Physikalisch-
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DKD

Guideline
DKD-R 4-2

Sheet 3

Calibration of instruments and standards for roughness metrology

Calibration of standards with periodic profiles in horizontal direction by means of stylus instruments

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German Calibration Service (DKD)

Calibration laboratories from industrial enterprises, research institutes, technical authorities, and monitoring and testing institutions have been combined to form the DKD. On May 3, 2011, the DKD was reestablished as a *technical body* of PTB and the accredited laboratories.
Bearing the name ‘Deutscher Kalibrierdienst’ (*German Calibration Service* – DKD), this body is under the direction of PTB. The guidelines and guides elaborated by DKD are state-of-the-art in the respective technical field and are available to DAkkS (the German accreditation body – *Deutsche Akkreditierungsstelle GmbH*) for the accreditation of calibration laboratories.
As the legal successor of the accreditation body of the DKD, the accredited calibration laboratories are now accredited and monitored by DAkkS (German Accreditation Body). They calibrate measuring devices and standards for the measured values and measuring ranges defined during accreditation. The calibration certificates they issue are proof of the traceability to national standards such as the DIN EN ISO 9000 family of standards and DIN EN ISO/IEC 1702.

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Foreword

DKD guidelines are application documents regarding the DIN EN ISO/IEC 17025 requirements. The guidelines contain a description of the technical, process-related and the organizational procedures which accredited calibration laboratories use as a model for defining internal processes and regulations. DKD guidelines may become an essential component of the quality management manuals of calibration laboratories. By implementing the guidelines, it is ensured that the devices to be calibrated are all treated equally in the various calibration laboratories and that the continuity and comparability of the work of the calibration laboratories are improved.

The DKD guidelines should not impede the further development of calibration procedures and processes. Deviations from guidelines as well as new procedures are allowed in agreement with the accreditation body if there are technical reasons to support this action.

This guideline was prepared by the Technical Committee ‘Length’ in cooperation with PTB and accredited calibration laboratories. The guideline was adopted by the Technical Committee ‘Length’. After its publication, the guideline becomes binding on all DKD calibration laboratories, unless other rules of procedure have been authorized by the accreditation body.

1. Field of application

In many stylus instruments, the length in direction of the feed (x-axis) is determined on the assumption of a constant feed rate and a fixed sampling interval. Therefore, a traceabilty chain to the unit of length has to be established for the calibration of the horizontal axis. Sheet 3 describes how to calibrate horizontal parameters such as RSm on surface standards with a regular profile of type C according to DIN EN ISO 5436-1 (in normal usage called “geometrical standards“).This process corresponds to the third step of the traceability chain shown in Fig. 1. The thus calibrated standards are used to calibrate the horizontal axis of stylus instruments. This step is described in Sheet 4 of the Guideline 4-2. Through the dissemination of the unit of length by means of embodied standards, the entire measuring chain of the instrument, from the stylus tip to the display, is included during calibration.

Other applicable standards and regulations

JCGM 100: 2008	Evaluation of measurement data – Guide to the expression of uncertainty in measurement, September 2008
DAkkS-DKD-3	Angabe der Messunsicherheit bei Kalibrierungen, 2010[1]
DKD-R 4-2	Kalibrieren von Geräten und Normalen für die Rauheitsmesstechnik Blatt 1: Kalibrieren von Normalen für die Rauheitsmesstechnik[2]

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1 Indication of the measurement uncertainty in calibrations

2 Calibration of measuring instruments and standards for roughness metrology. Sheet 1: Calibration of standards for roughness metrology.

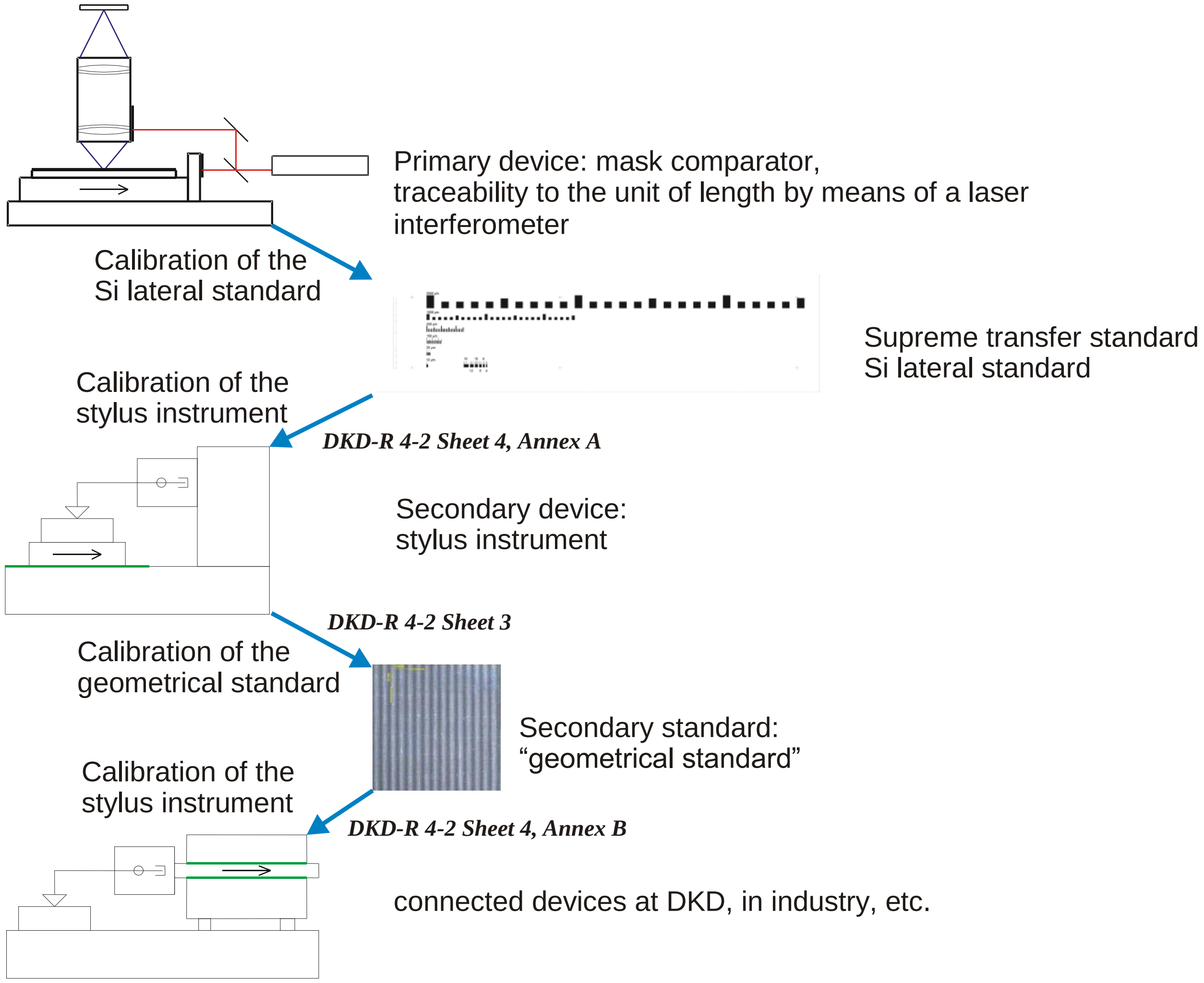

Fig. 1: Dissemination of the unit of length in horizontal direction during roughness measurement

2. Terms and definitions

2.1 Terms taken from standards

The terms for the characterization of surface measuring devices are adopted from the standard DIN EN ISO 3274 and ISO/DIS 25178-601. Definitions from the standard DIN EN ISO 4287 are used in connection with surface parameters, while the measurement conditions are specified according to the standard DIN EN ISO 4288. Instructions for the calibration of stylus instruments are given in accordance with DIN EN ISO 12179.

2.2 Terms and abbreviations used herein

Rz_0 Background noise of the instrument

Wt_0 Waviness of the standard over the evaluation length *ln*

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L	Length of the lever arm that holds the stylus tip
H	Height of the pick-up
RSm_n	RSm of the reference standard used for traceability (from its calibration certificate)
$RSm(Bezug)$	Currently measured parameter at the reference standard
$RSm(Objekt)$	Measured parameter at the measuring object to be calibrated
Δx	Measuring point distance
l	Length of the profile: part of the measured length that has been included into the evaluation of *RSm*
n	Number of the profile elements that have been included in the evaluation of *RSm*
σ	Slope of the profile at the zero crossing
p	Wavelength of the profile elements

3. Measuring device

The measuring device to be used for the implementation of this guideline is a stylus instrument according to the standard DIN EN ISO 3274. The surface of the standard must be aligned parallel to the feed direction. The coordinate system is indicated in Fig. 5.

4. Ambient conditions

The temperature change during the measurement shall be less than ± 0.5 K.
The absolute temperature during the measurement should stay between 18°C and 25°C and must be indicated in the calibration certificate.
Temperature gradients caused, for example, by direct sunlight must be avoided.
Interferences due to vibrations must remain as low as to ensure that Rz < 30 nm when measuring the roughness on a good optical flat glass (flatness ≤ $\lambda/10$).

5. Calibration

The parameter RSm is determined for the horizontal calibration of the standard. The parameter describes the mean distance of the profile elements, which are arranged as clearly defined peaks and valleys on the standards defined in chapter 1. The considerations set out for RSm equally apply to PSm.

5.1 Calibration capability of the standard

The standard must comply with the following requirements:

- Upon visual inspection, the standard should be flat.
- The total length of the profile and the length of the profile elements in the measuring direction must meet the measurement conditions laid down in DIN EN ISO 4288.
- Perpendicular to the measuring direction, the standard must be wide enough to make sure that the required number of laterally offset measurements can be carried out.

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5.2 Preparatory activities

5.2.1 Cleaning

The standard can be cleaned with a soft microfibre cloth, moistened with isopropyl alcohol. The wiping direction must be parallel to the grooves.

5.2.2 Inspection of the stylus instrument

The z-axis of the device must be checked, for example, by measuring a groove of a setting standard (DIN EN ISO 5436-1 Type A) or a geometrical standard (Type C). The display value of a vertical parameter such as, for example, *Pt* or *d* in type A or *Rz* in type C, respectively, must not differ by more than 1% from the calibrated value of the standard.

Among other things, the background noise of the device must be determined in order to determine the measurement uncertainty of the ongoing measurement. For this purpose, Rz_0 has to be determined five times. This has to be done on an optical flat free from scratches and under the same measurement conditions used for the calibration of the standard.

5.2.3 Calibration of the horizontal axis of the stylus instrument

The calibration of the x-axis of the device has to be ensured. Here, the guideline DKD-R 4-2, Sheet 4 shall be applied accordingly. On a horizontal reference standard, the mean value $RSm(reference)$ is determined under the same measurement conditions (λ_c) as on the standard to be calibrated. The measuring point plan used for the calibration of the reference standard must also be used when calibrating the horizontal axis. The result leads to the definition of a correction factor $C = \frac{RSm_n}{RSm(reference)}$ for the subsequent measurements of horizontal parameters.

5.3 Measurement conditions

The radius of the stylus tip should be 2 µm to 5 µm, the measuring point distance should be ≤ 0,5 µm. The feed rate should be ≤ 0.5 mm/s.

5.4 Measurements on the standard that is to be calibrated

At least 12 traversing lengths have to be distributed over the standard. The traversing lengths should only use about 80 % of the standard's length or width, respectively. The measuring point plans, which are shown as examples in Fig. 2, also consider the following aspects:

- repeatability of the device,
- deviations of the profile elements from the ideal shape,
- uncertainty in the positioning of the measuring points with regard to the future use of the standard.

In addition to these measurements, the waviness of the standard is determined by a measurement of Wt_0, in order to calculate the measurement uncertainty. The measurement of Wt_0 is carried out parallel to the tracks of the measuring point plan on the surrounding flat surface of the standard. If the standard does not contain flat surfaces, then Wt_0 can also be determined on a traverse length with λ_c= 0,8 mm, in the centre of the measuring point plan.

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Due to the limited filtering effect of the wave filter, a small part of the sinusoidal roughness profile is maintained, which increases the value of Wt_0. The size relationship that usually exists between the additional roughness and Wt_0, and the small sensitivity coefficient of Wt_0 allow this procedure.

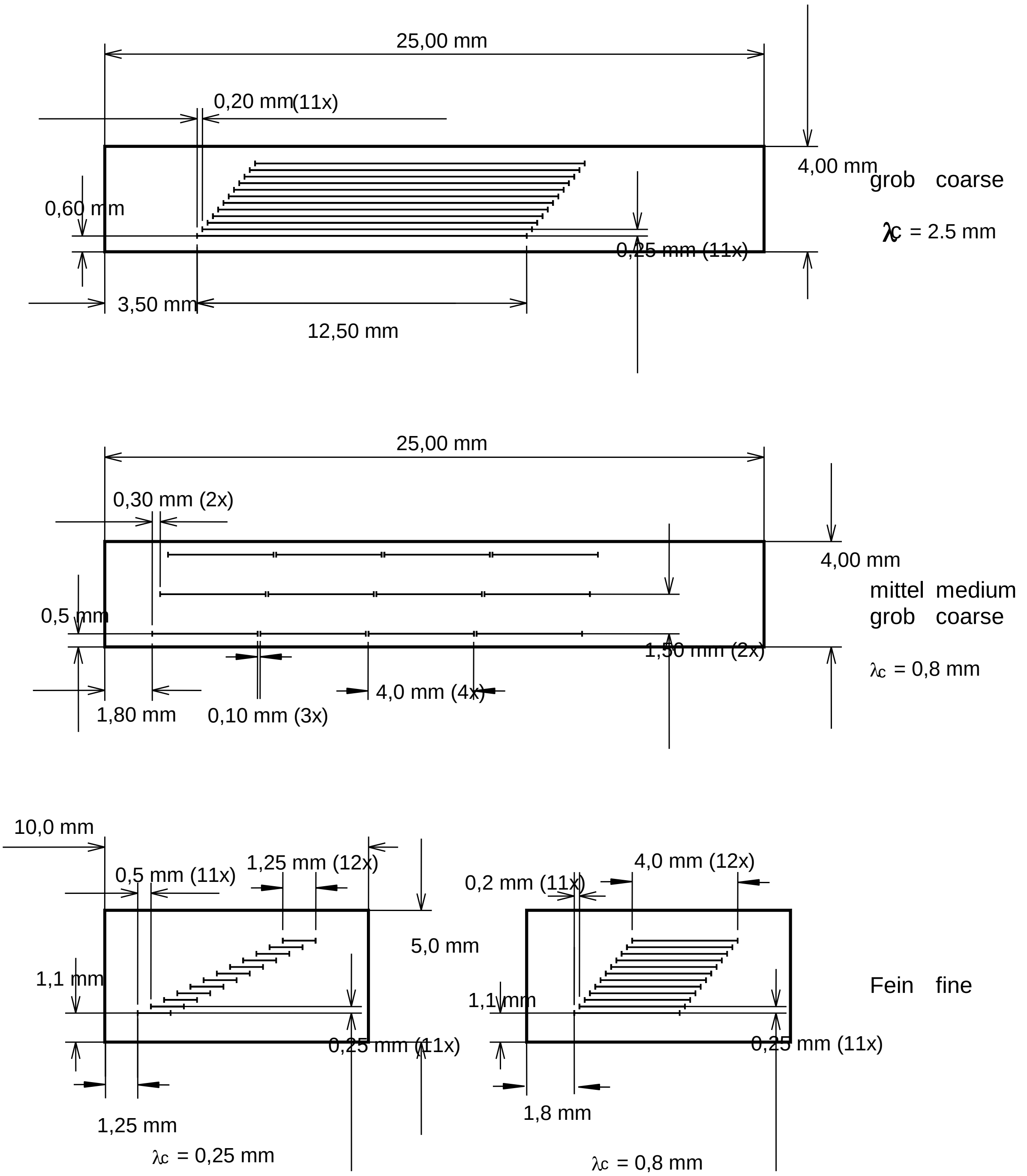

Fig. 2: Measuring point plans for geometrical standards of type C (DIN EN ISO 5436-1)

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5.5 Evaluation

- The mean value *RSm(reference)* is derived from the measurements on the reference standard and, if necessary, a correction factor $C = RSm_n / RSm(reference)$ for subsequent measurements is identified. RSm_n can be taken from the calibration certificate of the reference standard.
- The mean value of $RSm(object)$, standard deviation, minimum and maximum are derived from the 12 measurements on the standard that is to be calibrated. The measurement results form part of the calibration certificate.
- The mean value Rz_0 is derived from the 5 optical flat measurements. The result is required for the calculation of the measurement uncertainty.

5.6 Summary of the calibration process

Objective	Activity	Object used	Result
Background noise of the device	measuring 5 times *Rz*, averaging	Optical flat	Rz_0 for the calculation of measurement uncertainty
Horizontal instrument calibration	measuring *RSm* according to the measuring point plan of the reference standard	Reference horizontal standard	Calibration checked or correction factor determined
Waviness of the measuring object	measuring *Wt*	plane area of the measuring object	Wt_0 for the calculation of measurement uncertainty
Mean period of the measuring object	measuring 12 times *RSm*, averaging	Measuring surface of the measuring object	Measurement result of $RSm(object)$

Table 1: Summary of the calibration activities

5.7 Content of the calibration certificate

The calibration certificate must contain the following information and measurement results:

- Date
- Temperature
- Place of installation of the measuring device
- Type of calibration object according to the nomenclature in DIN EN ISO 5436-1
- Measuring device used and its essential components such as basic unit, drive unit, probe
- Measurement conditions (filter, probing speed, stylus tip, contact force, measuring point distance)
- Reference standard used and date of its last calibration (can be omitted in DKD calibration certificates)

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- Measuring point plan or corresponding literature references
- Description of the evaluation or corresponding literature references
- Mean value of *RSm,* standard deviation, measurement uncertainty, minimum and maximum (or range)

6. Measurement uncertainty

6.1 Model

The squares of the standard uncertainties of the influence quantities that affect the uncertainty of the characteristic value *RSm* are added, and the sum is then multiplied by the coverage factor *K* which guarantees a coverage probability of 95 %.
According to the definition set out in DIN EN ISO 4287

$RSm = \frac{1}{n} \cdot \sum_i \Delta x_i$, with *i* being the number of the i-th profile element of the length Δx_i. Since the profile elements are seamlessly connected to each other, *RSm* can be defined using the profile length *l*.

$RSm = \frac{1}{n} \cdot (x_e - x_a) = \frac{1}{n} \cdot l$, wherein the profile length l is the distance between the starting point (x_a) and the end point (x_e) of the evaluated part of the measuring length.
As to the uncertainty of *RSm*, the following equation applies:

$$u^2(RSm) = \frac{1}{n^2}[u^2(x_e) + u^2(x_a) + u^2(l)].$$

The uncertainties for the start and end points are the same, $u(x_a) = u(x_e) = u(x_i)$, so that the uncertainty is

$$u^2(RSm) = \frac{1}{n^2} \cdot [2 \cdot u^2(x_i) + u^2(l)]. \qquad \text{Eq. 1}$$

The points x_a and x_e are so far apart that they are not correlated by the λ_s filter. Due to the waviness filter, the uncertainty of the points of the roughness profile is practically equal to the points of the unfiltered profile (reference: /1/). Therefore, these considerations apply to *RSm* as well as to *PSm*.
Note
After the revision of the ISO standard 4287 in 2011, *RSm* is evaluated from a profile data set of the measuring length in forward and reverse direction, and the mean value is formed from both evaluation directions. The forward and backward evaluations are correlated with each other. At the same time, there is a double amount of profile elements to be evaluated, so that there is no change regarding the statistical observation of the profile elements. As compared to the previous definition, the measurement uncertainty according to the new definition of *RSm* may result in a smaller value. This is due to the fact that when counting the profile elements within the measuring length there are fewer profile elements to be omitted than before, that is to say when counting the profile elements within an individual sampling length.

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6.2 Uncertainty components

The following model is valid for positional deviations of the points:

$$\Delta x_i = x_o + x_w + x_b + x_{dig} .$$

The individual influence values are:

x_0 noise in the x-position due to noise of the contacting system in vertical direction,

x_w positional deviation due to the waviness Wt_0 of the standard,

x_b deviation caused by arc-shaped movement,

x_{dig} uncertainty in the determination of a profile element due to the measuring point distance.

The following model applies to the length l of the measuring length:

$$l = l_r + l_g .$$

l_r correct length

l_g deviation due to an unknown position of the stylus tip in the direction of feed

6.2.1 Uncertainty components in detail

6.2.1.1 Traceability

This component describes the uncertainty of the transfer of the unit of length to the horizontal axis of the device. It contains:

1. The uncertainty of the horizontal scaling factor which is determined during instrument calibration by determining RSm over the profile length $l = n \cdot RSm$ on a reference standard. In addition to the unit of length, it is the uncertainty of the reference standard $u(RSm_n)$ that is disseminated and which is indicated in its calibration certificate.

2. It must be taken into account that the measurement position on the reference standard during the calibration of the instrument may be different from the position during the calibration of the reference standard. An estimate value for the uncertainty is determined from the standard deviation. This standard deviation results from the measurement of RSm over the profile length $l = n \cdot RSm$ at the positions m_t where the reference standard was calibrated according to the calibration certificate.

$$u^2(l_r) = n^2 \cdot u^2(RSm_n) + \frac{n^2}{m_t} \cdot s^2(RSm(reference))$$

Both variances have a Gaussian probability distribution.

6.2.1.2 Measurement position

The incomplete knowledge regarding the position of the profile length l on the measurement object implies a random and a systematic component.

$$u^2(l_g) = u_s^2(l_g) + u_t^2(l_g)$$

An estimated value for the random component is the standard deviation of the mean value of m_t measurements of the profile length l on the assumption of a Gaussian probability distribution.

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$$u_s^2(l_g) = \frac{n^2}{m_t} \cdot s^2\left(\overline{RSm(object)}\right)$$

The systematic component results from the influence of the temperature difference between the calibration and the use of the reference standard. The thermal expansion coefficient α of the carrier material can indeed be taken into account in order to calculate an altered length, but the uncertainty $u(\alpha)$ and the difference in temperature ΔT have to be considered as sources of uncertainty for RSm. The probability distribution is rectangular.

$$u_t^2(l_g) = \frac{1}{12} \cdot (\Delta T \cdot u(\alpha) \cdot l)^2$$

6.2.1.3 Measuring point distance

The zero crossing of the signal for the localization of a profile element can only be determined with a deviation of up to $\pm \Delta x / 2$. The resulting uncertainty has an equal distribution with Δx as margin. The variance of this contribution to a single position is

$$u^2(x_{dig}) = \frac{1}{12} (\Delta x)^2 .$$

6.2.1.4 Noise

Due to the slope of the profile when passing through the zero line, a vertical noise leads to an uncertainty in the horizontal measurement (see Fig. 3). Therefore, the following model is applied for x_0. If the vertical noise is characterized by Rz_0, then $x_0 = \frac{Rz_0}{\sigma}$. Here, the equation $\sigma = Pt \cdot \frac{\pi}{p}$ describes the slope of the profile at the zero crossing of the sinusoidal profile, while p represents the wavelength of a profile element. Assuming a rectangular probability distribution, then

$$u^2(x_0) = \frac{1}{12} \cdot \left(\frac{Rz_0}{\sigma}\right)^2 .$$

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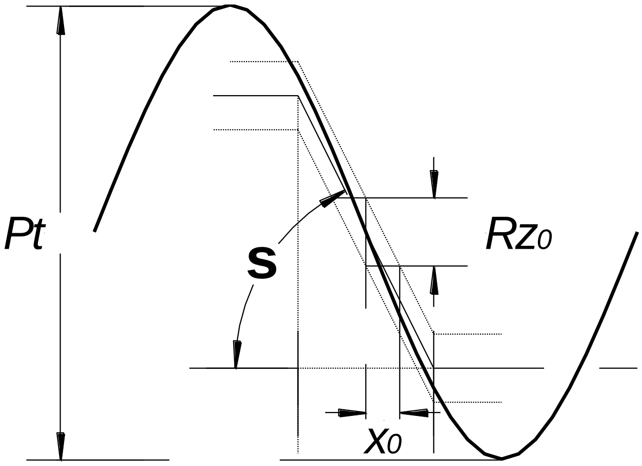

Fig. 3: Influence of the basic noise on the profile elements

6.2.1.5 Waviness

Due to the waviness of the standard's surface, the centre line meets adjacent profile elements at different heights (see Fig. 4).

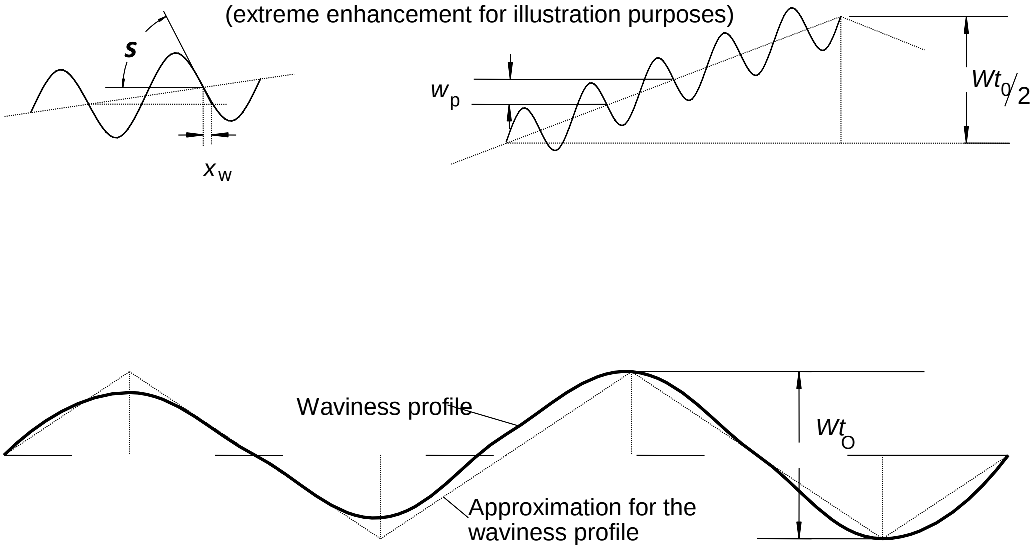

Fig. 4: Influence of the waviness on the profile elements

The corresponding lateral displacement of the zero crossing is $x_w = \frac{w_p}{\sigma}$. Subsequently, it is estimated which fraction of the waviness of the standard affects the height difference of adjacent profile elements. Experience has shown that the waviness contains two periods which are approximated as sinusoidal. The profile is distributed on approximately 40 profile elements. Piecewise linearized by triangles, the waviness profile consists of eight triangles, each having the height of $Wt_0 / 2$ and the length of five profile elements. So the maximum height difference of adjacent profile elements w_p amounts to one-fifth of $Wt_0 / 2$, hence

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$w_p = \frac{1}{10} \cdot Wt_o$. Assuming a rectangular distribution, the variance for the shifting of the zero crossing is

$$u^2(x_w) = \frac{1}{12} \cdot \left(\frac{Wt_0}{10 \cdot \sigma} \right)^2 .$$

6.2.1.6 *Arc-shaped movement*

In many stylus instruments, the transmission mechanism –from the stylus tip movement to the displacement transducer– is the angular movement of a lever (length L). The vertical movement enforced by surface contact causes a circular motion of the stylus tip as a function of the change in height dz. (See Fig. 5). The lever may be inclined opposite the surface at an angle that, in Fig. 5, corresponds to the medium angle $\frac{\alpha_1 + \alpha_2}{2}$ Without loss of generality, α_2 may also be zero (lever arm in the initial position parallel to the x-axis).

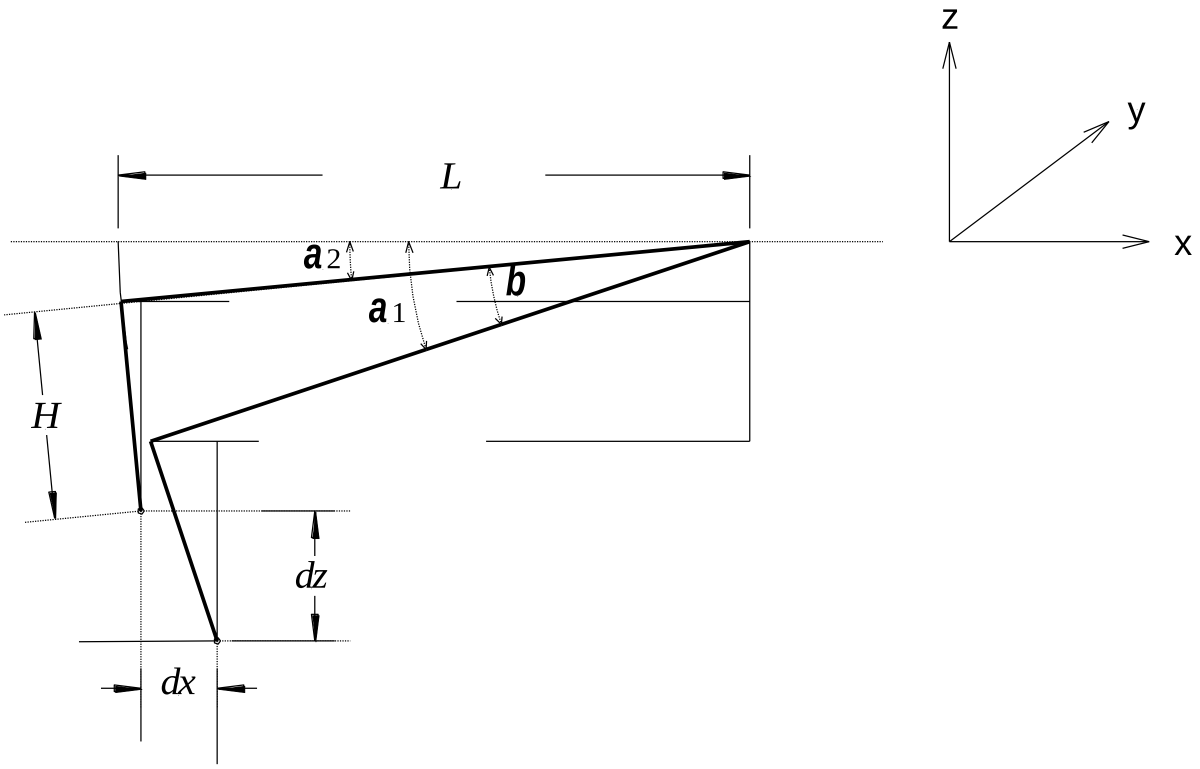

Fig. 5: Influence of the arc-shaped movement

The movement of the stylus tip, which is deflected by the height dz, is the combination of the rotation of the end of the lever arm on an arc around the angle β and a tilting of the stylus tip axis of the length H from angle α_1 to angle α_2. The resulting horizontal component of the stylus tip movement is

$$dx = [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})] \cdot dz .$$

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In case of an ideal standard, this deviation remains the same for each profile element and would thus not affect a horizontal distance parameter such as *RSm*. However, in case of a standard with flatness deviations, *dz* represents the change of height between adjacent profile elements due to waviness.
In chapter 6.2.1.5, the change in height of adjacent profile elements due to local waviness has been estimated as $u(w_p) = \frac{1}{10} \cdot Wt_0$. The corresponding error in the arc-shaped movement leads to an uncertainty in the x direction. Based on the assumption of a rectangular probability distribution, this uncertainty amounts to

$$u^2(x_b) = \frac{1}{12} \cdot (\frac{Wt_0}{10})^2 \cdot [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})]^2 .$$

6.3 Combined uncertainty

If the uncertainty components from chapter 6.2.1 are used in equation 1, then

$$u^2(RSm) = \frac{1}{n^2} \cdot \{ \ n^2 \cdot u^2(RSm_n) \ + \ \frac{n^2}{m_t} \cdot s^2(RSm(reference)) \ + \ \frac{n^2}{m_t} \cdot s^2\left(\overline{RSm(object)}\right) \ +$$
$$\frac{1}{12} \cdot (\Delta T \cdot u(\alpha) \cdot l)^2 \ + 2 \cdot (\ \frac{1}{12}(\Delta x)^2 + \frac{1}{12} \cdot \left(\frac{Rz_0}{\sigma}\right)^2 \ + \ \frac{1}{12} \cdot \left(\frac{Wt_0}{10 \cdot \sigma}\right)^2 \ +$$
$$\frac{1}{12} \cdot (\frac{Wt_0}{10})^2 \cdot [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})]^2 \ ) \ \}$$
$$u^2(RSm) = \ u^2(RSm_n) \ + \ \frac{1}{m_t} \cdot s^2(RSm(reference)) \ + \ \frac{1}{m_t} \cdot s^2\left(\overline{RSm(object)}\right) +$$
$$\frac{1}{12} \cdot (\Delta T \cdot u(\alpha) \cdot RSm_n)^2 \ + \frac{1}{6 \cdot n^2}(\Delta x)^2 + \ \frac{1}{6 \cdot n^2} \cdot \left(\frac{Rz_0}{\sigma}\right)^2 \ + \ \frac{1}{6 \cdot n^2} \cdot \left(\frac{Wt_0}{10 \cdot \sigma}\right)^2 \ +$$
$$\frac{1}{6 \cdot n^2} \cdot (\frac{Wt_0}{10})^2 \cdot [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})]^2 \qquad \text{Eq. 2}$$

Table 2 shows the uncertainty components and their typical values when calibrating a geometrical standard with a period of *RSm* = 200 µm and an amplitude of *Pt* = 10 µm according to equation 2.

6.4 Table of the uncertainty components

Chap.	Short name	Determined by	Input quantity Example value	Method Distribution	Variance /nm^2
6.2.1.1	Reference standard	$u^2(RSm_n)$	$u(RSm_n)$= 2 nm	B Gauss	4
6.2.1.1	Calibrating position	$\frac{1}{m_t} s^2(RSm(reference))$	$s(RSm(reference)) = 50nm$, m_t=12	A Gauss	208

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Chap.	Short name	Determined by	Input quantity Example value	Method Distribution	Variance /nm^2
6.2.1.2	Statistics Object	$\frac{1}{m_t} \cdot s^2\left(\overline{RSm(object)}\right)$	$s(\overline{RSm(object)})$ = 50 nm, $m_t = 12$	A Gauss	208
6.2.1.2	Temperature Object	$\frac{1}{12} \cdot (\Delta T \cdot u(\alpha) \cdot RSm_n)^2$	$\Delta T = 3\,K$ $u(\alpha) = 1 \cdot 10^{-6}\,K^{-1}$	B Rectangle	0.03
6.2.1.3	Measuring point distance	$u^2(x_{dig}) = \frac{1}{6 \cdot n^2} \cdot (\Delta x)^2$	n = 40 Δx = 500 nm	B Rectangle	26
6.2.1.4	Noise	$\frac{1}{6 \cdot n^2} \cdot \left(\frac{Rz_0}{\sigma}\right)^2$	Rz_0 = 10 nm σ=0.314	A Rectangle	0.1
6.2.1.5	Waviness	$\frac{1}{6 \cdot n^2} \cdot \left(\frac{Wt_0}{10 \cdot \sigma}\right)^2$	Wt_0 = 20 nm	A Rectangle	0.02
6.2.1.6	Arc-shaped movement	$\frac{1}{6 \cdot n^2} \cdot (\frac{Wt_0}{10})^2 \cdot [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})]^2$	L = 10 mm H = 1,5 mm $\tan(\frac{\alpha_1 + \alpha_2}{2}) = 0.3$	B Rectangle	≈ 0
6.2.1.6	Arc-shaped movement	$\frac{1}{6 \cdot n^2} \cdot (\frac{Wt_0}{10})^2 \cdot [\frac{H}{L} + \tan(\frac{\alpha_1 + \alpha_2}{2})]^2$	L = 10 mm H = 1.5 mm $\tan(\frac{\alpha_1 + \alpha_2}{2}) = 0.3$	B Rectangle	≈ 0
6.3	$u^2(RSm)$	Sum of the variances			446.15
6.1	$u(RSm)$				21 nm
6.1	$U(RSm)$	$2 \cdot u(RSm)$	K=2		42 nm
	$U_{rel}(RSm)$	$U(RSm)/RSm$			$2 \cdot 10^{-4}$

Table 2: Compilation of measurement uncertainty components with example values

The sensitivity coefficients are all equal to 1.

6.5 Simplification

In Equation 2, the smallest summands can be neglected to simplify the calculation. Despite their small value in Table 2, this does not apply to the summands ‘reference standard’ and ‘measuring point distance’ which, on a case by case basis, can also accept values much higher than shown in Table 1.

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$$u^2(RSm) = u^2(RSm_n) + \frac{1}{m_t}\cdot s^2(RSm(reference)) + \frac{1}{m_t}\cdot s^2\left(\overline{RSm(object)}\right)$$
$$+\frac{1}{6\cdot n^2}(\Delta x)^2 + \frac{1}{6\cdot n^2}\cdot\left(\frac{Rz_0}{\sigma}\right)^2 \qquad \text{Eq. 3}$$

Since the neglected components have a share of approximately 0.1 % of the total variance, the uncertainty of *RSm* should be rounded.

7. Quoted standards and other references

Standard or reference	Title, keywords describing the content
DIN 1319 - 3	Fundamentals of metrology; Terms for measurement uncertainty and for the assessment of measuring devices and systems
DIN 1319 - 4	Fundamentals of metrology; Treatment of uncertainties in the evaluation of measurements
DIN 4768 (1974) (withdrawn)	Determination of Surface Roughness R_a, R_z, R_{max} with Electric Stylus Instruments; Terms, measurement conditions
DIN 4768 (1990) (withdrawn)	Determination of Surface Roughness R_a, R_z, R_{max} with Electric Stylus Instruments; Terms, measurement conditions
DIN V 32950 (04.97) ISO/TR 14638	Geometrical product specification (GPS); Master plan
DIN EN ISO 3274 (04.98)	Surface texture: Profile method - Nominal characteristics of contact (stylus) instruments
DIN EN ISO 4287 (10.98)	Surface texture: Profile method Terms, definitions and surface texture parameters
DIN EN ISO 4288 (04.98)	Surface texture: Profile method; Rules and procedures for the assessment of surface texture
DIN EN ISO 5436-1 (11.2000)	Surface texture: Profile method; Measurement standards - Part 1: Material measures
DIN EN ISO 5436-2 (2.2000))	Surface texture: Profile method; Measurement standards - Part 2: Software measurement standards
DIN EN ISO 11562 (09.98)	Surface texture: Profile method Metrological characteristics of phase correct filters
DIN EN ISO 12179 (11.2000)	Surface texture: Profile method Calibration of contact (stylus) instruments
DIN EN ISO 13565-1 (06.98)	Surface texture: Profile method; Surfaces having stratified functional properties Part 1: Filtering and general measurement conditions

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Standard or reference	Title, keywords describing the content
DIN EN ISO 13565-2 (04.98)	Surface texture: Profile method; Surfaces having stratified functional properties Part 2: Height characterization using the linear material ratio curve
DAkkS-DKD-3 (2010)	Indication of the measurement uncertainty in calibrations
DKD-R 4-2 Blatt 2 (2007)	Calibration of instruments and standards for roughness metrology. Sheet 2: Calibration of the vertical measuring system of stylus instruments.
WECC Doc. 19	Guidelines for the Expression of the Uncertainty of Measurement in Calibrations (“GUM”)
/1/	M. Krystek: Einfluss des Wellenfilters auf die Unsicherheit eines Messergebnisses bei Rauheitsmessungen. Tagungsband der DIN-Tagung „GPS 99“, 5.-6.-Mai 1999, Mainz, S. 4-1 – 4-11. Beuth-Verlag, ISBN 3-410-14534-6
EAL-G20	Calibration of stylus instruments for measuring surface roughness, ed. 1, 1996.
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