DEUTSCHER KALIBRIERDIENST

DKD-R 4-2
Calibration of Devices and Standards for Roughness Metrology

Sheet 2: Calibration of the vertical measuring system of stylus instruments

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1. Purpose and field of application

In this sheet of the Directive, the calibration of the vertical measuring system of stylus instruments (DIN EN ISO 3274) is described. The basic regulations of DIN EN ISO 12179 are taken into account. Procedures for calculation of the measurement uncertainty in the calibration of stylus instruments with depth setting standards and roughness standards are stated. The calibration with depth setting standards establishes traceability to the national length standard, the calibration with roughness standards validates the function of the complete transmission chain of the stylus instrument.

2. Terms and symbols

Here, only the terms and symbols which are specific for this sheet are explained. Generally valid terms are mentioned in the surface standards stated in chapter 10.

Rz_0	Basic noise of the device
Wt_0	Straightness deviation of the guidance
U_n	Uncertainty of the reference standard
$\overline{Pt_m}$	Mean value of Pt of the currently measured profile depth
m_w	Number of repetition measurements performed at the same probing place
m_t	Number of repetition measurements for changed probing places

Indices:

t	Due to topography
w	Due to repetition measurement
pl	Due to plastic deformation
sp	Due to stylus tip

3. Measuring device

The stylus instrument in accordance with DIN EN ISO 3274 consists of a basic unit, a feed device (with a guidance of its own) and a probing system. If different device components are combined, each device combination must be calibrated separately.
Before calibration is carried out, correct functioning of the stylus instrument is checked in accordance with its operating instructions.
Feed device and surface of the standards are to be aligned in parallel to each other.

4. Ambient conditions

The stylus instrument should be calibrated at is place of use. This guarantees that the influences of the ambient conditions, which also prevail in the later use of the stylus instrument, are taken into account for the calibration.
Temperature gradients, e.g. by direct sun light, must be avoided.

5. Calibration

For a calibration, the following three types of standards are used:

- Plane glass plate
- Depth setting standard, type A in accordance with DIN EN ISO 5436-1
- Roughness standard, type D in accordance with DIN EN ISO 5436-1

Table 1 shows a survey of their use in the calibration activities to be performed.

Objective	**Design**	**Chapter**
Determination of the basic noise	5x measurement of Rz_0 on plane glass plate	5.1
Determination of the guidance deviation	5x measurement of Wt_0 on a plane glass plate	5.1
Determination of the vertical amplification	Measurement of the depth of different grooves on a depth setting standard	5.2
Determination of the repeatability	5x measurement of the depth of a groove at the same place on a depth setting standard	5.2
Checking of the transmission chain function	Measurement of roughness parameters on a roughness standards	5.3
Monitoring of the device proper ties	Regular calibration and documentation	9

Table 1: Summary of the calibration activities

5.1 Plane glass plate

On a plane glass plate, Rz_0 is determined in five surface profiles under the measurement conditions used for the calibration of the device with roughness standards. The mean value is to be indicated in the calibration certificate as s $\overline{Rz_0}$.

On the plane glass plate, Wt_0 is determined in five surface profiles for the area of the guidance which will later be used for the measurements. The mean value is required as $\overline{Wt_0}$ for the calculation of the measurement uncertainty of parameters which are evaluated at the unfiltered profile (see chapter 6.2).

5.2 Depth setting standards, type A (DIN EN ISO 5436-1)

The measurements on the depth setting standard must be carried out for the profile depths which will be important for the later use. The smallest possible measurement range which suits the profile depth must be selected.
The groove of a depth setting standards is to be measured five times in the same position at a calibrated place (for determination of $s_w^2(Pt_m)$) and in five profile sections which are close to one another (for determination of $\overline{Pt_m}$). A plan of measurement points in accordance with Fig. 1 has proved its worth.

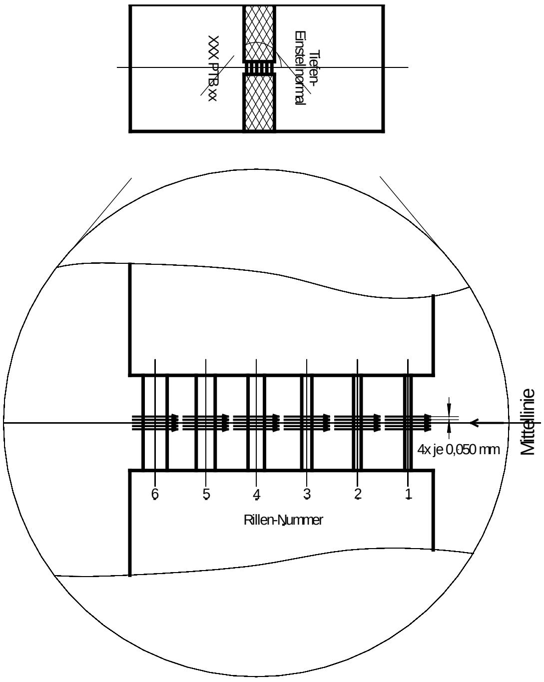

Fig. 1: Example of a plan of measurement points for calibration of the stylus instrument with a depth setting standards (here: type A2). For calibration of the device, five measurements are carried out in the centre of the groove of this standard and five measurements for a range of 300 µm around the centre.

The evaluation of the profile depth Pt on a depth setting standard is described in Directive DKD-R 4-2, sheet 1, Annex B. Before the evaluation is realized, the reference level of the standard is to be aligned horizontally with the aid of two partial ranges on the left and on the right of the groove by means of the least squares method.
The deviation of the mean value $\overline{Pt_m}$ (which has been obtained by five measurements) from the calibration certificate of the device is indicated in percent from the measurement value and in micrometers.
For evaluation of the groove depth D (in accordance with DIN EN ISO 5436-1) described in Directive DKD-R 4-2, sheet 1, in Annex B, the same procedure is valid.

5.3 Roughness standard, type D (DIN EN ISO 5436-1)

On a roughness standard with an irregular profile, 12 profile sections are recorded on the measurement face. The smallest possible measuring range suiting the roughness is to be selected (DIN EN ISO 4288). For the limiting wavelength λ_c = 0.8 mm, the plan of measurement points according to Fig. 2 has proved its worth.

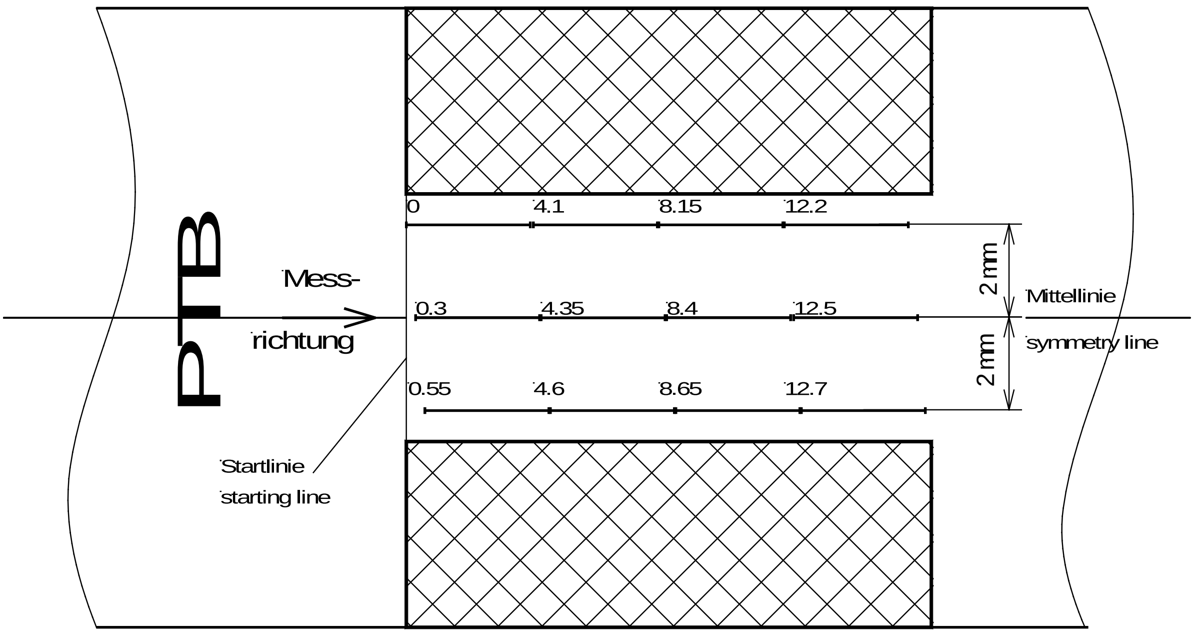

Fig. 2: Example of a plan of measurement points on a roughness standard with λ_c= 0.8 mm; indicated are the starting points of the measurement sections (each 4 mm in length). From this, the probing sections are obtained in accordance with the filter properties of the device.

From the 12 profile sections, the arithmetic mean of the desired roughness parameters is calculated in accordance with DIN EN ISO 4287 or DIN EN ISO 13565-1,2. The deviations of the currently determined values from the values stated in the calibration certificate of the standard are to be indicated in the calibration certificate of the device in percent of the measurement value and in micrometers.

6. Measurement uncertainty

6.1 Joint model in Directive DKD-R 4-2

The calculation of the measurement uncertainty in Annex A of Directive DKD-R 4- 2 is based on the generally valid model of the probing process of the stylus instrument on a mechanical surface. From this model, the quantities which affect the calibration of stylus instruments with depth setting standards and with roughness standards are compiled. In accordance with GUM, the standard uncertainties of the influence quantities are quadratically added, and the sum is multiplied by the coverage factor K. This guarantees for the result a coverage probability of 95%. As some of the influence quantities have a small degree of freedom, the value of K must be calculated from the effective degree of freedom of the overall uncertainty. A concrete description of the procedure can be found in DKD-3.

6.2 Device calibration with depth setting standards

The model of the interaction during the measurement on depth setting standards is described in Directive DKD-R 4-2, sheet 1, Annex B. On the basis of this model, the uncertainty components, which are influenced by the device properties and the calibration process, are taken into account when the measurement uncertainty is determined during the calibration of the devices with depth setting standards in accordance with DIN EN ISO 12179.
The model:

$$U_{Gerät}(Pt) = 2 \cdot [\ u_n^2 + \frac{1}{m_t} \cdot s_t^2(Pt_m) + \frac{1}{m_w} \cdot s_w^2(Pt_m) + \frac{1}{12} \cdot \left(\overline{Wt_0}\right)^2 + \frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2\ ]^{1/2} \qquad \text{eq. 1}$$

u_n — Standard uncertainty of the reference standard used for the device calibration. $u_n = U_n / K$. The expanded uncertainty U_n and the coverage factor K are taken from the calibration certificate of the reference standard.

$\frac{1}{m_t} s_t^2(Pt_m)$ — Influence, which results in the dissemination from the topography of the reference standard by an inexact localization of the probing place. As estimated value serves the standard deviation s_t^2 of the mean value of the currently measured profile depth Pt_m of the reference standard for m_t measurements and for a slight variation of the probing place.

$\frac{1}{m_w} \cdot s_w^2(Pt_m)$ — Probing repeatability of the device to be calibrated. The standard deviation s_w^2 of the mean value of the currently measured profile depth Pt_m of the reference standard serves as an estimated value for m_w measurements when the measurements are carried out at the same probing place.

$\frac{1}{12} \cdot \left(\overline{Wt_0}\right)^2$ — Straightness deviations of the guidance of the device to be calibrated

$\frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2$ — Noise of the device to be calibrated

Table 2 shows a survey of the influence quantities for a device calibration in accordance with equation 1 on the basis of parameter Pt. The numbers of the chapters in the table relate to the chapters in Annex A of Directive DKD-R 4-2 sheet 1.

Chapter	Input quantity keyword	Calculation of the input quantity	Example value for Pt=3µm	Sensitivity coeff.	Method of determination, distribution	Variance/ nm^2
3.1	Reference standard	$\frac{1}{4} \cdot U_n^2$	U_n = 15 nm (Cal. certificate)	1	B Gaussian	56

Chap-ter	Input quantity keyword	Calculation of the input quan-tity	Example value for Pt=3µm	Sensitivity coeff.	Method of determina-tion, distribution	Variance/ nm²
3.2	Difference between measurement place and cali-bration place	$\frac{1}{m_t} s_t^2(Pt_m)$	$s_t(Pt_m) = 6$ nm (m_t=5)	1	B Gaussian	7,2
3.3	Repeatability	$\frac{1}{m_w} \cdot s_w^2(Pt_m)$	s_W = 5 nm, m_W = 5	1	A Gaussian	5
3.5	Guidance de-viation	$\frac{1}{12} \cdot \left(\overline{Wt_0}\right)^2$	$\overline{Wt_0} = 50\,\text{nm}$	1	B equal	208
3.6	Basic noise	$\frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2$	$\overline{Rz_0} = 20\,\text{nm}$	1	A equal	33
	Device, totally	Sum column above	$u_{device}^2(Pt)$			309,2
		$\sqrt{Zelle\ oberhalb}$	$u_{device}(Pt)$			18 nm
		K = 2	$U_{device}(Pt)$			36 nm
		$U_{Gerät}(Pt)/Pt$	U_{rel}(device, Pt)			1,2 %

Table 2: Calculation of the measurement uncertainty of the device calibration in the measurement of the profile depth Pt with example values

The same procedure can also be applied when the measurement uncertainty of the device calibration is determined during the measurement of the groove depth D (DIN EN ISO 5436-1).

6.3 Device calibration with roughness standards

Based on the model shown in Directive DKD R 4-2, sheet 1, Annex A, the uncertainty components which are influenced by the device properties and the calibration process are taken into account for the determination of the measurement uncertainty when stylus instruments are calibrated with roughness standards in accordance with DIN EN ISO 12179.
The model:

$$u_{gerät}(Rz) = 2 \cdot [\, u_{RN}^2 + \frac{1}{m_w} \cdot s_w^2(Pt_m) + \frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2 + \frac{a_{pl}^2}{3} + \frac{1}{3} \cdot \left(u(r_{sp})\right)^2 \,]^{1/2} \qquad \text{eq. 2}$$

u_{RN}^2 Standard uncertainty of the measurand on the reference standard (RS) used for device calibration. $u_{RN} = U_{RN} / K$. Die uncertainty U_{RN} and the coverage factor K are taken from the calibration certificate of the roughness standard. This also includes the determination of a possible amplification deviation.

$\frac{1}{m_w} \cdot s_w^2(Pt_m)$ Probing repeatability of the device to be calibrated. The standard deviation s_w^2 of the mean value of the currently measured profile depth of the reference standard serves as an estimated value for m_w measurements of the profile depth Pt_m of the reference depth setting standard when the measurements are carried out at the same probing place.

$\frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2$ Noise of the device to be calibrated

$\frac{a_{pl}^2}{3}$ Plastic deformation on the standard by stylus tip

$\frac{1}{3} \cdot \left(u(r_{sp})\right)^2$ Influence of the deviation of the stylus tip from the nominal radius

Table 3 shows a survey of the influence quantities for device calibration in accordance with equation 2 on the basis of roughness parameter Rz. The numbers of the chapters in the table relate to the chapters in Annex A of Directive DKD-R 4-2, sheet 1.

Chapter	Input quantity keyword	Calculation of the Input quantity	Example value for Rz = 3 µm	Sensitivity coeff.	Method of determ., distribution	Variance [nm²]
3.1	Traceability	u_{RN}^2	$U_{RN}(Rz) = 3\%$ from the cal. cert. of RS ⇒ u = 45 nm	1	B Gaussian	2025
3.3	Repeatability	$\frac{1}{m_w} \cdot s_w^2(Pt_m)$	s_w = 5 nm, m_w = 5 repeat measurements	1	B Gaussian	5
3.6	Basic noise	$\frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2$	$\overline{Rz_0} = 20$ nm	1	A equal	33
3.7	Plast. deform.	$\frac{a_{pl}^2}{3}$	a_{pl} = 5 nm	1	B equal	8
3.8	Stylus tip	$\frac{1}{3} \cdot \left(u(r_{sp})\right)^2$	$u(r_{sp})$ = 0.5 µm	-20 nm/µm	B equal	33
	Device, totally	Sum column above	$u_{device}^2(Rz)$			2104
		$\sqrt{Zelle\ oberhalb}$	$u_{device}(Rz)$			46 nm
		K = 2	$U_{device}(Rz)$			92 nm
		$U_{device}(Rz)/Rz$	U_{rel}(device, RN)			3%

Table 3: Calculation of the measurement uncertainty of the device calibration for determination of the roughness parameter Rz with example values.

As a wave filter is used, guidance deviations do not exert any influence in the case of roughness standards.

Note

Consequently, the device calibration is mainly determined by the uncertainty of the reference roughness standard, whose uncertainty is in turn mainly determined by its standard deviation during its calibration. As, according to DIN EN ISO 12179, the influences due to the imperfection of the standards do not have to be taken into account for the uncertainty of the device calibration, this summand would actually have to be omitted. As the influence of the topography is, however, unavoidably connected with the calibration, it must remain included.

7. Admissibility for calibration

The admissibility for calibration is determined in two steps.
First, the calibration is carried out with a depth setting standard (reference standard) in accordance with chapter 5.2. If - after an adjustment of the device - the deviations of the results are still larger than the expanded measurement uncertainty plus a constant amount (for DKD laboratories, an amount of 0.01 µm has proved its worth), the device is regarded as not admissible for calibration. If the deviation is smaller, the measurement uncertainty of the device calibration can be determined with depth setting standards in accordance with chapter 6.2.
If this requirement is met, calibration with a roughness standard is carried out in the second step in accordance with chapter 5.3. The device is suitable for roughness measurements if the results of the measurement of the roughness parameters on the reference standards deviate by less than their expanded measurement uncertainty plus a constant amount (for DKD laboratories, an amount of 1% of the calibrated parameters has proved its worth). If the deviation is smaller, the measurement uncertainty of the device calibration can be determined with roughness standards in accordance with chapter 6.3.

8. Calibration certificate

The calibration is documented in the calibration certificate. It shall contain the following information:

- Place of the calibration
- Components of the calibrated device combination (manufacturer, type, serial number)
- Standards used (identification number, official mark and date of the latest calibration)
- Description of the calibration procedure, possibly also with reference to standards, directives or relevant scientific texts
- Measurement conditions (temperature, measurement range, feed velocity, probing section, limit wavelength, filter type, stylus radius)
- Measurement result of $\overline{Rz_0}$ on the plane glass plate
- Measurement results whose measurement uncertainty and deviations (in µm and percent) deviate from the calibrated values of the depth setting standard and the roughness standard.

9. Recalibration, intermediate test

The calibration is to be repeated at regular intervals. Depending on the measurement task, recalibration periods between 1 month and 2 years are usual. The recalibration period is influenced by the

- stability of the environmental conditions
- change of components of the device
- frequency of the use
- requirements for the uncertainty

For interim checks of the functional capacity of the device, it has proved its worth to measure the parameters *Rz* and *RSm* at shorter intervals on a roughness standard with a regular profile (type C1 in accordance with DIN EN ISO 5436-1) and to document the deviations of the displayed values.

10. Literature

DIN EN ISO 3274 (04/1998):
Geometrical Product Specifications (GPS) - Surface texture: Profile method - Nominal parameters of contact (stylus) instruments

DIN EN ISO 12179 (11/2000):
Geometrical Product Specifications (GPS) - Surface texture: Profile method - Calibration of contact (stylus) instruments

DIN EN ISO/IEC 17025 (2005):
All General requirements for the competence of testing and calibration laboratories

DIN EN ISO 4287 (10/1998):
Geometrical Product Specifications (GPS) - Surface texture: Profile method ; Terms, definitions and surface texture parameters

DIN EN ISO 5436-1 (1998):
Geometrical Product Specifications (GPS) - Surface texture: Profile method ; Standards; part 1: Material measures

DIN EN ISO 4288 (10/1998):
Geometrical Product Specifications (GPS) - Surface texture: Profile method ; Rules and procedures for the assessment of surface texture

DIN 4768 (5/1990)
Determination of the roughness parameters R_a, R_z, R_{max} with electrical stylus instruments; terms, measurement conditions
Note: This withdrawn standard is mentioned here due to the definition of the widely-used parameter *Rmax*.

Directive DKD-R 4-2:
Calibration of measuring instruments and standards for roughness metrology; sheet 1: Calibration of standards for roughness metrology

EN 10049 (2006):
Measurement of roughness average *Ra* and peak count *RPc* on metallic flat products

DKD-3 (edition 2, 2002)
Expression of the measurement uncertainty in calibrations
Published by the Accreditation Body of the German Calibration Service (DKD),
http://www.dkd.eu