DEUTSCHER KALIBRIERDIENST

DKD Guideline 4-2

Calibration of measuring instruments and standards for roughness measuring technique

Sheet 1: Calibration of standards for roughness measuring technique

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1 Scope

This Sheet is applicable to the calibration of standards of types A, C, D and E according to ISO 5436-1. These standards are used in roughness measurement by the contact stylus method.

2 Terms, definitions

The definitions in ISO 5436-1 and standards cited therein shall be valid.

3 Standards/standard measuring devices

The traceability of the standards/standard measuring devices named in section 5.3 – Scope of calibration / carrying-out of calibration by contact stylus method – must be ensured by calibration against suitable measuring systems whose traceability with the national standards in accordance with the International System of Units (SI) has been verified. The calibration of the contact stylus instrument is to be based on the DKD Guideline DKD-R 4-2 Sheet 2.

4 Ambient conditions

The influence of the ambient conditions is determined by roughness measurements on an optical flat. For this purpose, the best possible resolution of the measuring signal is to be set and a traversing length on an optical flat sector free from scratches is to be searched. This length is traced five times under the same conditions of measurement as for the calibration of the standard (in accordance with ISO 4288 and ISO 3274). The arithmetic mean of the Rz values is to be stated in the calibration certificate as Rz_0 and to be taken into account in the uncertainty considerations according to chapter 6.

5 Calibration

5.1 Calibratability

For the determination of the calibratability the standards are to be cleaned in a suitable way (e.g. with a non-fluff cloth or cotton bud soaked with isopropanol).

For assessing the calibratability rapidly and at low cost, visual inspection is recommended, a distinction being made between glass standards and metal standards.

5.1.1 Glass standards

The glass standards are to be checked for scratches, traces of use and chipping. For this to be done, tenfold magnification (using, for example, a magnifying lens) has proved to be suitable since this allows all damages of relevance to the measurements to be identified.

The measuring area must not show more than two critical or four slight damages. Otherwise, the standard is to be classified as non-calibratable.

Under critical damages chippings and/or deep or long scratches substantially influencing the measurement result is to be understood (e.g. scratches diagonally crossing the measuring area).

Damages are classified as slight if they no longer have an effect when the measuring scheme is slightly modified.

5.1.2 Metal standards

The traces of use and manufacturing defects of metal standards must be evaluated as regards their effects on calibratability. Here visual inspection with about tenfold magnification is recommended. When the light strikes the surface obliquely, the overall structure and all scratches are detected, whereas in the case of vertical incidence of illumination only the scratches of relevance to calibratability are seen. Critical scratches which do not run in the direction of measurement limit the measuring area allowed. If this leads to the useful measuring area becoming too small, the standard is to be classified as non-calibratable.

More than eight critical scratches in the direction of measurement lead to the measuring area allowed to be limited. If these scratches are uniformly distributed over the measuring area, the standard is classified as non-calibratable.

5.2 Calibration procedure

The calibration is carried out by the contact stylus method according to ISO 3274 and DIN 4772 by means of contact stylus systems incorporating a reference guide. Depth-setting standards can also be calibrated by interference-optical methods according to VDI/VDE 2655-1.1.

5.3 Scope of calibration/carrying-out of calibration

5.3.1 Calibration by the profile method

For the whole calibration sequence the standards should be mechanically aligned in the best possible way. The deviation of the alignment – measured around the electrical zero – must be smaller than 10% of the nominal range of measurement of the probe. It has to be ensured that the smallest possible range of measurement of the probe is selected for calibration. For Pt measurements the separate conditions stated in section 5.3.1.1 are valid.

The minimum number of profiles to be covered depends on the type of the standard to be calibrated and can be taken from Table 1:

Table 1: Minimum number of profiles

Type acc. to ISO 5436-1	**Number of profiles**
A	5
C	12
D	12
E	3

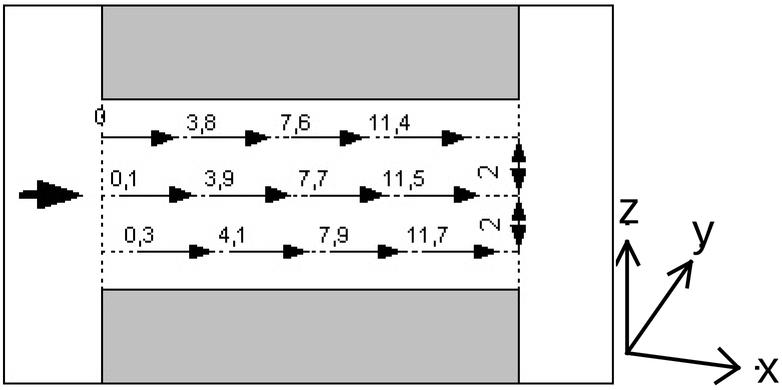

Figure 1: Measuring scheme for cutoff wavelength 0,8 mm and coordinate system

The distribution of the profiles is governed by a measuring scheme to be documented in the calibration certificate. This plan depends on the kind of the standard to be calibrated, a distinction being made between:

- Type A (depth-setting standards)

  For the calibration, about 75% of the groove length is to be used, the profiles obtained being symmetrically and uniformly distributed in the y-direction over the groove length.

- Type C (roughness standards with regular profile, sine wave standards)

  The profiles are to be uniformly distributed over the whole measuring area, about 75% of the length and width of the measuring area having to be used for each profile.

- Type D (roughness standards with irregular profile)
  - Type D1

    The profiles are to be uniformly distributed over the whole measuring area, about 75% of the length and width of the measuring area having to be used for each profile. In the particular case of the PTB roughness standards for the cutoff wavelength 0.8 mm the measuring scheme shown in Figure 1 has proved to be suitable.

  - Type D2

    The 12 profiles are to be uniformly distributed over the measuring area.

- Type E (sphere)

  Three profiles are to be obtained over the zenith of the sphere.

5.3.1.1 Depth-setting standard

Two different evaluation methods can be applied for the calibration of depth-setting standards:

a) regression method according to ISO 5436-1
b) determination of *Pt* according to ISO 4287

The regression method according to ISO 5436-1 allows the measure of depth of depth-setting standards to be disseminated with the best reproducibility and the smallest uncertainty of measurement.

For calibration by method (b), the requirements for profile alignment are much higher than for the regression method. The maximum permissible alignment deviation may not exceed 50% of the uncertainty of measurement of the standard but must not be greater than 20 nm. The traversing length is to be selected such that it is about three times the groove width, the groove having to be situated in the middle of the traversing length. If low-pass filtering is used, a λs of 8 µm has proved to be suitable.

5.3.1.2 Roughness standards

The conditions of measurement are to be selected in accordance with ISO 4288 / ISO 3274. Deviations from these specifications are permitted only in well-founded exceptional cases. Furthermore, these deviations have to be specifically mentioned in the calibration certificate.

5.3.2 Assessment of the measurement results

From the measurements carried out a mean value is to be formed which is to be stated as result in the calibration certificate. Furthermore, the standard uncertainty of the measurement values is to be determined and considered in the determination of the uncertainty budget according to chapter 6.

The individual values are to be checked for erroneous measurements and damages to the standards. One outlier at most may be replaced by the measurement value from a check measurement. Should further outliers be discovered, the allowed measuring area is to be limited or the measurement values are to be taken into account in the determination of the calibration result.

6 Uncertainty of measurement

For a contact stylus system according to ISO 3274 a model is set up according to which the values for the surface parameters are determined from the traced profile $z_e(x)$ via a chain of functions. For the calculation of the uncertainty of measurement in accordance with GUM, it is calculated in a chain of consecutive functions what effects the uncertainty of the input quantities has on the uncertainty of the result value after the respective function has been applied. The result then is the input quantity for the uncertainty calculation for the next function.

Annex A is a detailed example of the calculation of the uncertainty of measurement of roughness standards. On this basis, the uncertainty of measurement for a depth-setting standard is calculated in Annex B, C and D under different assumptions of the model.

Value K of surface parameter P : K = P{Fc[Fs(G($z_e(x)$))]}

Explanation:

Device function :	$G(z_e(x)) = z_g(x)$	data influenced by device function (total profile)
λs-filter:	$Fs(z_g(x)) = z_s(x)$	data influenced by λs (primary profile)
λc-filter:	$Fc(z_s(x)) = z_c(x)$	data influenced by λc (roughness profile)
Parameter function:	$P(z_c(x)) = K$	parameter function P calculates value K of surface parameter P

The functions from inside to outside:

6.1 Device function

$$z_g(x) = C \cdot \{z_e(x) + z_{ref}(x) + z_0(x) + z_{pl}(x) + z_{sp}(x)\} = C \cdot z_u(x)$$

The points of the total profile $z_g(x)$ include the influences of the standard, of the device and of the interaction between the two as well as the effect of the ambient influences.

The symbols are:

- C calibration factor
- z_g total profile
- z_e traced profile
- z_{ref} profile of reference plane
- z_0 background noise of device
- z_{pl} plastic deformation of surface
- z_{sp} change in profile due to stylus tip geometry
- z_u uncorrected profile data

For the uncertainty $u^2(z_g)$ the following are obtained as derived in Annex A:

$u^2(z_g) =$

$u^2(Pt_n)$, uncertainty of reference standard (depth-setting standard)

$+u^2(\Delta Pt)$, uncertainty of transfer from reference standard

$+u^2(b)$, repeatability of the contacting process on a reference standard

$+u^2(z_e)$, uncertainty of profile obtained due to dispersion on standard

$+u^2(z_{ref})$, uncertainty of reference profile

$+u^2(z_0)$, uncertainty due to background noise of device

$+u^2(z_{pl})$, uncertainty due to insufficient knowledge of plastic deformation

$+u^2(z_{sp})$, uncertainty due to insufficient knowledge of stylus tip geometry

Numerical values for these input quantities can be determined by specific measurement or from empirical values. Their effects depend on the parameter or type of standard so that different combinations are obtained; some examples are given in the Annexes.

6.2 λs filter

For the measuring points of the profile $z_s = Fs(z_g) = C \cdot Fs(z_u)$ is valid and for their uncertainty according to /1/:

$$u^2(z_s) = u^2(C) \cdot Pt_n^2 + f_s^2 \cdot u^2(z_u) \text{ .}$$

$f_s = \sqrt{\frac{\Delta x}{\alpha \cdot \lambda s \cdot \sqrt{2}}}$ for the ideal filter, Δx = sampling spacing, $\alpha = \sqrt{\frac{\log 2}{\pi}} = 0{,}4697$

$\lambda s =$ cutoff wavelength of short-wave low-pass filter

Table 2: Filter factor for different ratios of short-wave low-pass filter λs and sampling spacing Δx .

λs /µm	Δx /µm	f_s
2,5	0,5	0,55
8	1,5	0,53
8	0,5	0,31

For the values specified for λs and the traversing lengths in DIN EN ISO 4287, the effect of the short-wave filter thus is approximately equal and reduces the stochastically component of the uncertainty of the filtered profile points approximately by half.

6.3 λc filter

After filtering with low pass filter with cutoff wavelength λc the following is valid for the points of the waviness profile:

$$u(w) = \sqrt{\frac{\Delta x}{\alpha \cdot \lambda c \cdot \sqrt{2}}} \cdot u(z_s) = f_c \cdot u(z_s)$$ for the ideal filter.

Table 3: Filter factor for different ratios of low-pass filter λc and sampling spacing Δx .

λc /µm	Δx /µm	f_c
250	0,5	0,055
800	0,5	0,031
2500	1,5	0,017

For the points of the roughness profile, $z_c = z_s - w$ is valid,

for the uncertainty: $u^2(z_c) = u^2(z_s) - \left(2 \cdot \sqrt{2} - 1\right) \cdot u^2(w) \cong u^2(z_s)$ /1/

Due to the small value for f_c, the uncertainty $u^2(z_c)$ of the points of the roughness profile is practically equal to the uncertainty $u^2(z_s)$ of the points of the λs-filtered profile.

6.4 Parameter function

According to its algorithm, the uncertainty $u_{sys}(K)$ of a parameter is linked in very different ways with the uncertainty of the measuring points for the roughness profile. The calculation of the uncertainty has to take into account that the data of the waviness profile *w* and of the roughness profile z_c are correlated due to the filtering with λc and λs.

The result is the systematic uncertainty of the parameter $u_{sys}(K)$.

6.5 Unknown systematic deviations

In the measurement chain unknown systematic deviations can occur as a result of:

- the lack of conventions in the algorithms of the parameters in ISO 4287
- permitted deviations in the filters in ISO 11562, e.g. by approximations in the filter algorithms
- uncertainty due to linearity deviations of the converter, bandwidth limitation for the amplifier, resolution of the A/D converter
- deviations of the stylus tip from the nominal form
- uncertainty of the measuring point in the direction of feed.

For the uncertainty calculation unknown systematic deviations of the functions must therefore be taken into account. Software standards according to ISO 5436-2 allow these deviations to be more exactly localized. In the metrological practice, these uncertainties are discovered by comparison measurements, for example within the scope of intercomparisons, on materialized standards according to ISO 5436-1, with different devices and different realizations of the algorithms, if possible. These uncertainties $u_v(K)$ are compiled in a table containing statistically confirmed comparison results in dependence on parameter, type of standard and range of measurement. These are added quadratically to the systematic uncertainty.

The expanded uncertainty of measurement (coverage probability = 95%) is

$$U(K) = 2 \cdot \sqrt{u_{sys}^2(K) + u_v^2(K)}$$

The following influence quantities which basically could have an effect are not included in the model, since either their influence is negligible or they have been indirectly allowed for in the model by the kind of use: temperature of standard and device, drift of the standard, air pressure, air temperature and air humidity.

7 Documentation of measurement results

The measurement results determined for the roughness parameters are to be documented in the calibration certificate. The documentation covers the calculated mean values with the associated expanded uncertainty of measurement, the standard uncertainty as well as the minimum and maximum measurement values. A record of the primary profile is an integral part of the calibration certificate or it is to be attached as an annex. The specifications of DKD-5 are to be complied with.

The influence of the ambient conditions is to be stated with the Rz value from the background noise measurements (Rz_0) (cf. chapter 4).

8 Terms and abbreviations used

C calibration factor

$z_e(x)$ profile traced

$z_{ref}(x)$ profile of reference plane

$z_0(x)$ background noise of device

$z_{pl}(x)$ plastic deformation of surface

$z_{sp}(x)$ profile variation due to stylus tip deviation

$z_g(x) = G(z_e(x))$ data influenced by device function (total profile)

$z_s(x) = Fs(z_g(x))$ data influenced by λs (primary profile)

$z_c(x) = Fc(z_s(x))$ data influenced by λc (roughness profile)

$z_u(x)$ uncorrected profile data

$P(z_c(x))$ parameter function = computation rule to determine a parameter P

K value of a parameter P

λs cutoff wavelength of the short-wave low-pass filter

Δx spacing of measuring points

λc cutoff wavelength of long-wave low-pass filter

f_s filter factor as a function of $\lambda s/\Delta x$

f_c	filter factor as a function of $\lambda c/\Delta x$
u_{sys}	systematic uncertainty component
u_v	unknown uncertainty component supported by comparison measurements
u_n	uncertainty of depth-setting standard (reference standard)
Pt_n	total height of profile (according to ISO 4287) of reference standard
D_n	groove depth (according to ISO 5436) of reference standard
G	gradient in the depth of reference standard
Pt_m	total height of profile (according to ISO 4287) of standard to be measured
D_m	groove depth (according to ISO 5436) of standard to be measured
r_t	stylus tip radius
A	alignment deviation
Pt_r	noise in the area of reference line sections
Rz_0	averaged peak-to-valley height on an optical flat under the conditions of measurement for the object to be measured
z_h	topmost profile point
z_l	bottommost profile point

9 Standards cited and other documents

Reference or standard (edition)	Title
DIN 1319 – 3	Grundbegriffe der Messtechnik; Begriffe für die Meßunsicherheit und für die Beurteilung von Meßgeräten und Meßeinrichtungen
DIN 1319 – 4	Grundbegriffe der Meßtechnik; Behandlung von Unsicherheiten bei der Auswertung von Messungen
DIN 4768 (1990) (withdrawn)	Ermittlung der Rauheitskenngrößen R_a, R_z, R_{max} mit elektrischen Tastschnittgeräten Begriffe, Meßbedingungen Beiblatt 1 (1978) Derivation of R_a into R_z und vice versa
ISO 14638	Geometrical Product Specification (GPS) overview
ISO 3274 (1996)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Nominal characteristics of contact (stylus) instruments
ISO 4287 (1997)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Terms, definitions and surface texture parameters
ISO 4288 (1996)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Rules and procedures for the assessment of surface texture
ISO 5436-1 (2000)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method; Measurement standards-- Part 1: Material measures
ISO 5436-2 (2001)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method; Measurement standards -- Part 2: Software measurement standards
ISO 11562 (1996)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Metrological characteristics of phase correct filters
ISO 12085 (1996)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Motif parameters
ISO 12179 (2000)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method-- Calibration of contact (stylus) instruments
ISO 13565-1 (1996)	Geometrical Product Specifications (GPS)--Surface texture: Pofile method; Surfaces having stratified functional properties-- Part 1: Filtering and general measurement conditions
DKD-3	Ermittlung von Messunsicherheiten

Reference or standard (edition)	Title
DKD-5	Anleitung zum Erstellen eines DKD-Kalibrierscheines
DKD-R 4-2 Sheet 2	Richtlinie zum Kalibrieren von Tastschnittgeräten im Deutschen Kalibrierdienst (DKD)
GUM	Guide for the expression of uncertainty in measurement
/1/	M. Krystek: Einfluss des Wellenfilters auf die Unsicherheit eines Messergebnisses bei Rauheitsmessungen. Conference Volume of DIN Meeting "GPS 99“, Mainz, May 5-6, 1999, pp. 4-1–4-11. Beuth-Verlag, ISBN 3-410-14534-6

Documentation of revisions

DKD Guideline 4-2
Calibration of measuring instruments and standards for roughness measuring technique
Sheet 1: Calibration of standards for roughness measuring technique

Draft 1 (07/11/1996)

From Draft 1 to Draft 2 (17/12/1996)
Number of Guideline was changed from 4-3 into 4-2
1.) More detailed specification of standards (types A, C, and D) was included
2.) Formulation modified
3.) Year for DKD-R 4.2 deleted
Sheet 1 included
4.) Best possible resolution for optical flat measurements included
Formulation modified
5.1) Acetone deleted
Differentiation only between glass standards, formed and metallic standards
5.1.1) Direct light method deleted
Five- to tenfold magnification changed into approx. tenfold magnification
Definition of coarse and slight damages included
5.1.2) Heading changed from Steel standards into Metallic standards
Formulation by Dr. Rau included
5.1.3) Heading changed from Nickel standards into moulded standards
Formulation modified
5.1.4) Not applicable
5.2) Included that deviation is permitted in accordance with DKD-5
Minimum calibration dropped
5.3) Inclusion of DIN 4772
Inclusion of optical calibration of depth-setting standards
5.4) In enumeration Setting standards changed into Depth-setting standards
Outlier test/limitation of measuring area (formulation by Dr. Rau) included
6.) Formulation by Dr. Krüger adopted in a slightly modified form

From Draft 2 to Draft 3 (12/05/1997)
In the title of the Guideline, tracing systems changed into measuring instruments
Sheet numbering modified:
Sheet 1: Calibration of standards for roughness measuring technique
Sheet 2: Calibration of tracing systems
(Sheet 3: Calibration of interference-optical roughness measuring instruments – guideline remains to be prepared)
In the whole Guideline, standard deviation was changed into standard uncertainty
1.) Type E and dating of ISO / CD 5436-1 included
2.) Formulation modified
3.) Reference to other sections or sheets of Guideline updated
4.) Carrying-out of optical flat measurement described in more detail (searching of unaberrated optical flat sector, five measurements on one trace)
5.1) Formulation modified
5.1.1) Visual inspection changed from discretionary into mandatory provision
5.1.2) Manufacturing defects included, range of measurement changed into measuring area, formulation modified
5.1.3) Section dropped, numbering of subsequent chapters adapted

Documentation of revisions

5.2) (old) section dropped, numbering of subsequent chapters adapted
5.2) (new) profile method specified (demand for reference area tracing system included)
Optical calibration changed into interference-optical, VDI / VDE 2604 included
5.3) Section completely new
Type designation acc. to ISO 5436-1 included
Types C and E included
Other standards dropped
5.3.1.1) Maximum alignment deviation limited to 20 nm
λ_s = 8 µm included
5.3.1.2) ISO 3244 in ISO 3274
6.) Order modified: (depth-setting standards before roughness standards)
R_{z0} changed into R_z
7.) Formulation modified
Statement of associated overall uncertainty of measurement in the statement of the mean value included
Profile record of primary profile as annex
For background noise measurements a reference to para. 4 was included
8.) Heading modified ("and other documents" included)
Standards arranged by increasing numbers

From Draft 3 to Draft 4 (27/10/1997)

1.) Date in statement of ISO 5436 dropped
4.) Formulation modified
5.1.2) Formulation modified, reference to outlier consideration dropped
5.3.1) Formulation modified (smallest possible range of measurement to be selected for all calibrations, not valid for depth-setting standards)
Table 1: Designation of table added, structure of table modified
Description of type D1 / D2 standards modified
Outlier consideration dropped in this section
5.3.2) Paragraph newly added, outlier consideration completely revised as compared with Draft 3 (revision as a result of the objection that the measurement values of the individual measurements can be directly checked for outliers and not – as in Draft 3 – after termination of the 12 individual measurements)

From Draft 4 to Draft 5 (25/03/1998)

General: Numbers <10 in the text written in full
Indices of roughness parameters no longer subscripted
Spelling errors corrected
5.1) "an optical assessment is suitable" changed into "a visual inspection is recommended"
5.1.2) Optical assessment changed into visual assessment
In statement of magnification "approx." was added
5.3.1.1) Formulation modified
5.3.2) In the table, *R*max was changed into *Rz1*max and a footnote was included
Some formulations were modified
7) Formulation modified
8) For DIN ISO 3274 and 4288 the titles of the German drafts were stated.

Documentation of revisions

From Draft 5 to Draft 6 (16/09/1998)

5.1.1) To unify the designation for glass standards and metallic standards, "coarse damage" is replaced by "critical damage".

5.3.1) Caption of Figure 1 extended by "for cutoff wavelength 0,8 mm”.

5.3.1.1) “The maximum permissible alignment deviation here must not exceed 50% of the uncertainty of measurement of the standard or 20 nm." was changed into:
” The maximum permissible alignment error here may exceed 50 % of the uncertainty of measurement of the standard but not 20 nm.”
“For low-pass filtering, a □s of 8 µm has proved to be suitable.” has been changed into:
“If low-pass filtering is used, a □s of 8 µm has proved to be suitable.”

5.3.2) Section completely revised. As it has not been possible to give a generally applicable definition for outliers, the former definition has been dropped. Furthermore, the instruction for the carrying-out of check measurements has been dropped.

6) Section completely revised.

From Draft 6 to Draft 7 (17/11/1999)

6) Section completely revised.