s) of the instrument that generate(s) the reference surface, in which the probing system moves relative to the surface being measured according to a theoretically exact trajectory

Note 1 to entry: In the case of x- and y-scanning areal surface texture measuring instruments, the areal reference guide establishes a reference surface [ISO 25178-2:2012, 3.1.8]. It can be achieved through the use of two linear and perpendicular reference guides [ISO 3274:1996, 3.3.2] or one reference surface guide.

2.2.2
lateral scanning system
system that performs the scanning of the surface to be measured in the (x,y) plane

Note 1 to entry: There are essentially four aspects to a surface texture scanning instrument system: the x-axis drive, the y-axis drive, the z-measurement probe and the surface to be measured. There are different ways in which these may be configured and thus there will be a difference between different configurations as explained in Table 2.

Note 2 to entry: When a measurement consists of a single field of view of a microscope, x- and y-scanning is not used. However, when several fields of view are linked together by *stitching* methods, see Reference [2], the system is considered to be a scanning system

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Table 2 — Possible different configurations for reference guides (x and y)

		Drive unit				
		Two reference guides (x and y)[a]			One areal reference guide	
		Px o Cy	Px o Py	Cx o Cy	Pxy	Cxy
Probing System	A: without arcuate error correction	Px o Cy-A	Px o Py-A	Cx o Cy-A	Pxy-A	Cxy-A
	S: without arcuate error or with arcuate error corrected	Px o Cy-S	Px o Py-S	Cx o Cy-S	Pxy-S	Cxy-S

a For two given functions f and g, f o g is the combination of these functions.

P x = probing systems moving along the x-axis

P y = probing systems moving along the y-axis

C x = component moving along the x-axis

C y = component moving along the y-axis

2.2.3
drive unit x
component of the instrument that moves the probing system or the surface being measured along the reference guide on the x-axis and returns the horizontal position of the measured point in terms of the lateral x-coordinate of the profile

2.2.4
drive unit y
component of the instrument that moves the probing system or the surface being measured along the reference guide on the y-axis and returns the horizontal position of the measured point in terms of the lateral y-coordinate of the profile

2.2.5
lateral position sensor
component of the drive unit that provides the lateral position of the measured point

Note 1 to entry: The lateral position can be measured or inferred by using, for example, a linear encoder, a laser interferometer, or a counting device coupled with a micrometer screw.

2.2.6
speed of measurement
V_x
speed of the probing system relative to the surface to be measured during the measurement along the x-axis

[SOURCE: ISO 25178-601:2010, 3.4.13]

2.2.7
static noise
N_S
combination of the instrument and environmental noise on the output signal when the instrument is not scanning laterally

Note 1 to entry: *Environmental noise* is caused by e.g. seismic, sonic and external electromagnetic disturbances.

Note 2 to entry: Notes 2 and 3 in 2.1.9 apply to this definition.

Note 3 to entry: Static noise is included in *measurement noise* (2.1.10)

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2.2.8
dynamic noise
N_D
noise occurring during the motion of the drive units on the output signal

Note 1 to entry: Notes 2 and 3 in 2.1.9 apply to this definition.

Note 2 to entry: Dynamic noise includes the static noise.

Note 3 to entry: Dynamic noise is included in *measurement noise* (2.1.10).

2.3 Terms and definitions related to optical systems

2.3.1
light source
optical device emitting an appropriate range of wavelengths in a specified spectral region

2.3.2
measurement optical bandwidth
$B_{\lambda 0}$
range of wavelengths of light used to measure a surface

Note 1 to entry: Instruments may be constructed with light sources with a limited optical bandwidth and/or with additional filter elements to further limit the optical bandwidth.

2.3.3
measurement optical wavelength
λ_0
effective value of the wavelength of the light used to measure a surface

Note 1 to entry: The measurement optical wavelength is affected by conditions such as the light source spectrum, spectral transmission of the optical components, and spectral response of the image sensor array (see Annex A).

2.3.4
angular aperture
angle of the cone of light entering an optical system from a point on the surface being measured

[SOURCE: ISO 25178-602:2010, 3.3.3]

2.3.5
half aperture angle
α
one half of the angular aperture

Note 1 to entry: This angle is sometimes called the "half cone angle" (see Figure 5).

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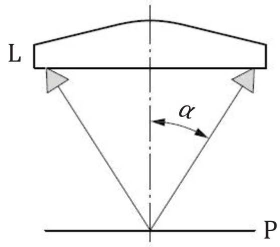

Key

L lens or optical system

P focal point

α half aperture angle

Figure 5 — Half aperture angle

2.3.6
numerical aperture
A_N
sine of the half aperture angle multiplied by the refractive index n of the surrounding medium

$$A_N = n \sin\alpha$$

Note 1 to entry: In air for visible light, $n \cong 1$.

Note 2 to entry: The numerical aperture is dependent on the wavelength of light. Typically, the numerical aperture is specified for the wavelength that is in the middle of the measurement optical bandwidth.

2.3.7
Rayleigh criterion
quantity characterizing the spatial resolution of an optical system given by the separation of two point sources at which the first diffraction minimum of the image of one point source coincides with the maximum of the other

Note 1 to entry: For a theoretically perfect, incoherent optical system with a filled objective pupil, the Rayleigh criterion of the optical system is equal to 0,61 λ_0/A_N.

Note 2 to entry: This parameter is useful for characterizing the instrument response to features with heights much less than λ_0 for optical 3D metrology instruments.

2.3.8
Sparrow criterion
quantity characterizing the spatial resolution of an optical system given by the separation of two point sources at which the second derivative of the intensity distribution vanishes between the two imaged points

Note 1 to entry: For a theoretically perfect, incoherent optical system with a filled objective pupil, the Sparrow criterion of the optical system is equal to 0,47 λ_0/A_N, approximately 0,77 times the *Rayleigh criterion* (2.3.7).

Note 2 to entry: This parameter is useful for characterizing the instrument response to features with heights much less than λ_0 for optical 3D metrology instruments.

Note 3 to entry: Under the same measurement conditions as the notes above, the Sparrow criterion is nearly equal to the spatial period of 0,50 λ_0/A_N, for which the theoretical instrument response falls to zero.

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2.4 Terms and definitions related to optical properties of the workpiece

2.4.1
surface film
material deposited onto another surface whose optical properties are different from that surface

Note 1 to entry: This concept may also be called “surface layer”.

2.4.2
thin film
film whose thickness is such that the top and bottom surfaces cannot be readily separated by the optical measuring system

Note 1 to entry: For some measurement systems with special properties and algorithms, the thicknesses of thin films may be derived.

2.4.3
thick film
film whose thickness is such that the top and bottom surfaces can be readily separated by the optical measuring system

2.4.4
optically smooth surface
surface from which the reflected light is primarily specular and scattered light is not significant

Note 1 to entry: An optically smooth surface behaves locally like a mirror.

Note 2 to entry: A surface that acts as optically smooth under certain conditions, such as wavelength range, numerical aperture, pixel resolution, etc., can act as optically rough when one or more of these conditions change.

2.4.5
optically rough surface
surface that does not behave as an optically smooth surface, i.e. where scattered light is significant

Note 1 to entry: A surface that acts as optically rough under certain conditions, such as wavelength range, numerical aperture, pixel resolution, etc., can act as optically smooth when one or more of these conditions change.

2.4.6
optically non-uniform material
sample with different optical properties in different regions

Note 1 to entry: An optically non-uniform material may result in measured phase differences across the field of view that can be erroneously interpreted as differences in surface height.

2.5 Terms and definitions specific to phase-shifting interferometric microscopy

2.5.1
phase-shifting interferometric microscopy
PSI
surface topography measurement method whereby an optical microscope with illumination of a known effective wavelength is integrated with an interferometric attachment and produces multiple successive optical images with interferometric fringes from which the profile or areal surface topography image is calculated

Note 1 to entry: Phase-shifting interferometric (PSI) microscopes provide a non-contact measurement of surface texture for which the average roughness (Ra or Sa) is typically less than $\lambda_0/10$.

Note 2 to entry: Typical illumination sources include lasers, light emitting diodes (LED), narrow-band filtered white light sources, or spectral lamps.

[SOURCE: ISO 25178-6:2010, 3.3.5]

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2.5.2
phase-shifting measurement algorithm
algorithm that determines the number of phase shifted images to be acquired, the relative phase difference between images and the measurement equations used to calculate the texture

2.5.3
phase unwrapping algorithm
algorithm used to construct the measured surface given that the measured height at each point is a multivalued function and can be ambiguous by integral multiples of $\lambda_0/2$

Note 1 to entry: Phase unwrapping algorithms typically assume that the height difference of adjacent measured points is less than $\lambda_0/4$.

2.5.4
sample tilt
angle between the surface normal and the optical axis of the system during measurement

Note 1 to entry: Sample tilt is typically measured by the number of fringes in the field of view across an ideally flat sample (see Annex A).

2.5.5
reference root mean square variation
rms of the height deviations measured by the system when an ideally flat and smooth surface is measured

Note 1 to entry: The reference root mean square variation arises from several sources of error in the instrument including imperfections in the reference mirror and elsewhere in the optical system. The reference root mean square variation may be reduced by an appropriate averaging procedure as outlined in Annex A.

Note 2 to entry: The reference root mean square variation may be resolved into components, such as residual flatness and measurement noise.

3 Descriptions of the influence quantities

3.1 General

Phase-shifting interferometric instruments provide a measurement of lateral (x and y) and height (z) values from which surface texture parameters are calculated. Phase-shifting interferometric instruments use the following measurement process.

— The instrument is focused on the surface as indicated by the appearance of interference fringes.

— For measurement of randomly rough surfaces, the tilt of the sample relative to the optical axis of the system is adjusted to minimize the number of the fringes across the field of view. For measurement of surfaces having step features, the tilt of the sample is adjusted to provide 3 to 5 fringes.

— According to the selected phase-shifting measurement algorithm, a number of phase shifted images are acquired and analysed to calculate surface texture with an appropriate phase unwrapping algorithm. The phase unwrapping algorithm is included since the height at a measurement point is a multivalued function of phase and can be ambiguous by integral multiples of $\lambda_0/2$, where λ_0 is the effective wavelength of the nominally monochromatic light used for measurement.

— Deviations of form such as residual tilt, curvature and cylinder are numerically removed from the areal measurement resulting in a modified topography image representing the areal surface texture. Further filtering may be applied to the texture data as required.

— For surfaces with rms roughness on the order of the reference rms variation, additional signal averaging techniques may be needed to separate the surface roughness from instrument imperfections.[3]

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3.2 Influence quantities

Influence quantities for phase-shifting interferometric instruments are given in Table 3. This table indicates the metrological characteristics (see 2.1.21, Table 1) that are affected by deviations of influence quantities.

NOTE For a theoretically perfect, incoherent optical system with a filled objective pupil and when measuring features with heights much smaller than λ_0, the lateral period limit D_{LIM} (2.1.17) of PSI systems is at least twice the *Rayleigh criterion* (2.3.7).

Table 3 — Influence quantities

Component	Element	Influence quantities		Metrological characteristic affected ...
Light source		λ_0	Measurement optical wavelength (see 2.3.3)	α_z
		$B_{\lambda 0}$	Measurement optical bandwidth (see 2.3.2)	α_z
		S, P, C, U	The state of polarization of the light impinging on the measured surface. The polarization is typically described as S, P, circular, or unpolarized.	α_x, α_y, α_z
Microscope imaging system		A_N	Numerical aperture (see 2.3.6)	α_x, α_y, α_z, D_{LIM}
		M_{IMG}	Magnification between object sizes on the surface and image sizes on the sensor	α_x, α_y
		Δ_{PATH}	Wavefront distortion, a function describing net deviations in the measured optical path of the system, derived from deviations in both the reference and measurement arms	α_z
		Q_{OPT}	General quality of the optical components used including aberrations, transmission, alignment errors, etc.	α_x, α_y, α_z, z_{FLT}, l_x, l_y, l_z, D_{LIM}, Δ_{PERxy}
		P_{DISxy}	Lateral distortion of the magnified image on the camera	α_x, α_y, α_z, z_{FLT}, l_x, l_y, l_z, D_{LIM}, Δ_{PERxy}
Camera		Δ_x	*x*-pixel spacing	D_{LIM}
		Δ_y	*y*-pixel spacing	D_{LIM}
Controller	Acquisition software	A_{ACQ}	Acquisition method – Manner in which the shifted images are acquired (e.g. continuously, discretely stepped...)	α_z, l_z
		A_{ALG}	Phase-shifting measurement algorithm (see 2.5.2)	α_z, l_z
		Φ_{FR}	Phase shift adjustment, the absolute phase difference between shifted frames for a measurement	α_z, l_z
		W_{MOD}	Fringe intensity modulation threshold - the minimum peak-valley intensity variation that the controller recognizes to be an interference fringe	α_z, l_z
		D_Z	Digitization step in *z* (see 2.1.14)	N_M
	Phase unwrapping algorithm	A_{PHUN}	See 2.5.3	α_z, l_z
	Profile analysis software	C_z	*z*-scale calibration factor, height adjustment coefficient	α_z, l_z

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Table 3 *(continued)*

Component	Element		Influence quantities	Metrological characteristic affected ...
Instrument overall		D_x or D_y	Lateral sampling interval (see 2.1.12 and 2.1.13)	D_{LIM}
		N_I	Instrument noise (see 2.1.9)	N_M
		N_{VIB}	Environmental vibration – Unwanted motion between the surface being measured and the optical system	N_M
		T_I	Integration time required to complete a single scan in z	N_M
		x_{HYS}, y_{HYS}, z_{HYS}	Hysteresis (2.1.20)	l_x, l_y, l_z
Sample		θ_{TLT}**	Tilt - Relative angle between the optical axis of the system and the sample normal	α_x, α_y, α_z
		Φ_{DIS}**	The relative phase shift upon reflection of dissimilar materials.	α_z
		T_{FLM}**	Thickness of transparent or semi-transparent films. These films typically have thickness comparable to the illumination wavelength. Note that thinner contamination or native oxide films do not necessarily affect the phase measurement process.	α_z
**NOTE These influence quantities arise from the interaction between the instrument and the sample being measured.				

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Annex A
(informative)

Components of a phase-shifting interferometric (PSI) microscope

A.1 Light source

The light source used for PSI measurements typically consists of a narrow band of optical wavelengths as provided by a laser, light emitting diode (LED), narrow-band filtered white light source, or spectral lamp. The accuracy of the central wavelength and the bandwidth of the illumination are important to the overall accuracy of the PSI measurement.[4]

A.2 Optics

The optical components comprising the PSI instrument are typically arranged in the Mirau, Michelson or Linnik[5,6] configurations (typically the Tolansky interferometer[7] is not considered for PSI instruments). The illumination and imaging systems of the PSI components may include additional optical components to provide varying degrees of image magnification on the detection image sensor.

In each interferometer configuration, the surface being measured is compared with a reference surface. It is important that the reference surface be much flatter and smoother than the surface being measured. When this is not true, advanced measurement techniques may be implemented to separate the topography of the reference surface from that of the surface to be measured.

One advanced measurement technique is reference surface averaging[3] which involves averaging a number of measurements of a surface that is known to be much flatter and smoother than the reference surface used in the interferometer. The resulting reference surface measurement is then stored in the computer system and subtracted from future measurements of surfaces.

The advanced technique of absolute rms involves taking the difference between two measurements of the measured surface separated by a distance greater than the autocorrelation length. The rms roughness Sq of the measured surface is estimated by calculating the rms of the difference measurement divided by $\sqrt{2}$.[3] Note that the absolute rms technique does not produce an areal map but rather a measure of the Sq of the measured surface. For some applications, a reference surface that is shaped to match the form of the surface being measured may be used. For example, measurement of the surface texture of a cylindrical surface may be optimized with a cylindrically shaped reference surface.

A.3 Image sensor

The measurement of a surface profile may be accomplished by using an image sensor composed of a linear array of detection pixels. The measurement of an areal surface texture may be accomplished by using an image sensor composed of a matrix array of detection pixels. The spacing and width of the image sensor pixels are important characteristics, which determine attributes of instrument spatial resolution.[8]

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Annex B
(informative)

Phase-shifting interferometric (PSI) microscope — Theory of operation

The PSI instrument (Figures B.1, B.2, and B.3) consists of an interferometer integrated with a microscope. Within the interferometer, a beam splitter directs one beam of light down a reference path, which contains a number of optical elements including an ideally flat and smooth mirror from which the light is reflected. The beam splitter directs a second beam of light to the sample where it is reflected. The two beams of light return to the beam splitter and are combined, forming an image of the measured surface at the image sensor array superimposed with a series of dark and bright bands of light, known as fringes. The instrument is aligned so that best focus corresponds with maximum fringe contrast. During measurement, a known shift between the optical path to the measured surface and the optical path to the reference mirror is introduced and produces changes in the fringe pattern. There are several ways to shift the difference in optical paths. For example, in Figure B.1, the reference mirror of the system is translated with the use of a piezoelectric (PZT) actuator device.

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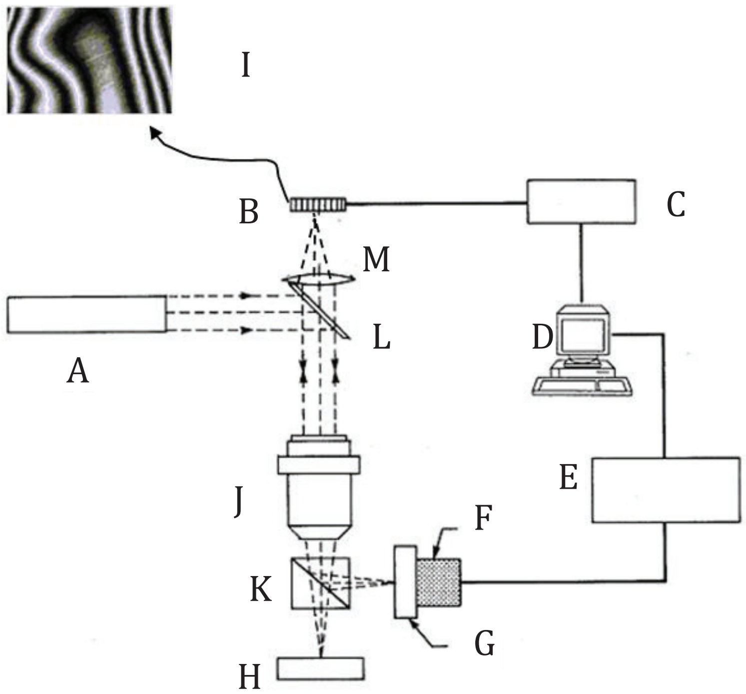

Key

A light source
B image sensor array
C digitizer
D computer
E PZT controller
F PZT drive
G reference mirror
H sample to be measured
I fringes across image sensor array
J interferometric objective lens
K interferometric beam splitter
L illumination beam splitter
M imaging lens

NOTE During phase-shifting, the component G is displaced along the optical axis.

Figure B.1 — Schematic diagram of a phase-shifting interferometric (PSI) microscope illustrating the Michelson configuration

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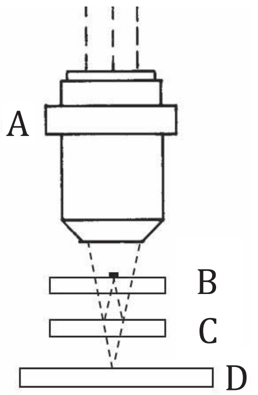


Key

A objective lens

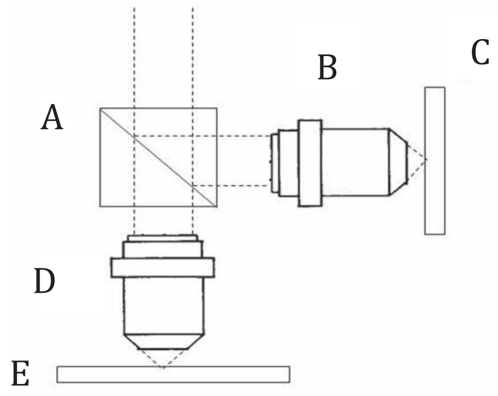
B reference mirror

C beam splitter

D sample to be measured

NOTE During phase-shifting, the components A, B and C are displaced relative to surface D.

Figure B.2 — Schematic diagram of a Mirau interferometer



Key

A beam splitter

B reference objective

C reference mirror

D objective lens

E sample to be measured

NOTE During phase-shifting, the components B and C are moved together relative to components D and E.

Figure B.3 — Schematic diagram of a Linnik interferometer

By measuring the intensity pattern from the various images during the shifting process, the phase variation of the wavefront Φ returning from the specimen may be measured. Given that the variation Φ_{ij} is a function of image sensor element *ij*, the relative surface height Z_{ij} at the *ij*'th location is determined by[9]

$$Z_i = \lambda_0 \Phi_{ij} / 4\pi \quad \text{(B.1)}$$

where

λ_0 is the wavelength of illumination.

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Formula B.1 is strictly correct for an idealized optical system consisting of a single point source of light for each point measured on the surface. The ramifications of practical illumination systems are covered in Reference [10].

Along the x-direction, the longest spatial wavelength of the profile that may be measured, λ_{Lx}, is given by

$$\lambda_{Lx} = N\Delta_x / M \tag{B.2}$$

where

M is the magnification of the optical system;

Δx is the spacing of the elements in the image sensor array along the x-axis, and

N is the total number of array elements in the image sensor along the x-axis (Figure B.4).

For a surface with a strongly periodic profile with spatial wavelength λ_{Rx} the shortest such spatial wavelength that should be assessed depends on the nature of the optical system being used. The recommendations below are aimed at recovering at least 90 % of the peak-to-valley value of the periodic spatial wavelength,[11] in contrast to the detection of only the rms value of the shortest spatial wavelength as given by the Nyquist criterion.[12] As a first recommendation, if the lateral resolution of the instrument is limited by a Gaussian λ_s filter or by the lateral period limit D_{LIM} of the optical system, then λ_{Rx}, is given by

$$\lambda_{Rx} \geq 2{,}6\,\lambda_s \quad \text{or} \quad \lambda_{Rx} \geq 2{,}6\,D_{LIM} \tag{B.3}$$

If, on the other hand, the lateral resolution is limited by the lateral sampling interval ($\Delta_x/M = D_x$) of the image sensor system, as is often the case at low magnification, then (Figure B.5) the shortest spatial wavelength that should be assessed is given by

$$\lambda_{Rx} \geq 5\,D_x \tag{B.4}$$

PSI devices relate height measurements to detected phase differences and are thus limited to establishing the absolute value of height differences less than $\lambda_0/4$ between adjacent points. The resulting maximum measurable surface slope, δ, is given by;

$$\delta \leq \arctan\left(\lambda_0 M / 4\Delta\right) \tag{B.5}$$

where M and Δ are the system magnification and image sensor point spacing respectively, as defined above.

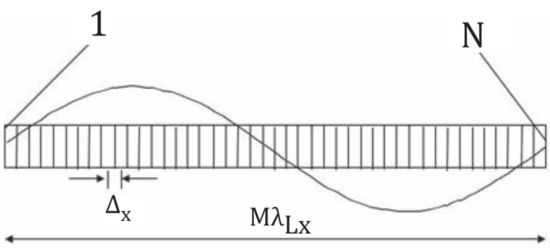

Figure B.4 — Illustration of the image sensor array along the x-direction, with element spacing Δ_x and the measurement of the longest spatial wavelength, λ_{Lx} covering the total number (N) of pixels

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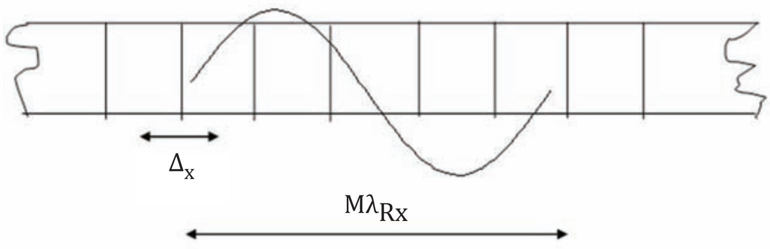

Figure B.5 — Illustration of the image sensor array along the x-direction with element spacing Δ_x and the measurement of the shortest spatial wavelength, λ_{Rx} covering 5 pixels

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Annex C
(informative)

Errors and corrections for phase-shifting interferometric (PSI) microscopes

C.1 Wavelength

One component of uncertainty in the height measurements is related directly to the uncertainty with which the wavelength of the illumination source λ_0 is established. The measurement of the wavelength of illumination and the spectral transmission of the optical band pass filter in the system may be done with standard spectroscopic techniques.

C.2 Signal processing algorithms

Measurements with PSI devices typically require that adjacent points measured on the surface have a height difference of less than $\lambda_0/4$. When adjacent points have a height difference greater than $\lambda_0/4$, errors in the image data may occur. These errors in the image data are manifested as abrupt steps, having step heights with integer multiples of $\lambda_0/2$. Thus, PSI microscopes contain phase unwrapping algorithms[6] to account for the $\lambda_0/2$ ambiguities to extend the measurement height range across the complete surface. In addition, algorithms may also be used to identify and eliminate bad data (outliers) and non-measured (missing) data, which may be caused by measurements on low reflectance or high scatter regions. See Figures C.1 and C.2.

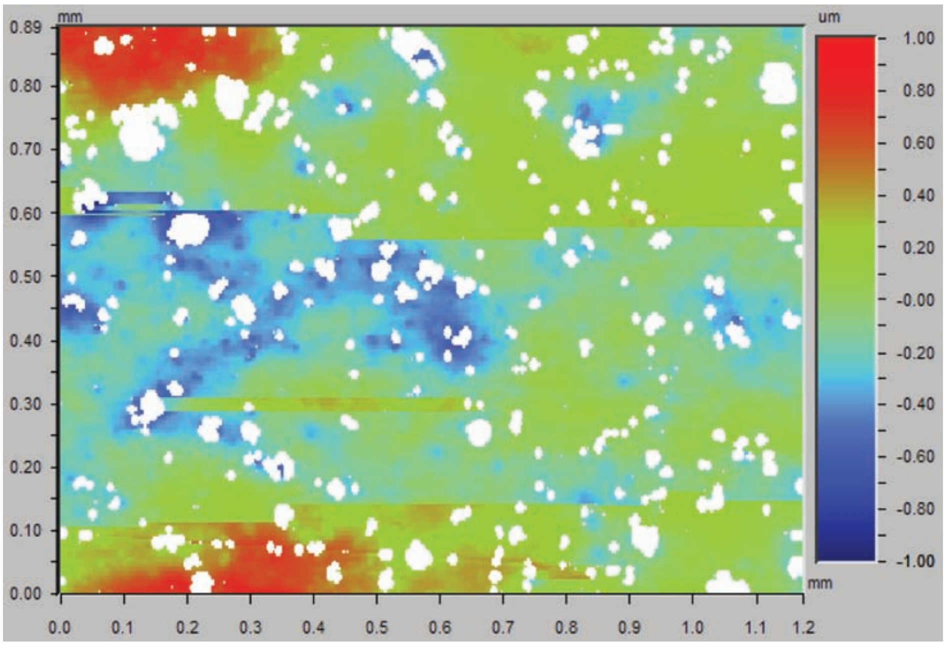

Figure C.1 — Illustration of a phase-shifting measurement with multiple horizontal $\lambda_0/2$ abrupt step errors and missing data (dropouts), the latter as indicated by the white spot-like regions

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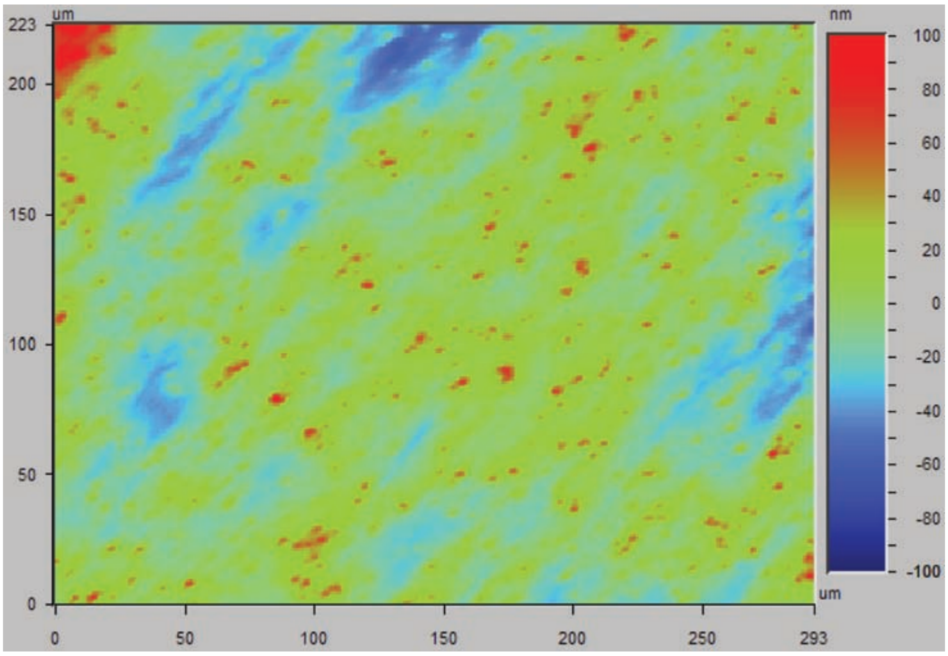

Figure C.2 — Illustration of a relatively error-free phase-shifting measurement lacking any abrupt $\lambda_0/2$ step errors or dropouts

C.3 Microscope numerical aperture

The numerical aperture (A_N) of the microscope system determines the cone angle of light impinging on the surface and the subsequent cone angle of detection by the optical system. As the numerical aperture increases, the surface is illuminated with light incident at increasingly large angles, which causes a modification in the measured surface heights. For A_N values greater than 0,20, the error in height measurements may vary from 1 % to 20 %.[13,14] The numerical aperture may also determine the lateral resolution of the measurement system.

C.4 Phase-shifting measurement mechanisms

The PSI device includes a means to provide a relative phase shift between the light in the reference path and the light returning from the surface being measured. There are a number of ways to produce the relative phase shift, including 1) mechanical motion of the reference mirror, optical components, or measurement surface, and 2) wavelength shifting of the incident light.

During the phase-shifting process, whether it is continuous or stepped, a number of algorithms have been developed to compensate for phase-shifting errors of the measurement process. Error sources include system vibration during the measurement, nonlinear phase-shifting characteristics, and nonlinear image sensor properties.[15]

C.5 Phase shift adjustment

The relative phase shift between the multiple images used to measure the heights on the measured and reference surfaces must be adjusted as required for the measurement algorithm selected. Techniques for phase-shifting adjustment are discussed in Reference [15].

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C.6 Relative sample tilt - Number of fringes

When the normal to the surface being measured is parallel to the optical axis, there is only one interference fringe across the image field. As the sample is tilted, the number of fringes across the field increases, which may cause measurement errors. For a recommendation of measurement tilt conditions, see 3.1.

C.7 Reference path rms variation

When the root mean square (rms) variation of the optical path difference across the reference arm is on the order of the rms roughness (*Sq*) of the measured sample, errors may result (A.2 and Reference [3]).

C.8 Sample surface reflectance

Insufficient effective sample reflectance may result in a low signal-to-noise ratio, which in turn may cause dropouts or inaccurate height measurements.

C.9 Sample surface local slope

Extreme surface slopes may result in a low signal-to-noise ratio, which in turn may cause dropouts or inaccurate height measurements.

C.10 Thin films

The presence of thin translucent films (see also 2.4) covering the surface being measured may affect the accuracy of a PSI measurement.[16]

C.11 Dissimilar materials

The PSI technique relies on relating the phases of the light reflected from a sample to real surface heights. Thus any property of the surface that alters the relative optical phase may be interpreted as a surface height variation. Surfaces composed of regions with different optical material constants may produce erroneous surface heights between those regions.

C.12 Environmental vibration

The PSI microscope should be situated in an environment isolated from sources of vibration.[17] Typically, the microscope is placed on a vibration isolation table, e.g. a rigid slab supported on air-damped legs. The degree of vibration isolation (and other sources of noise such as electrical and acoustical) may be assessed by measuring the rms variation of the difference between two profiles measured on a smooth measured surface (Ra or $Sa < \lambda_0/1\,000$) when the sample is not moved and the time is minimized between measurements. The rms variation of the difference between two profiles establishes an estimate of the height resolution of the PSI microscope and is typically less than $\lambda_0/2\,000$.

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Annex D
(informative)

Relation to the GPS matrix model

D.1 General

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

The ISO/GPS Masterplan given in ISO/TR 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.

D.2 Position in the GPS matrix model

This part of ISO 25178 is a general GPS standard, which influences the chain link 5 of the chains of standards on areal surface texture in the general GPS matrix, as illustrated in Table D.1.

Table D.1 — Fundamental and general ISO GPS standards matrix

		Global GPS standards						
		General GPS standards						
		Chain link number	**1**	**2**	**3**	**4**	**5**	**6**
Fundamental GPS standards		Size						
		Distance						
		Radius						
		Angle						
		Form of line independent of datum						
		Form of line dependent on datum						
		Orientation						
		Location						
		Circular run-out						
		Total run-out						
		Datums						
		Roughness profile					•	
		Waviness profile					•	
		Primary profile					•	
		Surface defects						
		Edges						
		Areal surface texture					•	

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D.3 Related standards

The related standards are those of the chains of standards indicated in Table D.1.

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