EUROMET SUPPLEMENTARY COMPARISON

SURFACE TEXTURE

Project No. 600

Technical Report

Final Version

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1 INTRODUCTION

At the length meeting in Prague in Oct. 1999 a new comparison was suggested on surface texture. The last comparison on this field was finished in 1989[1]. In the meantime the instrumentation, the standards and the written standards have been improved including some software filters. The pilot laboratories for this ***supplementary comparison*** on surface texture are the Centre for Geometrical Metrology at the Technical University of Denmark and the Micro- and Nanotopography Laboratory at the Physikalisch-Technische Bundesanstalt, Germany.

2 STANDARDS

The ISO 5436-1 describes several types of different standards for the calibration of instruments for roughness measurements. There are type A standards for the calibration of the vertical axis, type C for the calibration of the lateral axis, and Type D for the verification of the dynamical properties. There are a lot of parameters to describe the roughness of surfaces (see ISO 4287, ISO 12085, ISO 13565). An industrial survey of 1999 was a first initiative to analyse to what extend these parameters are actually used[2]. In attempt to cover most of the parameters, we used the following standards:

1 Depth setting standard of type A2	- see Datasheet 1,
3 Roughness standards of type C3	- see Datasheet 2,
3 Roughness standards of type D1	- see Datasheet 3,
1 Roughness standard of type D2	- see Datasheet 4,

(see the datasheets in Appendix A for more details)

a) b) c) d)

Fig. 1: Typical set of roughness standards: a) Depth setting standard type A2, b) roughness standard type C, c) roughness standard type D1, and d) roughness standard type D2

Due to the involved filtering routines more and more importance is attached to the software used for data analysis. Therefore we included some data sets which should be analysed by the participants:

3 files for software check - see Datasheet 5.

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[1] Hillmann, W., Comparison of roughness measurements in the European Community, Community Bureau of Reference, BCR, Report EUR 12 180 EN, 1989

[2] De Chiffre, L., Industrial survey on ISO surface texture parameters, CIRP, Vol 48(3) (1999) p. 74

The standards were sent by parcel service to the next participant. The package contained the following:

1) instructions (short version),
2) a copy of the technical protocol,
3) a data sheet with addresses of the participants, and
4) photographs of the standards in their initial state.

The package was accompanied by an ATA carnet.

3 PARTICIPANTS AND TIME SCHEDULE

3.1 ORGANISATION

Following the rules set up by the BIPM[3] a small group of participating laboratories has drafted this technical protocol. The two labs are the Centre for Geometrical Metrology at the Technical University of Denmark and the laboratory Micro- und Nanotopography at the Physikalisch-Technische Bundesanstalt, Germany. By their declared intention to participate in this supplementary comparison, the participants accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

3.2 REQUIREMENTS FOR PARTICIPATION

According to the WGDM recommendation No 2 (document CCDM/WGDM/97-50b), the participating laboratories should offer this measurement as a calibration service (now or in future), and be willing to participate in a regional comparison in order to provide a link between the interregional and the national comparisons.

3.3 PARTICIPANTS

The participants of this comparison are listed in table 1.

Table 1: Participating Laboratories

Laboratory	Responsible	Address	Phone, Fax, e-mail
BEV	M. Matus	Bundesamt f. Eich- u Vermessungswesen (BEV) Arltgasse 35 A-1160 Wien Austria	Phone: +43 1 49 110 540 Fax :+43 1 49 20 875 e-mail: m.matus@metrologie.at
CEM	E. Prieto	Centro Español de Metrología Del Afar, 2 28760 Tres Cantos (Madrid) Spain	Phone: +34 91 8074 716 Fax: +34 91 8074 807 e-mail: eprieto@cem.es
CMI	J. Borovsky	Czech Metrological Institute V. Botanice 4 150 72 Prague Czech Republic	Phone: +420 2 573 21 312 Fax: +420 2 573 28 077 e-mail: jborovsky@cmi.cz
GUM	B. Smereczynska	Glówny Urzad Miar / Central Office of Measures Surface Texture Measurements P.O. Box P-10 00 950 Warsaw Poland	Phone: +48 22 620 54 38 Fax: +48 22 620 83 78 e-mail: length@gum.gov.pl
ILM/ Since 4.01 ➔ ISTEC	D. Cuppini	Istituto di Scienza e Tecnologia dei Materiali Ceramici Strada delle Cacce 73 10135 Torino Italy	Phone: +39 011 397 7502 Fax: +39 011 346 288 e-mail: d.cuppini@to.istec.cnr.it

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[3] see http://www.bipm.fr/enus/8_Key_Comparisons/key_comparisons.html

IMGC	G. B. Picotto	CNR Istituto di Metrologia "G. Colonnetti" Strada delle Cacce, 73 I-10135 Torino Italy	Phone: +39 011 39 469/473 Fax: +39 011 39 77 459 e-mail: g.picotto@imgc.cnr.it
IPQ	Fernanda Saraiva Silvia Gentil	Institute Português da Qualidade Rua António Gião, 2 2829-513 Caparica Portugal	Fax: ++351 21 2948188 Tel: ++351 21 2948160 e-mail: FSaraiva@mail.ipq.pt Sgentil@mail.ipq.pt
METAS	F. Meli A. Küng	Swiss Federal Office of Metrology and Accreditation Lindenweg 50 CH-3003 Bern – Wabern Switzerland	Phone: +41 31 323 3346 Fax: +41 31 323 3210 e-mail: felix.meli@metas.admin.ch
MIKES	H. Lehto B. Hemmning	MIKES Konepajametrologia Metallimiehenkuja 6 FIN-02150 Espoo, Finland	Phone: +358 9 4565 350 Fax: +358 9 460 627 e-mail: Heikki.Lehto@mikes.fi
NMI-VSL	R. Koops	NMi-Van Swinden Lab. Length section Schoemakerstraat 97 2600 Ar Delft The Netherlands	Phone: +31 15 269 1500 Fax: +31 15 261 2971 e-mail: rkoops@nmi.nl
NPL	R. Leach	National Physical Laboratory Teddington, Middlesex TW11 OLW United Kingdom	Phone:+44 20 8943 6303 Fax: +44 20 8614 0420 e-mail: Richard.Leach@NPL.co.uk
SMU	M. Szmicsková	Slovenský Metrologický Ústav Karloveska 63 CS - 842 55 Bratislava Slovakia	Phone:+421 2 60 294 244 Fax: +421 2 65 429 592 e-Mail: szmicskova@smu.gov.sk
SP	M. Frennberg	Swedish National Testing and Research Institute Box 857 S-501 Borås Sweden	Phone: + 46 33 16 5474 Fax: +46 33 16 5620 e-Mail: Mikael.Frennberg@sp.se
VMC [4]	Vaidotas Gegevicius	Vilnius Metrology Center S. Darius IR S. Gireno 23 2038 Vilnius Lithuania	Phone: +370 2 235 882 Fax: +370 2 233727 e-mail: vmc@taide.lt
UME	T. Yandayan	TÜBÝTAK – Ulusal Metroloji Enstitüsü P.K. 54 Gebze Kocaeli 41470 / TÜRKÝYE	Phone: +90 (262) 679 50 00 Ext. 5300 Fax: +90 (262) 679 50 01 e-mail: Tanfer@ume.tubitak.gov.tr

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[4] *The VMC got the samples during the circulation, but they withdrew their participation later.*

Pilot labs			
PTB (Contact)	L. Koenders	Physikalisch-Technische Bundesanstalt (PTB) AG5.14 - Thin Films and Nanostructures Postfach 33 45 D-38023 Braunschweig Germany	Phone: +49 531 592 5120 Fax: +49 531 592 5105 e-mail: Ludger.Koenders@ptb.de
CGM	L. De Chiffre J. L. Andreasen	Centre for Geometrical Metrology (CGM) TU of Denmark Building 425 DK-2800 Lyngby Denmark	Phone: +45 4525 4760 Fax: +45 4593 0190 e-mail: lcd@ipl.dtu.dk jla@ipl.dtu.dk

**) The VMC got the samples during the circulation, but they withdrew their participation later.*

3.4 TIME SCHEDULE

The comparison was carried out in a mixed form, i. e. circulation and star type. The period of time available to each laboratory was 4 weeks for calibration and transportation to the next participant.

Table 2: Time schedule

Circle	No	Institute	Country	Time schedule planned	Time schedule actual	
1st circle	1	PTB	DE	May 01		May 01
	2	CEM	ES	June 01	1st	July 01
					2nd	Dec 02–Feb 03
	3	CMI	CZ	July 01		June 01
	4	ILM	IT	Aug 01		Aug 01
	5	IMGC	IT	Aug 01		Aug 01
	6	UME	TR	Sept 01		Sept 01
	7	METAS	CH	Oct 01		Oct 01
	8	BEV	AT	Nov 01		Nov 01
2nd circle	-	PTB	DE	Dec 01		Visual inspection
	9	CGM	DK	Jan 02		Jan 02
	10	MIKES	FI	Feb 02		Feb 02
	11	VMC *)	LT	March 02		March 02
	12	GUM	PL	Apr 02		Apr 02
	13	SMU	SK	May 02		Oct - Nov 02
	14	NMi-VSL	NL	June 02	1st	June 02
					2nd	Feb –March 03
	15	NPL	UK	July 02		July – Aug 02
	16	IPQ	PT	Aug 02		Sept – Oct 02
	17	SP	SE	Sept 02		May 02
End	-	PTB	DE	Apr 03		Apr - May 03

**) The VMC got the samples during the circulation, but they withdrew their participation later.*

4 REPORTS

4.1 GENERAL

The participating laboratories report the results of the measurements to the pilot laboratory. Their report should contain:

- the measurement set-up and the conditions
- the result(s) of the measurements,
- the combined standard uncertainty,
- the complete uncertainty budget,
- the degrees of freedom.

The measurands have to be stated for the reference temperature of 20°C.

4.2 DESCRIPTION OF MEASURING INSTRUMENT

The institutes should give a short description of the instrument(s) used under the aspects listed below:

- **Type of instrument**, like interference microscope, confocal microscope, scanning probe microscope, stylus instrument; name(s) (of components) if commercial
- **kind of operation**, like scanning white light, phase shift with wavelength and line width, inverse working, moving stylus, moving specimen, scan axis used, mount of feed unit at column or on table
- **conditions of data collection**, like vertical measurement range, magnification of optical system, numerical aperture, field of view, scan length, integration time, number of averages, stylus tip radius,
- **conditions of evaluation**, like compensation of reference plane, interpolation to equal data point density, missing point interpolation, linearity correction,
- **characterisation of instrument noise and deviation from ideal behaviour**, e.g. by a value of roughness parameter on flat glass with and without lateral movement, deviation from straightness or flatness of reference plane by value of waviness parameter or area parameter,
- **environment characterisation**, like vibration isolation, dust and/or noise protection cover, estimate of thermal stability.

Table 3: Instruments and software

Institute	Instrument	Software	Standards	Traceability
PTB	Zeiss Interference microscope (IM), Taylor Hobson Nanostep (NS), Rauheitsmessanlage (RMA)	RPTB, UBM Soft	A1, A2	Calibrated at PTB
CEM	Dektak-3ST (DT) Perthometer (MPC)	Talymap Universal 2.0 Perthometer Concept	VLSI A1	NIST
CMI	Hommeltester T8000 (HAT)	Turbo Roughness for Windows	A2 0908	Calibrated at PTB

ILM /ISTEC	Form Talysurf 120 with laser interferometer (FTS)	Version 4.0		ILM
IMGC	Talystep 1, Taylor-Hobson RTH (TS)	Talystep PC Software 0,01 SP RTH Groove 3.02P	Queensgate DPT-10	IMGC Laser-interferometer
UME	Perthometer Concept (MPC)	Perthometer Concept 6.3 GB	A2	Calibrated at PTB
METAS	Form Talysurf 120L with laser interferometer (FTS)	Ultra Version 6 METAS own	Sphere, gauge blocks	METAS Laserinterferometer
BEV	Interference microscope (IM)	IDEA		BEV
CGM	Taylor-Hobson Talysurf 5 – 120 with Heidenhain scale for x (FTS)	RCS4G (CGM)	A2	Calibrated at PTB
MIKES	Taylor Hobson Talysurf 2 inductive (FTS)	Ultra K510-1038-02 Issue 10	Gauge blocks, radius std., flat	MIKES Interferometer
GUM	Taylor Hobson Form Talysurf 120i (FTS)	RTH FTSS Version 6.10	A1	Calibrated at PTB
SMU	Talysurf 6 S112/1620 (FTS)	Talyprofil 3.0.8	A1	SMU Interference microscope
NMi-VSL	Taylor Hobson Form Talysurf 120L (FTS)	Ultra Version 4.3.14	z-scale with interferometer; x with line scale	NMi-VSL Laser interferometer
NPL	Nanosurf IV with laser interferometers in x- and z direction (NS4)	NPL software		NPL Frequency stabilized laser laser source
IPQ	Perthometer S8P (S8P)	Perthometer 1.1	A2	Calibrated at PTB
SP	Form Talysurf 120 inductive (FTS)	Form Talysurf (RTH), Version 4.0	Sphere, Type A2, D1	SP Laser interferometer

4.3 UNCERTAINTY BUDGETS

The uncertainty of the measurement should be estimated according to the *Guide to the Expression of Uncertainty in Measurement*. The participating laboratories were encouraged to use all known influence parameters for the method applied by them. The parameter y of the standards should be expressed as a function of the input quantities X_i

$$y = \mathrm{f}(x_\mathrm{i}). \qquad (1)$$

The combined standard uncertainty $u_\mathrm{c}(y)$ is the square sum of the standard uncertainties of the input quantities $u(x_\mathrm{i})$, each weighted by a sensitivity coefficient $\mathrm{c_i}$

$$u_c^2(y) = \sum_i c_i^2 u^2(x_i) \qquad (2)$$

with $c_i = \dfrac{\partial y}{\partial x_i}$

The uncertainty components should be divided into components associated with the realisation of the object compared, and those associated with the comparison method.

Contributions to the uncertainty budgets depending on the method and the instrument used:

1. Calibration of the instrument z and x-axis
- vacuum wavelengths of lasers
- refraction index of the air
- interferometer alignment
- non-linearity of the instrument
- uncertainty of reference standard
- uncertainty of position on the reference standard
- levelling of the profile for the evaluation

2. Measurement
- influence of topography of standard
- straightness of reference datum
- noise of instrument
- repeatability
- transfer characteristic of stylus tip
- data distance in x-direction

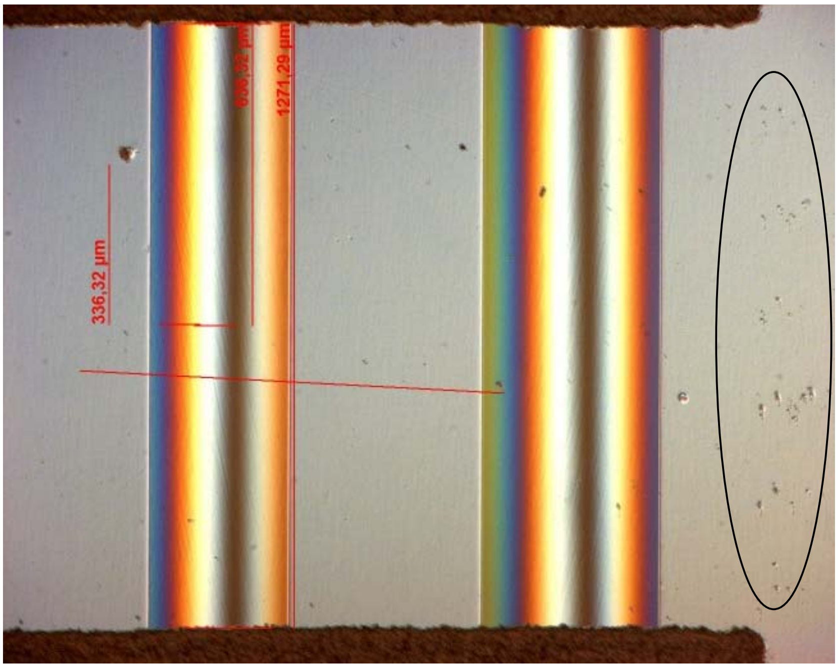
3. Data evaluation
- correlation of profile points due to filtering λs, λc
- software
- temperature of standards and samples during measurement
- unknown systematic deviations

For more details see the reports in Appendix (Reports of Institutes).

5 STABILITY OF STANDARDS

5.1 SURFACE DAMAGES OR SCRATCHES

The status of the standards were monitored at different times during the comparison by the pilot laboratory. Additionally each participant was asked to check the standards after reception and to send a report to the pilot laboratory. Due to some problems it was sometimes necessary to send the standards back to the pilot laboratory for checking and cleaning. However the reference area remains almost so that measurements were possible. The standards were finally checked and measured again at the end of the comparison by the pilot laboratory. Near the 6th groove of the depth setting standard we found some defects which could influence the measurements (see fig. 2).



Defects near the 6th groove.

Fig. 2: Depth setting standard

5.2 STABILITY OF PARAMETER VALUES

The standards were re-calibrated in May 2003 at the end of the comparison. Appendix C contains the tables with the measurement data at the beginning and at the end of the comparison. The table final_first containing the difference of the values between last and first measurements shows differences for four parameters which should be discussed here.

1. The *Pt* value of the 6th groove shows a difference which is much larger than the uncertainty of the final measurement. At the beginning the groove was measured with the Nanostep, as it was not possible to measure this groove with the interference microscope. The uncertainty for the first measurement is *U*(k=2)=30 nm due to the large noise of the Nanostep for this range. The final calibration was made with the interference microscope which has a smaller uncertainty of *U*(k=2)=13nm. The difference between the final and the first measurement is smaller than the sum of both uncertainties.

2. In the case of the standard 633g the difference of the *Rvk* parameters is within the range of the uncertainties before and after.

3. The difference of the *Rpk* parameters for standard 686sg and 633g is larger than the sum of the uncertainties of both measurements. But all the other parameters of this standard agree within their uncertainties. Therefore we checked the old data again and found that these differences were caused by the use of our former software. Using the reference software *RPTB* instead we calculate a value of *Rpk*=1,270 µm for the old data of standard 686sg. This is in good agreement with the value of the final measurement. The latter is in agreement with the reference value of the comparison, too, whereas the first value did not agree with the reference value of the comparison (see table 7a Type D1 – 686 sg).

Therefore we conclude that all the standards are stable over the time of the comparison.

6 MEASUREMENT RESULTS AS REPORTED BY PARTICIPANTS

The data for all parameters of all the participants are collected in Appendix D. Here we give an example for one parameter. The table below contains the data with the results for the smallest groove of the depth setting standard. Besides the institute some information about time of measurement, filter and measurement parameters are given.

Table 4: Example - Depth setting standard EN0806 $Pt \sim 0{,}2\ \mu m$

Institute	Pt	Country	Instrument	Measured Date						Depth standard EN 806 R1 0,2 µm						
					λc	λs	Speed	Force	Sampl-dist	Pt	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01						291	1	8	4	0,80	6,90	7,33
CMI	n	CZ	HT	Jun 01	0,06		0,1	0,75	0,03	195	7	72			102,90	71,93
CEM	n	ES	DT	Jan 03			0,1	0,9	0,5	284	2	10			13,90	9,47
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	314	5	17	8,5	0,93	16,10	16,70
IMGC		IT	TS	Aug 01			0,025 / 0,0025	0,03	0,1	301	9	16	8	0,19	3,10	15,68
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	316	3,6	40,9	20,45	0,44	18,10	40,77
METAS	n	CH	FTS	Oct 01		2,5	0,5	<1		321	17	20			23,10	19,74
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	307	5	34	17	0,27	9,10	33,85
MIKES		FI	FTS	Feb 02			0,500	1,000	0,250	299	2,123	50	25	0,02	1,10	49,90
GUM		PL	FTS	Apr 02			0,5	<1	0,25	287	2,4	34	17	0,32	10,90	33,85
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	302	1,4	14,522	7,2608981	0,28	4,10	14,16
NPL		UK	NS4	Jul 02			0,0	<0.1	0,1	298	3,5	3,7	1,85	0,02	0,10	1,86
IPQ		PT	S8P	Sep 02	0,08		0,1			340	10	119,18	59,59	0,35	42,10	119,14
SMU	n	CS	FTS	Nov 02			1	1		326	0,8	7,8			28,10	7,11
NMi-VSL	n	NL	FTS	Mrz 03			0,5	0,55	0,25	332	7	26			34,10	25,80
									Mean	300,87	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	33,56	nm	297,9	1,6	3,2	1,00	10

0=not measured
i=incomplete
n=excluded (En>1)

The table above displays the information for the *Pt* value as obtained from the institutes and necessary for the evaluation. The characters in the column Pt and D have the following meaning: “0” – parameters was not measured, “n” – excluded for the calculation of the reference value, because of En >1. The values “En” and “DoE” will be explained in the next chapters. The respective diagram for this parameter is shown below.

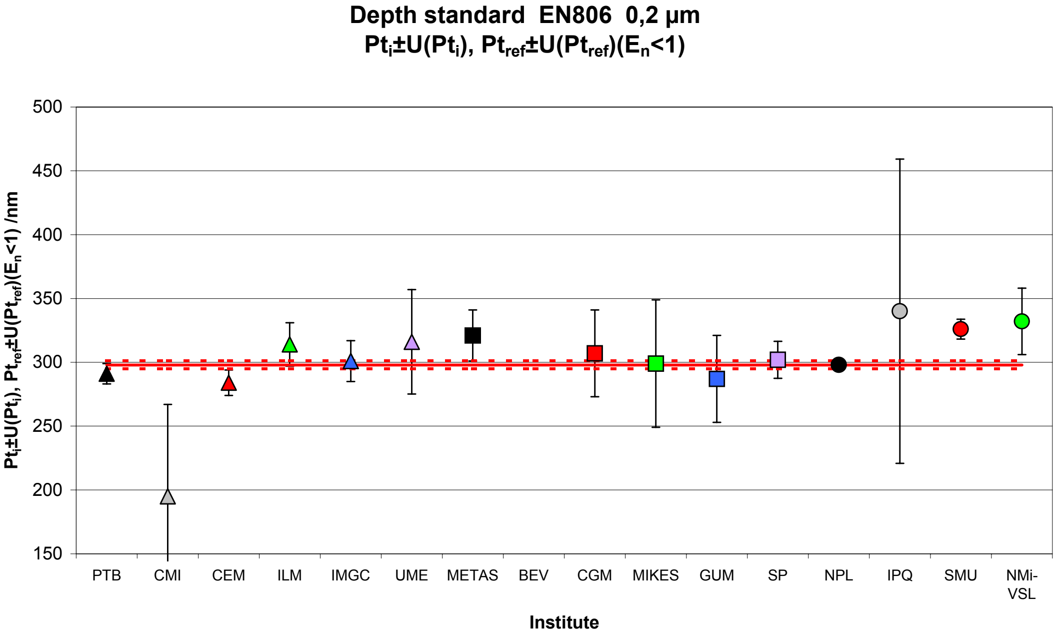


Fig. 3: Plot of the reported Pt_i values for the groove of nominal 0,2 µm on standard EN 806 together with the expanded uncertainty. The thick line represents the reference value and its uncertainty (dashed).

The values of the institutes are plotted together with their expanded uncertainty. The red line represents the reference value calculated for this parameter together with the expanded uncertainty. The calculation of the reference value and the procedure to evaluate this value for each parameter is described in the following.

7 REFERENCE VALUE, UNCERTAINTY AND BIRGE RATIO

The reference value y_{ref} for each parameter is calculated as the weighted mean of all measurements y_i. The weights are $u^{-2}(y_i)$. For each parameter a reference value was calculated. To set up the |En | ≤ 1 criterion[5], the expanded uncertainty U with a coverage factor of k = 2 was used [6].

Reference value

$$y_{ref} = \frac{\sum_{i=1}^{n} u^{-2}(y_i)\cdot y_i}{\sum_{i=1}^{n} u^{-2}(y_i)} \qquad (3)$$

Combined standard uncertainty

$$u_c(y_{ref}) = \left(\sum_{i=1}^{n} u^{-2}(y_i)\right)^{-\frac{1}{2}} \qquad (4)$$

Degree of freedom

$$\nu_{eff}(y_{ref}) = \frac{u_c^4(y_{ref})}{\sum_{i=1}^{n} \frac{u_i^4(y_{ref})}{\nu_{eff}(y_i)}} \qquad (5)$$

with

$$u_i(y_{ref}) = |\, c_i \,| \cdot u(y_i) = \frac{u^{-1}(y_i)}{\sum_{i=1}^{n} u^{-2}(y_i)} \qquad (6)$$

Expanded uncertainty using k=2

$$U(y_{ref}, k=2) = 2 \cdot u_c(y_{ref}) \qquad (7)$$

En-value

$$\mathrm{En}(y_i) = \left| \frac{y_i - y_{ref}}{\sqrt{U^2(y_i) + U^2(y_{ref})}} \right| \qquad (8)$$

The plus sign in the denominator of (8) is used although there is some correlation between a single measurement result and the reference value. With the plus sign the En values could be too small[7].

Measurements with En values larger than 1 have been omitted one by one for the calculation of the reference value. All other values contribute to the reference value.

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[5] http://www.euromet.org/pages/guides/guide.htm in Guidelines for the organisation of comparisons

[6] W. Wöger, Remarks on the E_n –Criterion Used in Measurem. Comp.: PTB-Mitteilungen 109 (1999) 24

[7] see comment in chapter 8, too.

The reference values y_{ref} calculated of the remaining results are listed in tables in Appendix D together with their uncertainties $u(y_{\mathrm{ref}})$ and $U(y_{\mathrm{ref}})$ and the calculated Birge ratio $\mathrm{R_B}$.

The Birge ratio is given by

$$\mathrm{R_B} = \frac{u_{ext}}{u_{in}} \qquad (9)$$

with

$$u_{ext} = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(y_i - y_{ref}\right)/u_i\right]^2}{(n-1)\sum_{i=1}^{n} u^{-2}(y_i)}} \qquad (10)$$

and

$$u_{in} = u_c(y_{ref}) \qquad (11)$$

$\mathrm{R_B}$ is calculated to check the statistical consistency of a comparison. It compares the observed spread of results u_{in} with the spread of the estimated uncertainty u_{ext}. The Birge ratio has an expectation value of $\mathrm{R_B}=1$, when considering standard uncertainties. For a coverage factor of k=2 the expectation value is increased and the data in a comparison are consistent provided that

$$R_B < \sqrt{1 + \sqrt{8/(n-1)}} \qquad (12)$$

where n is the number of participants [8]. In the case of 12 participants contributing to the reference value, $\mathrm{R_B}$ should be smaller than 1,36.

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[8] R. Kacker, R. Datla, A. Parr, metrologia 39 (2002) p. 279 - 293

8 EVALUATION AND DISCUSSION

The evaluation starts with the whole data set and successive removal of those measurement data (En>1) with the largest En value. After each removal a new reference value and its uncertainty were recalculated. This iteration stops when there is no data with En>1.

Due to the dependence of roughness parameters on the height/depth measurement and due to some problems with the last we start with the evaluation of the depth measurements and the discussion, first. Afterwards we evaluate and discuss the results obtained for the roughness parameters. We end this chapter with the reported values obtained from the software calculation.

8.1 EVALUATION FOR PARAMETERS *PT* AND *D* OF TYPE A STANDARDS

The data for the smallest groove is shown in table 4 together with the diagram (fig. 3). All tables for the parameters are in the Appendix D.

The *Pt* and *D* parameter should be determined without filter λc. But from the table 4 and tables in Appendix D this was not the case for the CMI and IPQ. Both institutes should check their parameters again. Perhaps this is a mistake in the report, because using such values for the λc filter would strongly influence the profile of the depth setting standard.

The "n" in the column Pt indicates which measurement did not fulfil the En criteria. From the remaining values the reference value, the standard and expanded uncertainty were calculated. All values are listed in the tables. The Birge ratio R_B calculated from the remaining values is in the range of 0,8 to 1,0. That means that the results are consistent. But this is a statistical point of view. Below there are the tables for those measurement data obtained on the depth setting standard that do not fulfil the En criteria.

Table 5a: Parameters and institutes (En>1) - Type A2 - EN 0806 *Pt* ~ 0,2µm

***Pt* ~ 0,2 µm**				
Parameter	***Pt***		***D***	
Iteration	**Institute**	**En(i)**	**Institute**	**En(i)**
1	SMU	3,02	SMU	2,25
2	CMI	1,42	GUM	1,38
3	NMi-VSL	1,31	CMI	1,22
4	CEM	1,26	METAS	1,14
5	METAS	1,12		

Table 5b: Parameters and institutes (En>1) - Type A2 - EN 0806 *Pt* ~ 1,5 µm

Pt ~ 1,5 µm				
Parameter	***Pt***		***D***	
Iteration	**Institute**	**En(i)**	**Institute**	**En(i)**
1	SMU	4,03	SMU	5,63
2	CEM	1,79	METAS	1,25
3	METAS	1,28		
4	NPL	1,02		

Table 5c: Parameters and institutes (En>1) - Type A2 - EN 0806 *Pt* ~ 8µm

***Pt* ~ 8 µm**				
Parameter	***Pt***		***D***	
Iteration	**Institute**	**En(i)**	**Institute**	**En(i)**
1	SMU	19,24	SMU	15,62
2	IPQ	3,84	CEM	1,87
3	CEM	1,36	GUM	1,45
4	NPL	1,10		

The evaluation of the data for the depth setting standard reveals that the measured values of the institute SMU failed completely. Going on with the analysis we found further that the determined data of the same institute failed for a number of roughness parameters, too. The reason for this seems to be a large deviation of the scale of the vertical axis of the instrument used. In this case this results in a strong dependence on the roughness parameters.

Therefore we decided to exclude all values of SMU for the evaluation of the reference values for the roughness parameters to avoid a too strong effect.

This dependence was not observed for the other institutes listed in table 5a – 5c. Nevertheless it could influence the determination of the reference value of other roughness parameters, but in these cases it seems to be within the limit of uncertainties given.

8.1.1 COMMENT ON THE INFLUENCE OF CORRELATION EFFECTS

Since some institutes, namely CMI, CGM, GUM, IPQ, and UME, used a standard calibrated at PTB we performed an analysis which takes correlation effects into account. We followed the rules given in DIN 1319-3. By this the ratio of the uncertainty of reference standard of the institute $u_{\mathrm{ref}}(\mathrm{i})$ to the uncertainty of the standard measured in the comparison $u_{\mathrm{i}}(y)$ is taken into account. Consequently the uncertainty of the reference value can increase.

The evaluation as described above produced some trouble. Going into the details we found that this was caused by an error in the uncertainty budget of the institute UME for the *D* values. Here the uncertainty of the reference standard is greater than the uncertainty of the sample calibrated within this comparison although the values are similar. By omitting the values of this institute we got stable results.

Nevertheless, applying the En-criteria gave the same institutes as listed above which had to be excluded, but with slightly different En values. The institute UME has to re-calculate the uncertainty for the D parameter, especially for the larger grooves.

8.1.2 COMMENT ON *PT* AND *D*

The analysis of the difference between the *Pt* and the *D* value shows an interesting detail (see fig. 4). The difference *Pt* – *D* lies for the most part within the range from 0 to 50 nm going from the 0,2 µm to the 8,0 µm groove. Only two exceptions occur. The differences of one institute increase up to 200 nm for the 8 µm groove. This could be caused by a large noise of the instrument itself. In the other case (SMU) the difference becomes negative, which cannot be true since the peak value *Pt* should be larger than the averaged *D* value.

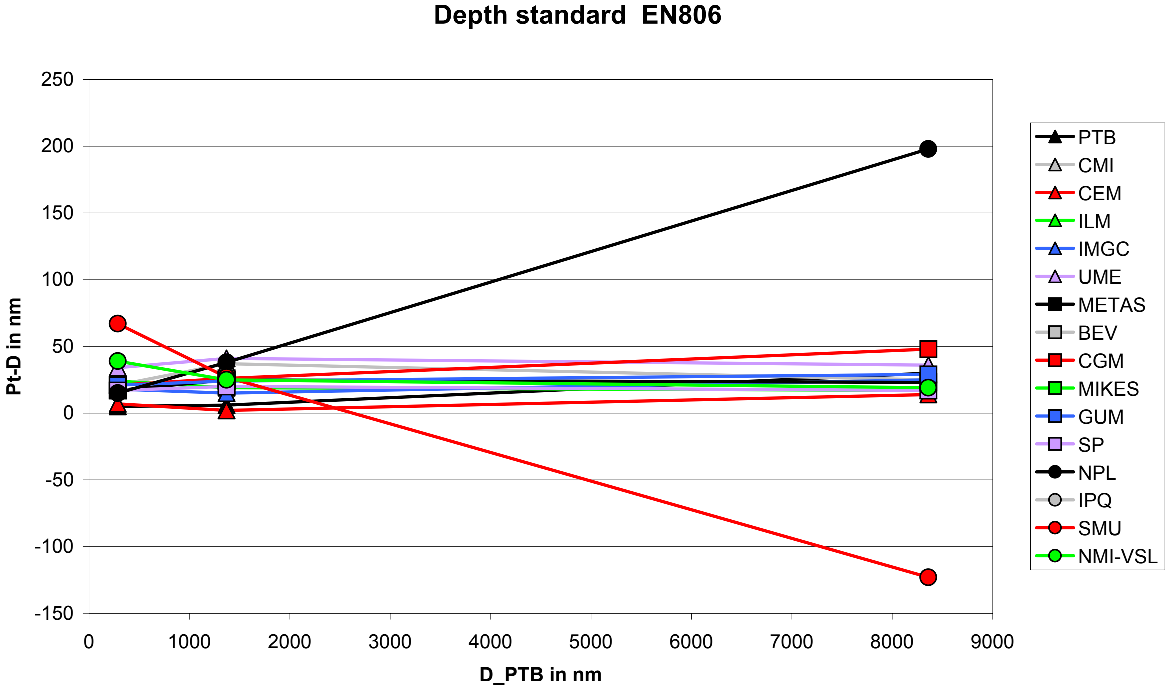

Fig. 4: Difference of Pt – D measured on EN 0806.

8.2 EVALUATION FOR THE *R*-PARAMETERS OF TYPE C STANDARDS

The tables of data, diagrams and tables with failed data are in Appendix D. We used in the report the En criteria to find outliers and to calculate the reference value. Nevertheless in some cases we observed problems which should be discussed in more detail.

8.2.1 PROBLEMS WITH PARAMETER *RSM*

The type C standards are used to determine the *RSm* value. In fig. 5 the difference *RSm* of institutes to *RSm* of reference are plotted as function of the reference value for the standards P114A/528-RS5 (RSm_{Ref} = 50030 nm), 8194/PGN3 (RSm_{Ref} = 120000 nm), and 7070/PGN10 (RSm_{Ref} = 199900 nm). Additionally, for some selected institutes a linear fit is shown.

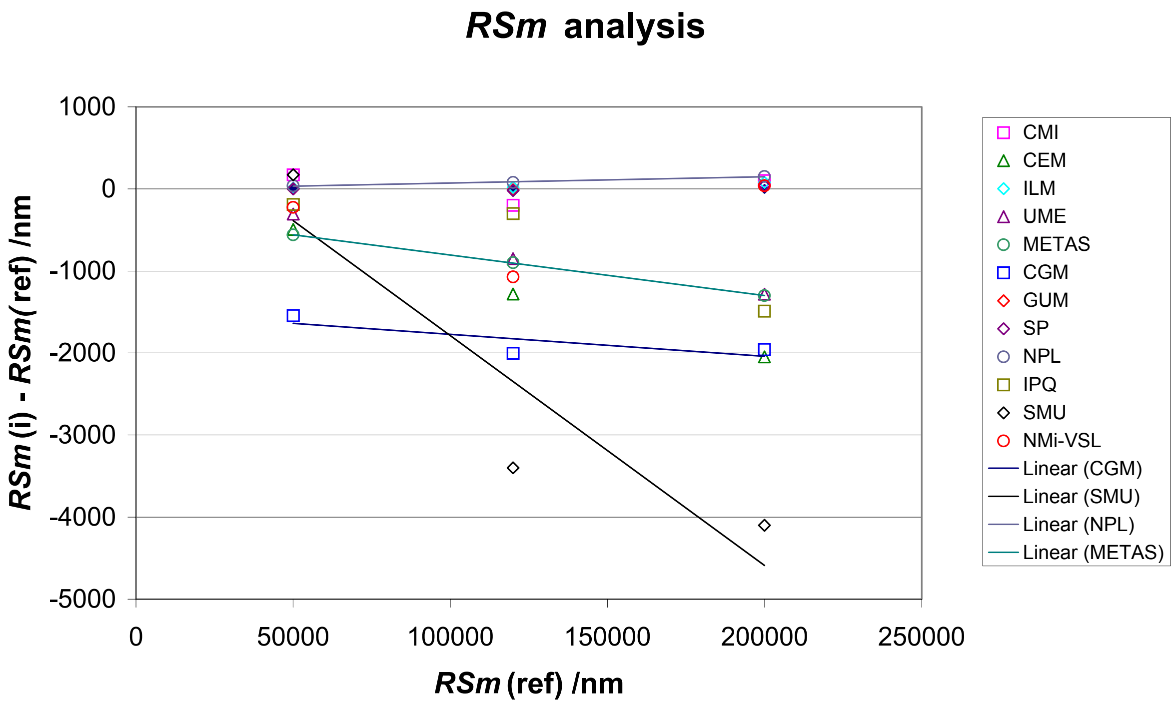

Fig. 5: Differences of RSm values of institutes to the reference value obtained on the geometrical standards.

The diagram shows that the difference increases with increasing *RSm* value in the case of CEM, UME, METAS, GUM, IPQ, and SMU. In the case of the CGM the differences have a large offset. Th above effects could be related to the calibration of the lateral axis of the stylus instrument or to the algorithm in the software [9].

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[9] R. K. Leach and P. M. Harris, Ambiguities in the definition of spacing parameters for surface-texture characterization, Meas. Sci. Technol. 13 (2002) 1924 - 1930

8.3 EVALUATION FOR THE *R*-PARAMETERS OF TYPE D STANDARDS

Again the tables of data, diagrams and tables with failed data are in Appendix D. We used in the report the En criteria to find outliers and to calculate the reference value. Nevertheless in some cases we observed problems which should be discussed in more detail. Some of them are already known from other comparisons.

8.3.1 PROBLEMS WITH *RMAX*

The results for the type D1 roughness standard 686sg are plotted in fig. 6 together with the expanded uncertainty. The red line indicates the reference value which is the weighted mean of all values that fulfil the En criteria. The blue line indicates the simple mean value.

In the case of the *Rmax* parameter, it seems that the reference value is fixed by two institutes with small uncertainty. Three other institutes have a different value in agreement with the simple mean value, but the uncertainty of their measurement values is not large enough to overlap with the reference value. To discuss this point in more detail we use the data in table 6 for *Rz* and *Rmax* for some selected institutes.

The values of the uncertainty for the *Rz* value of standard 686sg are 2 ... 4 times greater than for *Rmax* in the case of CGM, NMi-VSL, and NPL. On comparing this with the values for the different standards used, it is revealed that the uncertainty *U* increases in the case of *Rz* from the fine to the very coarse standard. But in the case of *Rmax* there is a decrease(!) from the coarse to the very coarse roughness standard. It seems that some contributions to the uncertainty of *Rmax* are estimated too small or that systematic effects exist which are not fully understood. This has to be clarified in future.

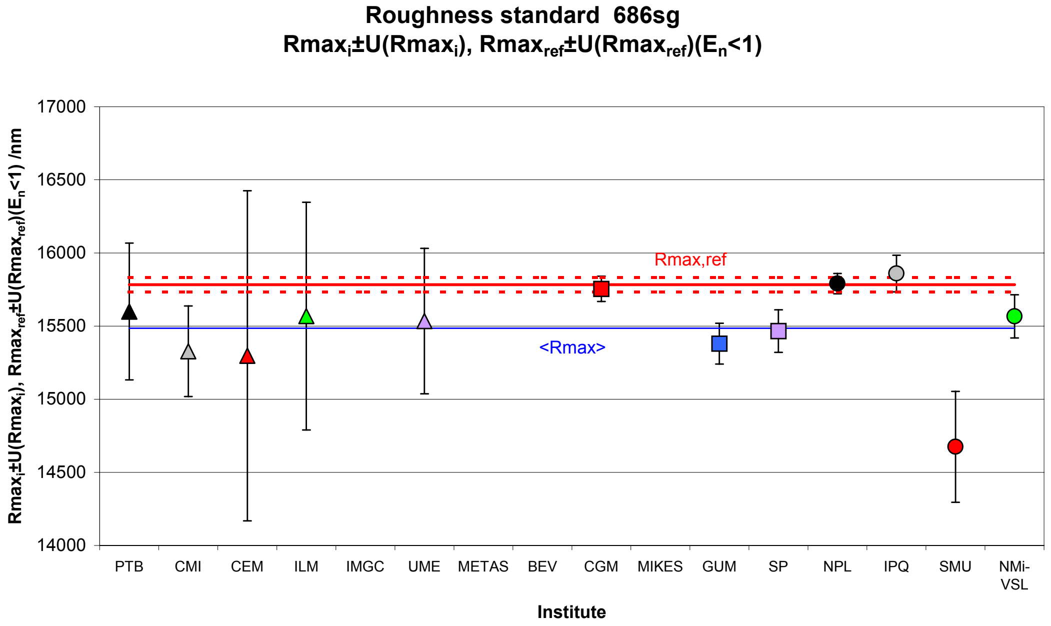

Fig. 6: Plot of the Rmax values for the institutes. The blue line give the simple mean, the red line the reference value together with the expanded uncertainty (dashed).

Table 6: Comparison of *Rz* and *Rmax* of some selected institutes

Vgl U(Rz) u(Rmax)			CEM		CGM		Nmi-VSL		NPL	
Geom. Standard			Rz	Rmax	Rz	Rmax	Rz	Rmax	Rz	Rmax
Rub	P114A/528-RS 5	value	1,575	1,588	1,60	1,61	1,592	1,604	1,636	1,703
		std. dev.	7	10	6	11	5	9	35,8	70,7
		Meas. Unc.	34,07	107,26	45	46	58	69	20,7	40,8
PTB	7070/PGN10	value	9,476	9,627	9,60	9,77	9,655	9,823	9,694	9,949
		std. dev.	39	60	34	84	44	56	43,9	95,2
		Meas. Unc.	181,9	735,21	70	84	127	151	25,4	55,0
PTB	8194/PGN3	value	3,091	3,113	3,07	3,09	3,097	3,118	3,192	3,391
		std. dev.	50,9	55,6	48	50	53	56	52,0	69,1
		Meas. Unc.	105,96	215,11	64	65	126	138	30,1	39,9
Roughn.standard			Rz	Rmax	Rz	Rmax	Rz	Rmax	Rz	Rmax
very coarse	686sg	value	14,046	15,297	14,3	15,8	14,330	15,567	14,353	15,791
		std. dev.	195	47	326	91	272	36	305,1	120,7
		Meas. Unc.	189,75	1128,65	200	86	556	148	176,2	69,7
coarse	633g	value	7,397	8,743	7,45	8,88	7,464	8,905	7,485	9,027
		std. dev.	195	128	88	259	174	121	182,9	189,5
		Meas. Unc.	125,28	667,3	84	164	358	261	105,6	109,4
fine	629f	value	1,248	1,428	1,24	1,40	1,258	1,440	1,236	1,545
		std. dev.	45	99	41	91	26	33	57,1	83,9
		Meas. Unc.	102,85	224,6	51	69	85	103	33,0	48,5
SFRN 150	1.006	value	0,13329	0,1729	0,137	0,173	0,146	0,185	140,14	189,36
		std. dev.	4,5	16,6	6	8	9	23	4,57	12,79
		Meas. Unc.	31,45	36,99	29	29	59	81	3,06	7,5
				U(Rmax)<<U(Rz)				U(Rmax(686sg))< U(Rmax(633g))		
				U(Rmax)<U(Rz)						

8.3.2 PROBLEMS WITH *RPK*

A similar case is observed for the *Rpk* parameter.

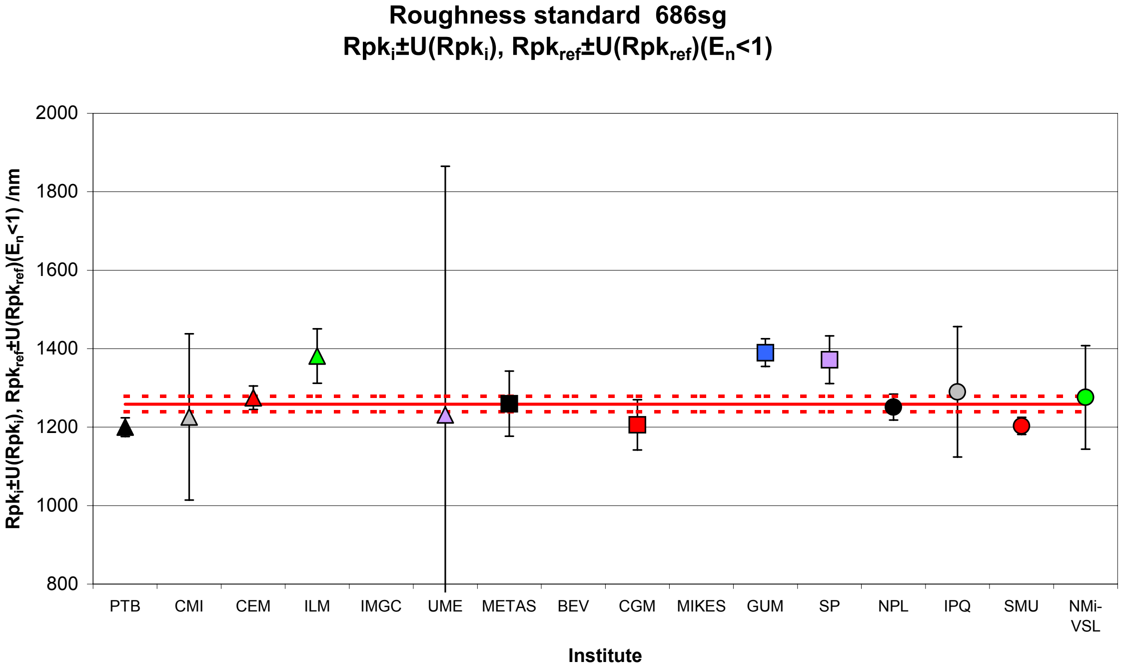

Fig 7a: Rpk parameter for the roughness standard 686sg

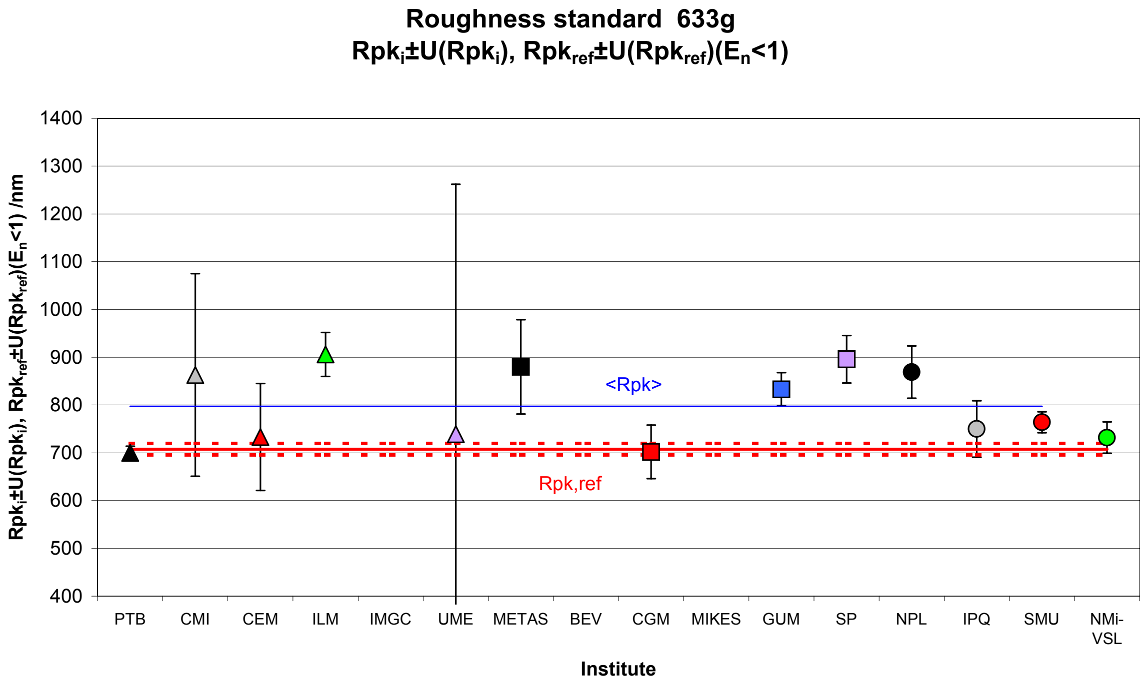

Fig 7b: Rpk parameter for the roughness standard 633g

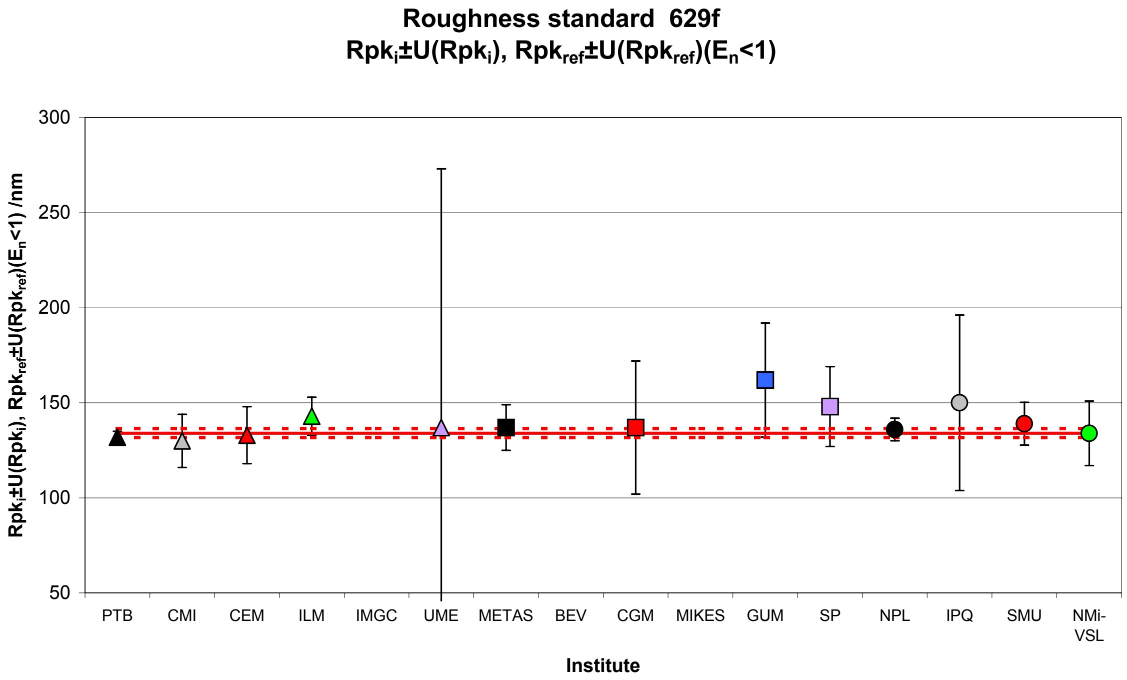

Fig 7c: Rpk parameter for the roughness standard 629f

Table 7: *Rk* parameter for various standards

			CEM	CGM	METAS	Nmi-VSL	NPL	PTB
Roughn.standard			Rpk*	Rpk*	Rpk*	Rpk*	Rpk*	Rpk*
very coarse	686sg	value	1,275	1,21	1,26	1,276	1,251	1,20
		std. dev.	95	53	52	66	56,9	100
		Meas. Unc.	30 *)	64	83	132	32,9	24 **)
coarse	633g	value	0,733	0,70	0,88	0,732	0,869	0,70
		std. dev.	34	15	144	14	94,7	20
		Meas. Unc.	112 *)	56	99	33	54,7	14
fine	629f	value	0,133	0,137	0,137	0,134	0,136	0,132
		std. dev.	6	7	12	4	10,2	6
		Meas. Unc.	15	35	12	17	6,0	3
SFRN 150	1.006	value	0,0261	0,028	0,03	0,028	27,24	0,027
		std. dev.	1,17	3	3	2	4,77	1,3
		Meas. Unc.	27	14	3,5	15	3,05	1,4

**) In the case of the CEM the uncertainty of Rpk of standard 686sg becomes smaller than those of standard 633g although the standard deviation increases. This is the case for the NPL, too, but here the standard deviation decreases.*
***) In the case of CEM and PTB the uncertainty U of the coarse roughness standard is much smaller than the standard deviation.*

First the *Rk*-parameter can be measured on sample with *Rz* values of up to 1,5 µm with good agreement. For example in the case of the CEM the uncertainty contribution amounts to approximately 5% of the *Rpk* value. Problems seem to occur for the coarse (*Rz* ~ 8 µm) and the very coarse standard (*Rz* ~ 14 µm). For example in the case of CEM the uncertainty amounts to 6,3% and 2,6% for the coarse and very coarse standard, respectively. As shown later the calculation of the *Rk* parameter gives some problems.

8.4 SUMMARY OF MEASUREMENT RESULTS

For the calculation of the reference value 12,8% of the 612 measurements have to be omitted. Fig. 8 shows the histogram of measurements failed for each group of parameters.

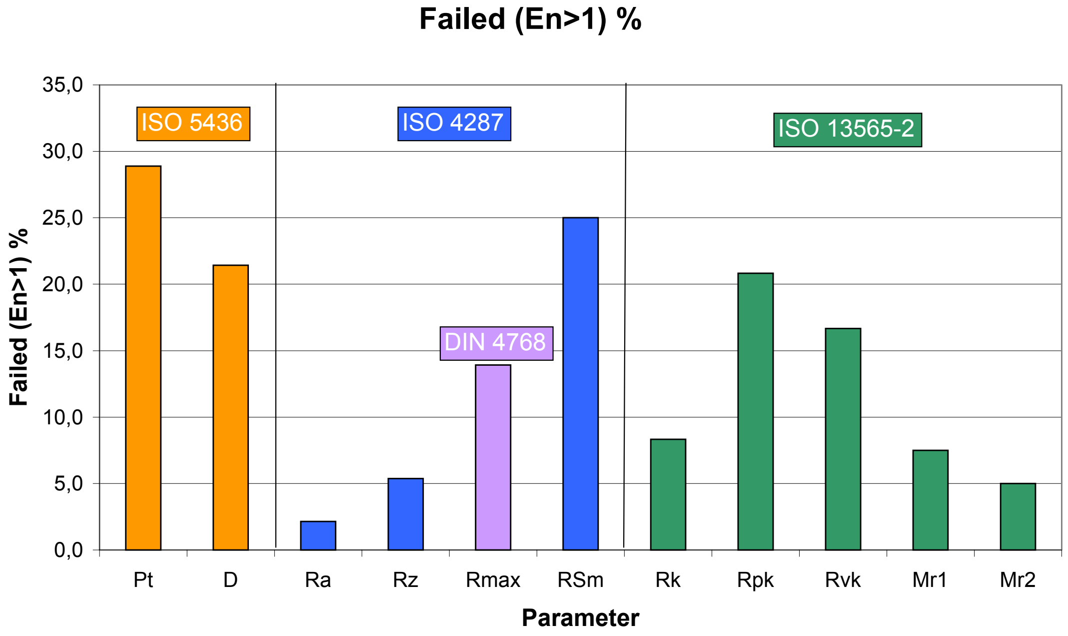

Fig. 8: Histogram of failed measurements based on results and expanded uncertainties. In the case of R parameters the histogram is based on measurements without SMU.

8.5 EVALUATION OF RESULTS FOR THE SOFTWARE GAUGES

Three data files were prepared by PTB for this test. The parameters are: *Ra*, *Rq*, *Rp*, *Rv*, *Rt*, *Rsk*, *Rz*, *RSm*, *Rmax*, and the *Rk* parameters *Rpk*, *Rk*, *Rvk*, *Mr1*, and *Mr2*. The values of λc and λs parameter should be set depending on the profile values (ISO 4288). The format of the software gauges is described in datasheet D5 and follows the rules given in ISO 5436-2 [10]. Since this is a brand new standard not all instruments can read this format. Therefore some participants wrote conversion routines. Both facts could be reasons why only eight of the fourteen institutes provided results for the software gauges.

The data are given in tables in Appendix D4. The reference values were calculated using the certified software ***RPTB*** Version 1.02[11] of PTB. This software is developed and proved at PTB[12]. An example is given in fig. 9a – 9c.

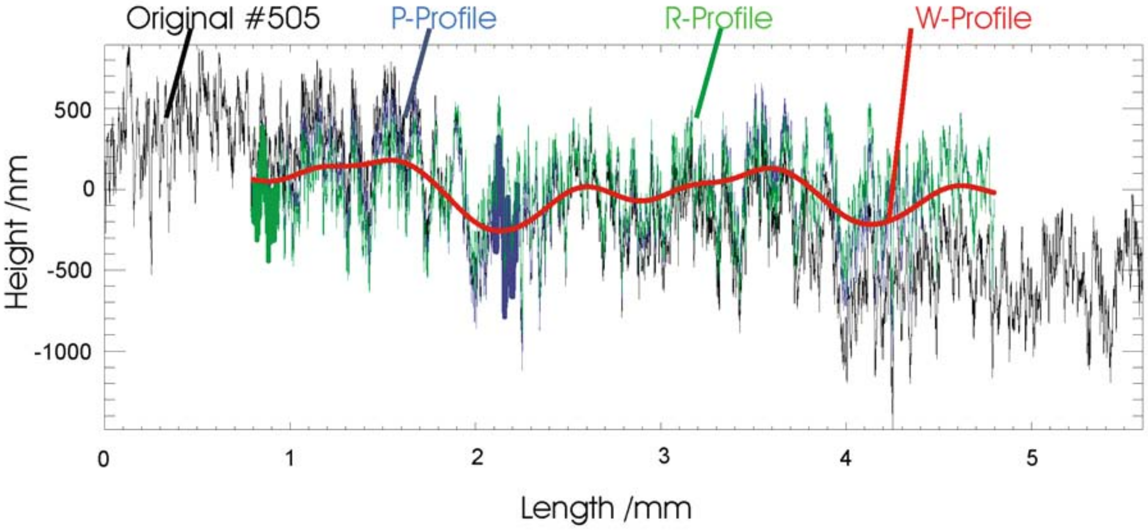

Fig. 9a: Original, P-profile, R-profile, and W-profile

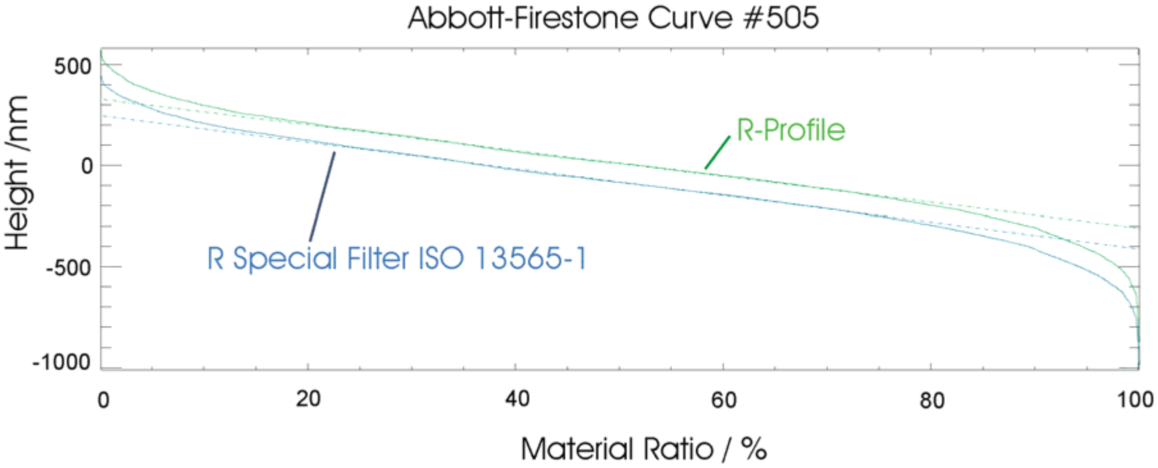

Fig. 9b: Abbott curve calculated from the R-profile and R-profile using the specific filter described in ISO 13565-1.

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[10] Comment of METAS "... the data in the soft gauge files is not exactly arranged according to the standard ISO 5436-2." See report of NMi-VSL "Notes on the analysis of software gauges", too. (Reports in Appendix B1).

[11] L. Jung et al., Proceedings of the EUSPEN 2001 May 2001, Turin, p.500 - 503

[12] TÜV Nord e.V *SEECERT* Certificate of Conformity DIN/ISO/IEC 12119, Registered No. H.SE.02.007.01.TLS

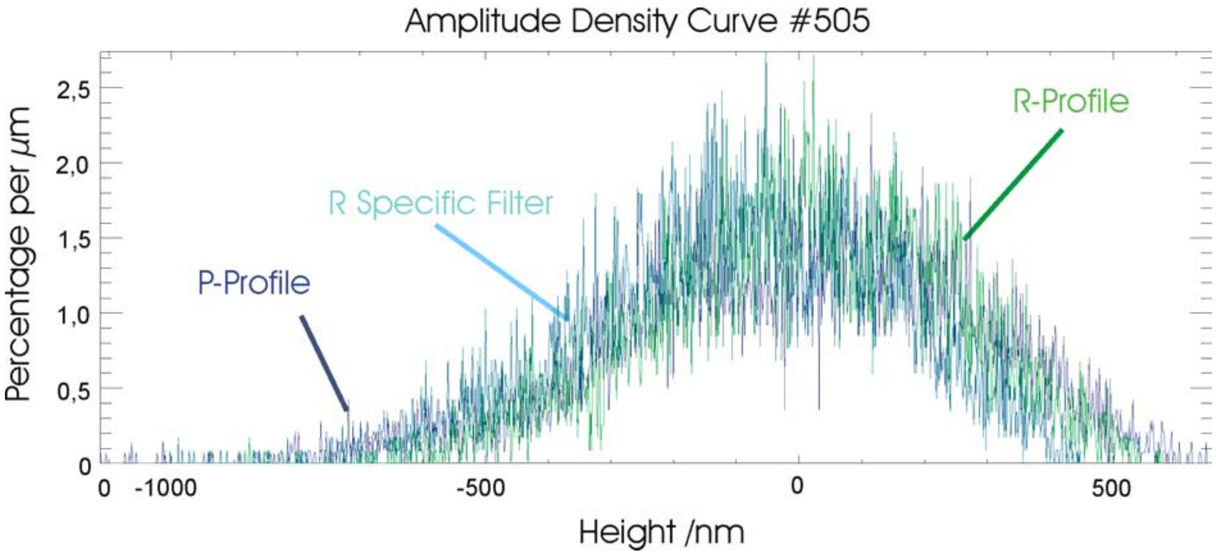


Fig. 9c: Density curves calculated from the P-profile, the R-profile and R-profile using the specific filter described in ISO 13565-1.

Table 8: Results obtained from software gauges 505.smd using the RPTB software (λc=0,8 mm, λs=2,5µm, FFT)

Values ISO 4287			
Thresholds:	*Lateral = 1,00%*	*Vertical = 10,00 %*	
Rp = 498,266 nm	*Rz = 1245,91n m*	*Rc = 467,65 nm*	*Rsk = - 0,222*
Rv = 747,64 nm	*Ra = 187,02 nm*	*RSm = 30,30 µm*	*Rku = 2,68*
Rmax = 1421,99 nm	*Rq = 231,05 nm*	*RDq = 0,0691*	*Rt = 1424,69 nm*
Values ISO 13565-2			
With specific filter ISO 13565-1:			
Rpk = 134,68 nm	*Rk = 636,93 nm*	*Rvk = 254,13 nm*	
Mr1 = 7,72 %	*Mr2 = 89,86 %*	*A1 = 5,20 mm^2*	*A2 = 12,88 mm^2*

For the further evaluation we calculated the differences between the results of the institutes and the reference values (see Appendix D4).

8.5.1 PROBLEMS WITH AMPLITUDE PARAMETERS

Some problems obviously occurred for the calculation of the *Rp*, *Rv* and *Rt* parameter. For example the data obtained from 505.smd for *Rp*, *Rv*, and *Rt* are listed in table 9. Fig. 10 shows the *Rt* values of the institutes.

Table 9: Data values for *Rp*, *Rv* and *Rt* and the difference *Rt* – (*Rp*+*Rv*)

Institute	Rp/nm	Rv/nm	Rt/nm	Rp+Rv /nm	Rt-(Rp+Rv) /nm
PTB	498,26	747,64	1424,69	1245,9	178,79
ILM	492	756	1248	1248	0
UME	520	780	1470	1300	170
METAS	510,7	725,7	1456,4	1236,4	220
CGM	520	782	1472	1302	170
SP	523,7	888,8	1412,5	1412,5	0
NPL	746	496	1422	1242	180
SMU	346	389	1430	735	695
NMi-VSL	509	724	1452	1233	219

[13] NPL: Rv= - 496 nm changed to Rv= 496 nm, because of sign error.

Independent of the sign error it seems that the values *Rp* and *Rv* are interchanged. The software of ILM and SP does not calculate *Rt* from the profile in the right manner. It seems to be calculated from mean *Rp* and *Rv* values of the evaluation length. But *Rt* is the maximum peak (*Rp*) to maximum valley height (*Rv*) of the profiles in the evaluation/assessment length.

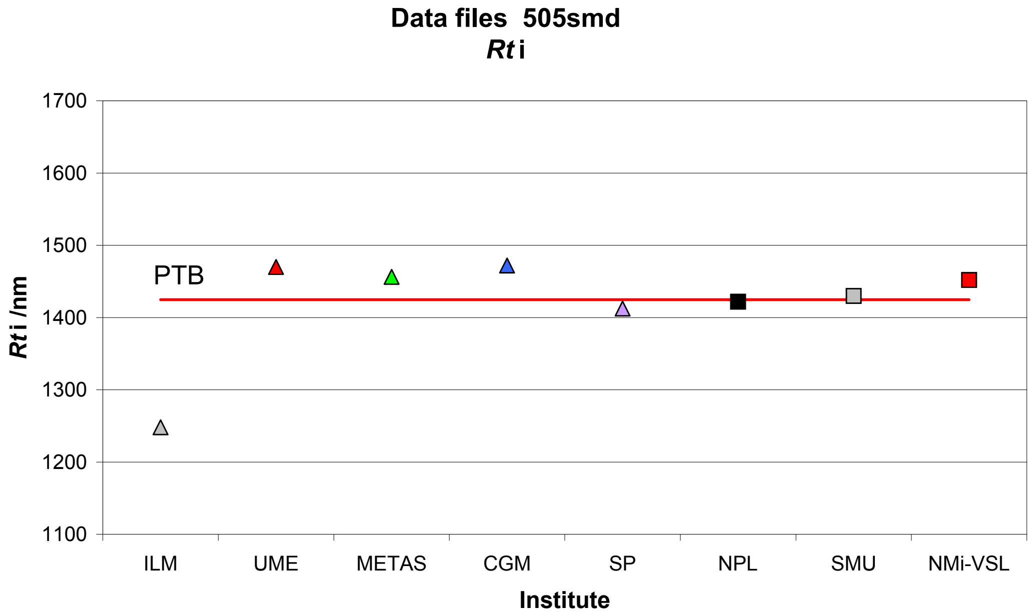


Fig. 10: Plot of Rt values for data file 505.smd for the different institutes. The red line indicates the reference value (PTB).

To estimate the influence of the software analysis we used the mean standard deviation of the software results obtained for data file 505.smd. This was compared to the uncertainty of measurement obtained for standard 629f. This standard has a similar profile and *Rz* value. To reduce the effect of outliers the data set of one institute was not used to determine the mean standard deviation. The results are listed in table 10. The influence of using different software for the same data set results in differences of approximately 13,8 nm and 18,6 nm for *Rz* and *Rmax*, respectively. Also for other parameters like *Rp*, *Rt* or *Rsk* the deviations are too large (see Appendix D4).

Table 10: Influence of software on the uncertainty of results

Parameter	***Ra* /nm**	***Rz* /nm**	***Rmax* /nm**	***Rk* /nm**	***Rpk* /nm**	***Rvk* /nm**	**Mr1 /%**	**Mr2 /%**
mean value *Rx*	149	1252,14	1434,3	456,54	139,85	300,85	8,75	87,99
u_c(*Rx*)	12,74	39,61	61,03	19,03	14,38	18,27	0,68	1,2
Deviation by software without SMU								
rel. mean standarddev.	0,6	1,1	1,3	2,7	1,3	1,3	7,4	0,4
Δ*Rx* /nm	0,9	13,8	18,6	12,3	1,8	3,9	0,6	0,4
Δ*Rx* /u_c(*Rx*) / %	7,0	**34,8**	**30,6**	**64,8**	12,6	**21,4**	95,2	29,3
excluding other (Rz,Rmax without ILM)								
rel. mean stddev. / %	0,6	0,5	1,3	2,7	1,3	0,6	7,4	0,4
Δ*Rx* /nm	0,9	6,3	18,6	12,3	1,8	1,8	0,6	0,4
Δ*Rx* /u_c(*Rx*) / %	7,0	**15,8**	**30,6**	**64,8**	12,6	9,9	95,2	29,3

This analysis shows that it is really important for accurate calibrations to have accurate instruments and accurate software. Therefore both have to be checked by appropriate means.

9 DEGREE OF EQUIVALENCE OF INSTITUTES

The *Degree of Equivalence* (DoE) of each laboratory with respect to the reference value is given by DoE(y_{ir}, U_{ir}) defined as:

$$y_{ir} = y_i - y_{ref} \quad \text{and} \quad U_{ir} = 2 * \sqrt{(u_i^2 - u_{ref}^2)}\,. \qquad (12)$$

These values are stated in the tables in Appendix E for each standard and for each institute. The reference values and their uncertainties allow to calculate the *Degree of Equivalence* of each institute or each instrument. This value (respectively pair of values) gives information about the quality of the measurement in this comparison. Furthermore it also indicates what should be improved - the instrument and/or the uncertainty budget.

Plotting the data gives a plot like fig. 11. Here the red lines indicate where the expanded uncertainty is equal to the difference of the measured value to the reference value.

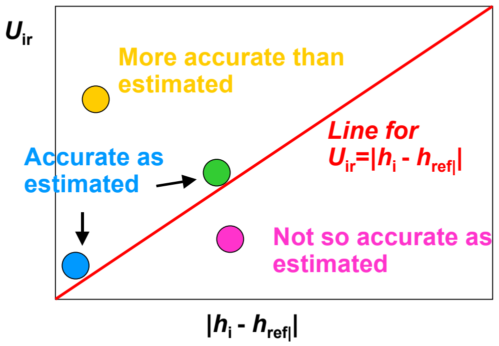


Fig. 11: Degree of equivalence for measurements

Fig. 12 shows the Degree of Equivalence for the 0,2 µm groove of the depth setting standard. For other parameters see Appendix (Degree of Equivalence).

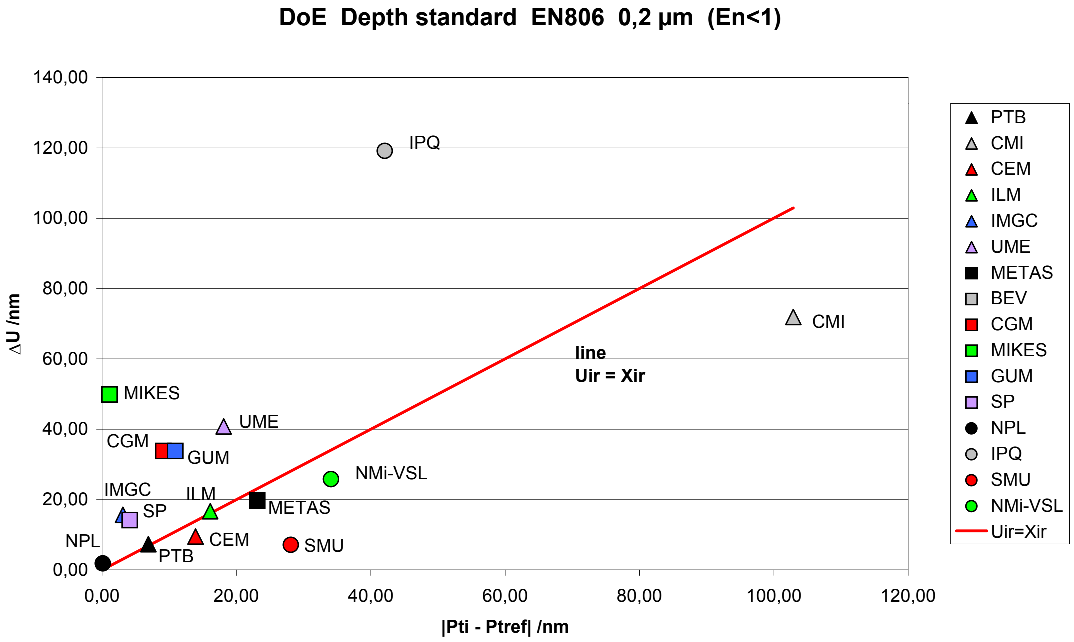


Fig. 12: Degree of equivalence for measurements of the Pt parameter on En0806 ~ 0,2 µm.

10 CONCLUSIONS AND REMARKS

The following conclusions are drawn from this comparison:

- It took 1 1/2 years from the decision to carry out this comparison until the Technical Report for the comparison was completed. This time was used to collect the data of all institutes which wanted to participate in the comparison. Also the decisions of which standards should be used and which parameters should be included into the comparison had been considered during this period.

- It took 2 years for the travelling of standards and measurements to be carried out at the laboratories until the first draft of the report could be issued. 15 institutes participated in this comparison. From the start of the comparison until Aug. 2002, the time schedule for the measurements, including transportation, was kept as planned. In the following, some delay occurred as it was necessary the check the standards at PTB (dust, scratches, etc., - but no cleaning was necessary), and due to problems with ATA carnet, no response of one participant, and using new devices. The travelling ended 22 months after beginning (17 planned). The time table was adjusted for four participants. CEM interchanged with CMI, and SMU with SP. Thanks are due to J. Borovsky, CMI, and Mikael Frennberg, SP, for helping us. Due to problems with the equipment during the first measurement time additional time was necessary for two institutes (CEM, NMi-VSL).

- This was an international comparison which checks the measurement of a large number of roughness parameters, which are used in the daily work. Therefore we extended the test to the *Rk*-parameters.

- Furthermore it is inevitable for national institutes to perform calibrations based on non ISO standards. For the industry it is important that such parameters can be calibrated with the same quality. For this reason we included the parameter *Rmax* which is based on the DIN 4787.

- Since most of the parameters are defined accordingly to more or less complex procedures the contribution of software is important. Therefore we included in the comparison a software test.

- For the calculation of the reference values 12,8% of the 612 measurements had to be omitted. The results of one institute were excluded completely. Big problems occur with the calibration of depth setting standard, the *RSm* parameter and with the more complex *Rk* parameters. While the last-mentioned demand a rather complex analysis, the former should be a standard technique in a surface texture laboratory. This is a result that was really not expected at the begin.

- The report shows further that it is really important for accurate calibrations to have accurate instrumentation <u>and</u> accurate software. Therefore <u>both</u> have to be checked by appropriate means.

11 REMARKS FROM THE PILOTS

A comparison should give a ***snapshot*** of the status of the measurement technique in the considered field. Therefore it is necessary to carry out a comparison and to report the results in short time to the participants. Afterwards all participants are invited to check their results and to discuss together in order to improve the knowledge about the measurement of surface texture.

This report is only at the beginning to find reasons for the failures. From the pilots point of view the time between the last measurements and this report was not sufficient to answer all questions. Therefore it would be helpful for each participant to examine their results and measurement processes in the light of this report, and seek explanations for any significant offsets of their results from those of other laboratories. Some questions to be answered are:

- What about the instrument (calibration, noise, ...)?
- What about the software used (effect of filters, enough data points measured,..)?
- What about the uncertainty budget?
- Are really all components of uncertainty included in the right manner?
- Are the estimated quantities sufficient?
- Although the instruments are slightly different: Is it possible to unify the calculation of the uncertainty budget?
- Are the descriptions in the written standards clear enough and do they allow to be transferred into a precise evaluation algorithm?

However we should try to maximise the scientific value of this comparison for the community, too. Therefore the pilots suggest to organise a small workshop with the participants of this comparison. This should improve the coincidence of results by improving instruments and software, having a better understanding of uncertainty and more precise definition of written standards.

12 ACKNOWLEDGEMENTS

The pilots would like to acknowledge the kind assistance and willingness to fund the necessary travel of all the colleagues involved for helping this comparison to run so smoothly. The four weeks time for measurement of all the standards and parameters were experienced by participants to be rather short. For future comparisons involving the same amounts of standards and parameters, two months are recommended. Thanks to those participants who were able to fulfil the measurements and the sending to the next participant within the expected time.

13 APPENDIX

Appendix A: Datasheets

Appendix A1: Datasheet 1 - Depth setting standard of type A2

Appendix A2: Datasheet 2 - Roughness standards of type C3

Appendix A3: Datasheet 3 - Roughness standards of type D1

Appendix A4: Datasheet 4 - Roughness standard of type D2

Appendix A5: Datasheet 5 – File format for software check

back

Appendix B: Reports of institutes

Appendix B1: Reports and comments

Appendix B2: Tables with measurement data

Appendix B3: Tables with software data

back

Appendix C: Stability of standards

back

Appendix D: Diagrams and tables for the various roughness parameters

Appendix D1: Depth setting standards A back

Appendix D2: Roughness standards type C back

Appendix D3: Roughness standards type D back

Appendix D4: Software standards F1 back

Appendix E: Diagrams with the Degree of Equivalence (DoE)

Appendix E1: Depth setting standards A

Appendix E2: Roughness standards type C

Appendix E3: Roughness standards type D back

DATASHEET 1

1 DEPTH SETTING STANDARD OF TYPE A2

The calibration standard (Fig. 1) serves to refer the vertical roughness parameter to the SI unit of length.

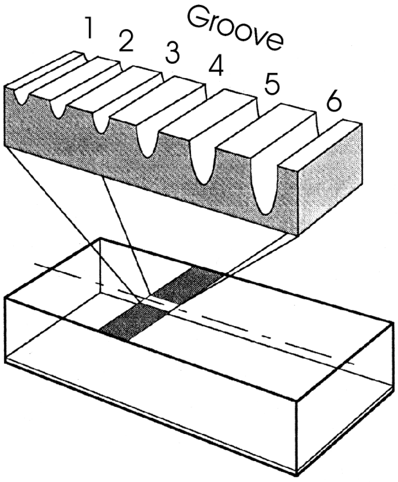


Fig. 1. ISO 5426-1 type A2 depth setting standard with six grooves

The calibration standard is a polished plane glass plate of the dimensions 40 mm x 20 mm x 10 mm. The centre of the measurement surface is provided with 6 grooves. The grooves have the shape of circular arcs with a radius of 1,5 mm. The width of the measurement surface is 1,2 mm. The nominal depths of the grooves are the following:

The depths of the following grooves should be measured: 1, 3, 6.

2 MEASURANDS

Pt (ISO 4287:1997), ***d*** (ISO 5436-1:1998)

3 CONDITIONS OF MEASUREMENT

Please, lift off the stylus during trace back!

Groove Number	Nominal value (µm)	Tracing length (mm)	Measuring force *) (mN)	Speed *) (mm/s)	Sampling spacing (µm)	Tip radius (µm)
R1	0,2	0,3	< 1	≤ 0,1	≤ 0,5	2
R3	1,5	0,5	< 1	≤ 0,1	≤ 0,5	2
R6	8,0	1,0	< 1	≤ 0,1	≤ 0,5	2

****) Please, try to use the conditions mentioned as close as possible, and check your stylus instrument according to the standards carefully!***

4 AREA OF MEASUREMENT

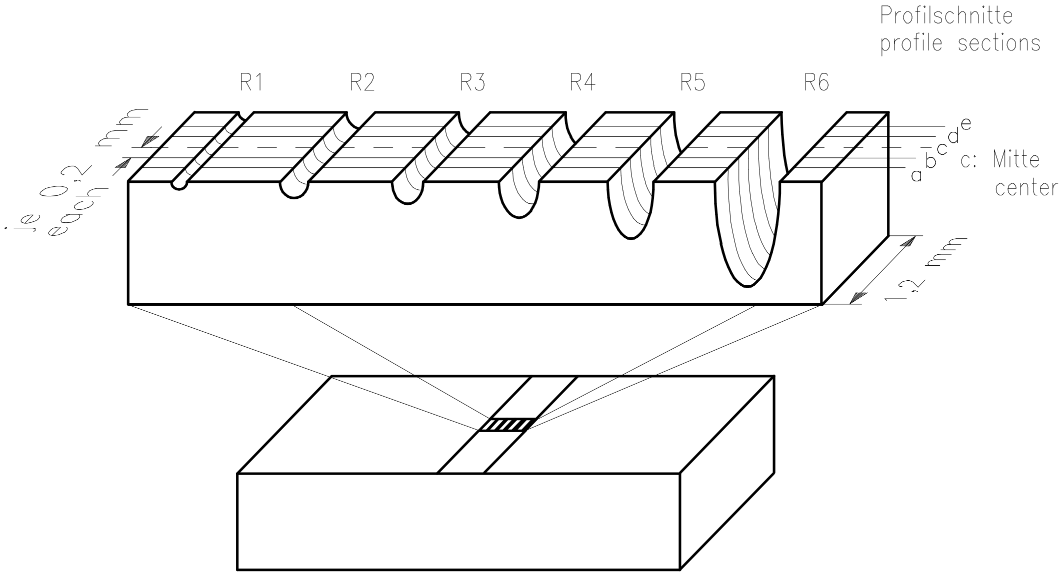


Fig. 2. A2 depth setting standard and profile sections

DATASHEET 2

1 ROUGHNESS STANDARD OF TYPE C3

These specimens are primarily intended for checking vertical parameters. They have a grid of repetitive grooves of simple shape. In our case we will use standards with a sinusoidal profile. Amplitude and period depends on the standard (see below). They are used to calibrate the lateral properties of stylus instruments, too.

The roughness standards are made from glass or stainless steel. The dimensions of the specimens are given below.

2 MEASURANDS

Ra, Rz, RSm (ISO 4287:1997) and ***Rmax*** (DIN 4768:1990)

The parameter ***Rmax*** is described in DIN 4768:1990 as the largest maximum height of profile (***Rz***) within the evaluation length.

3 CONDITIONS OF MEASUREMENT

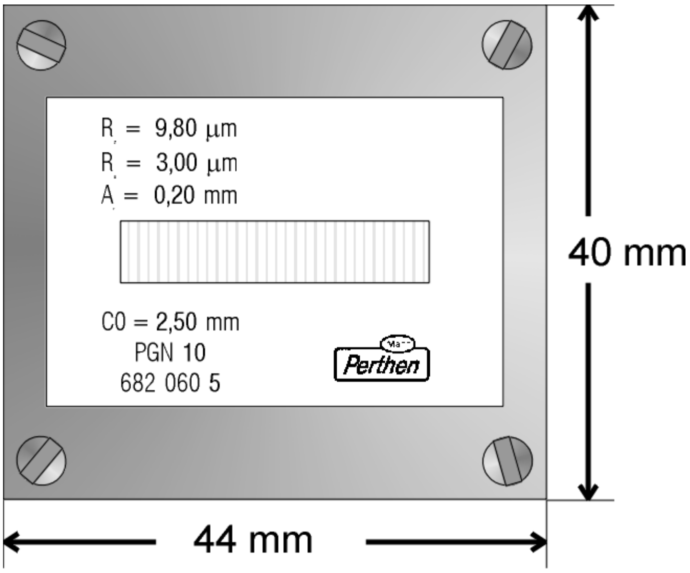
Phase correct profile filter according to ISO 11562:1996 must be used.

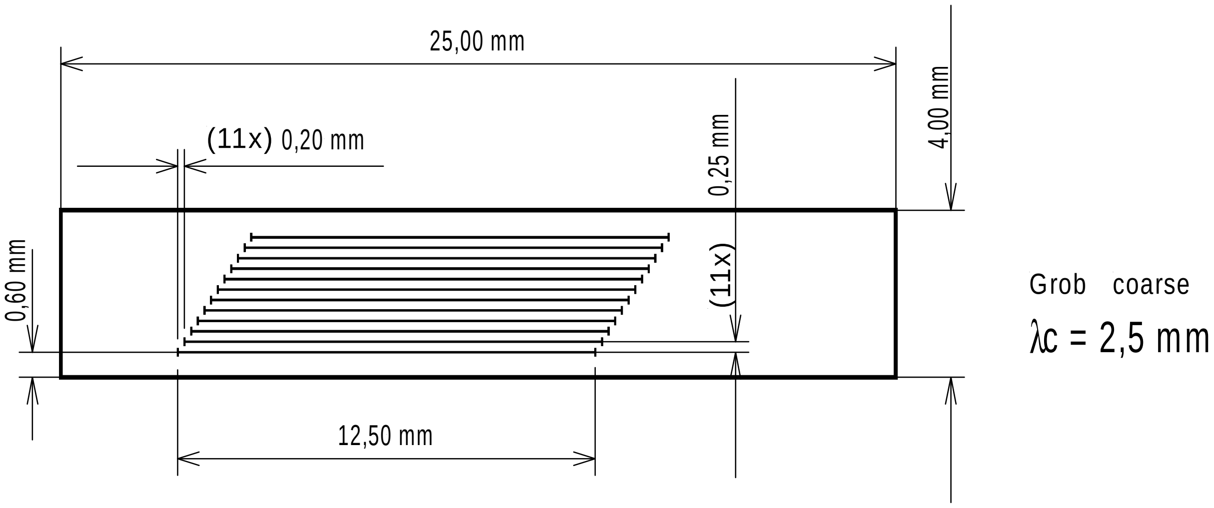
Specimen	Evaluation length (mm)	λc (µm)	λs (µm)	Measuring force *) (mN)	Speed *) (mm/s)	Sampling spacing (µm)	Tip radius (µm)
7070	12,5	2500	8	< 1	≤ 0,5	≤ 1,5	2
8194	4,0	800	2,5	< 1	≤ 0,5	≤ 0,5	2
P114A	1,25	250	2,5	< 1	≤ 0,5	≤ 0,5	2

) Please, try to use the conditions mentioned as close as possible, and check your stylus instrument according to the standards carefully!

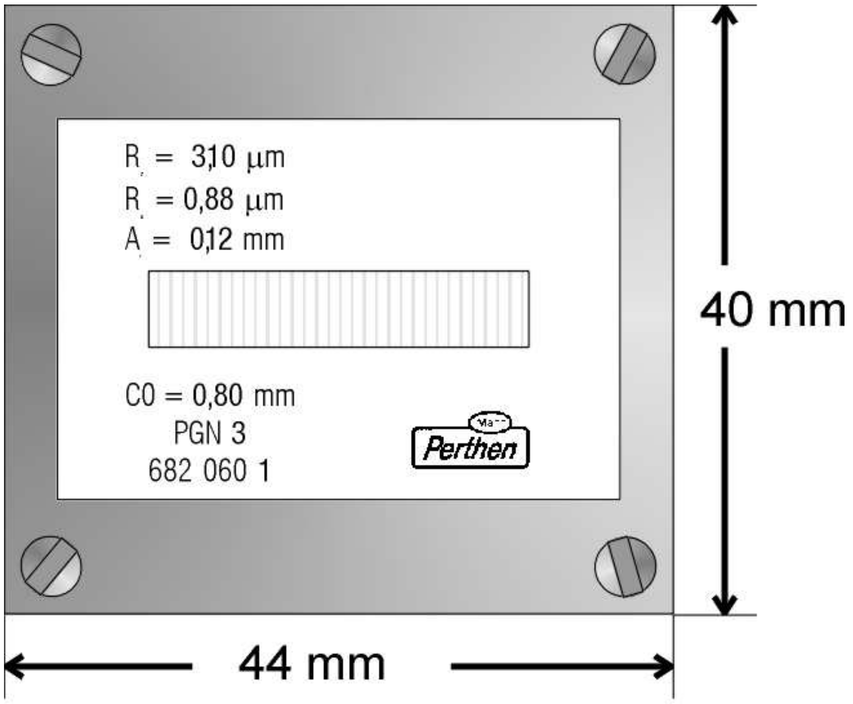
4 AREAS OF MEASUREMENT

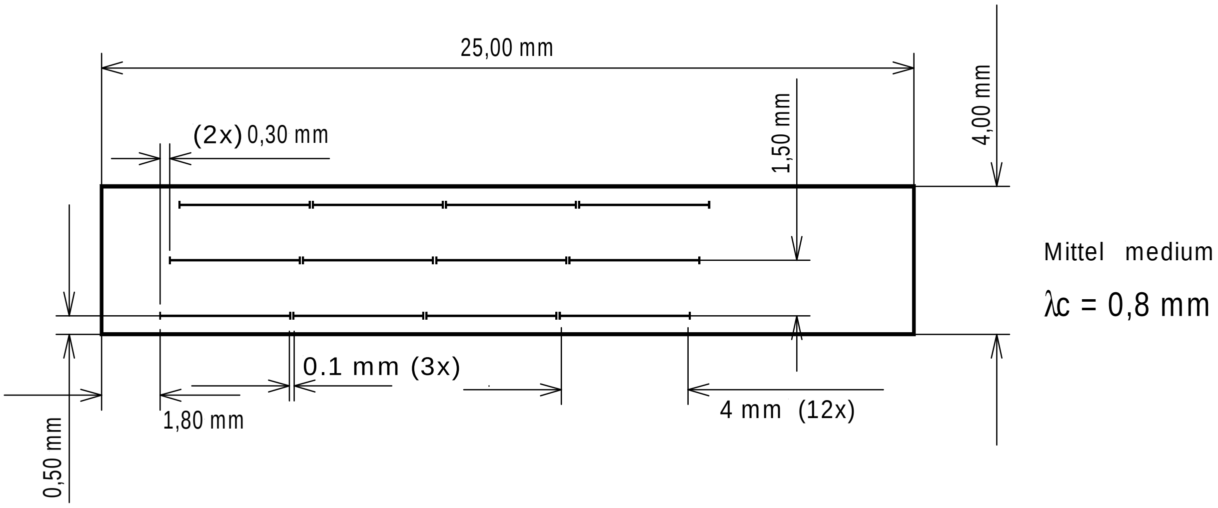
A) ROUGHNESS STANDARD 7070



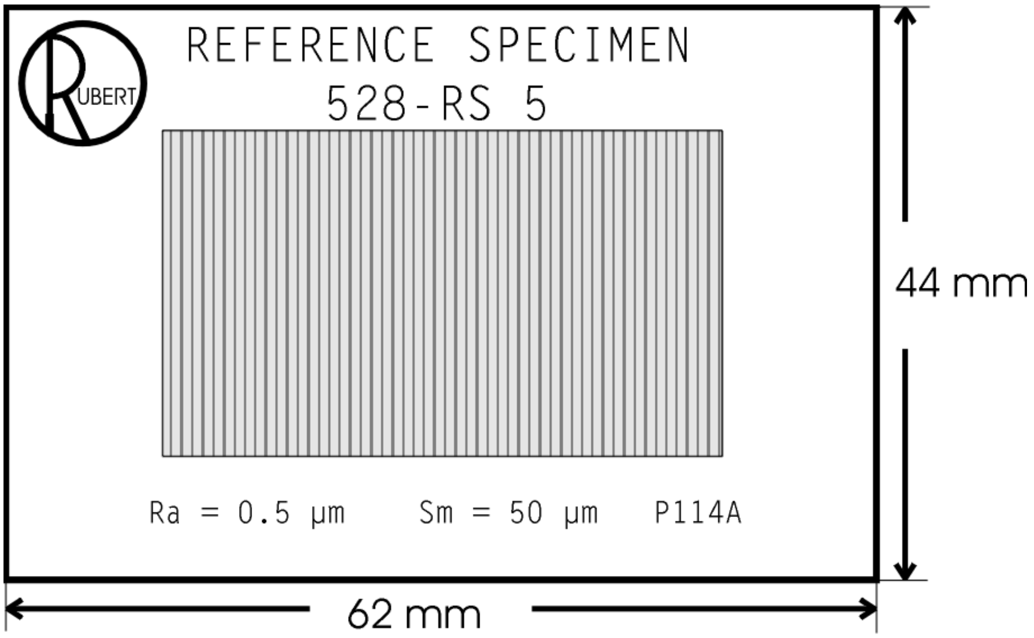


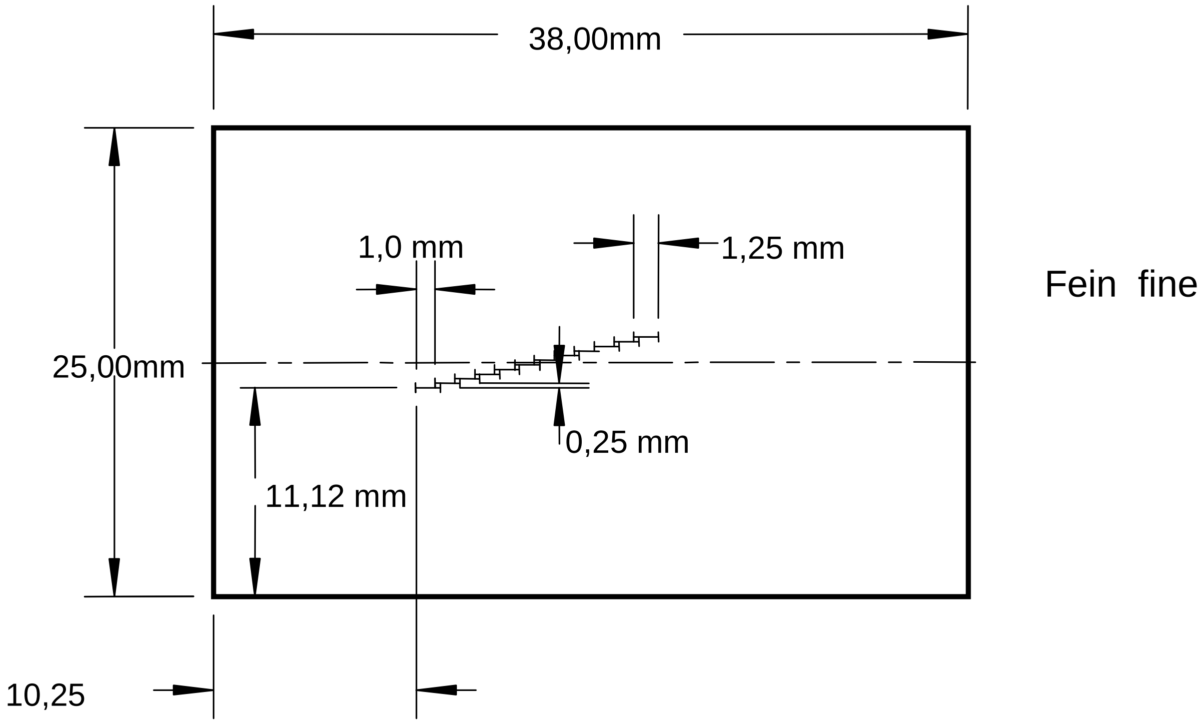
B) ROUGHNESS STANDARD 8194





C) ROUGHNESS STANDARD P114A





DATASHEET 3

1 ROUGHNESS STANDARDS OF TYPE D1

The roughness standards (Fig. 5) serve to calibrate and verify the complete contact stylus instrument, from the stylus to the indicating device.

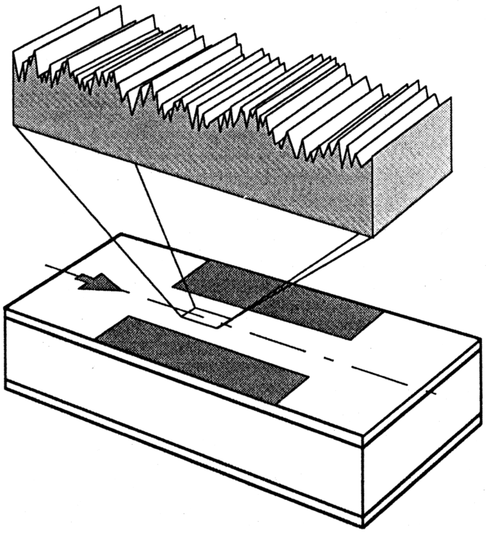


Fig. 5: Roughness standard with irregularly profile

The roughness standards are made from hardened, stainless steel of the dimensions 40 mm x 20 mm x 10 mm. They have an irregularly ground profile which is repeated every 4 mm in the longitudinal direction of the standard. Normal to the direction of measurement, the grooves produced on the measurement have a constant profile form within the area of the matt boundary surfaces.

The set used for the comparison consists of 3 roughness standards with the following nominal values (in µm):

Ra:	0,2	/	1,5	/	2,5
Rz:	1,5	/	8,5	/	14

The uniformity of the roughness standards is given by the standard deviation s < 3% found in 12 measurements of ***Ra*** and ***Rz***.

2 MEASURANDS

Ra, Rz (ISO 4287:1997) ***Rmax*** (DIN 4768:1990), ***Rpk, Rk, Rvk, Mr1, Mr2*** (ISO 13565-2:1996)
(mandatory with λs and optional if possible without λs)

The parameter ***Rmax*** is described in DIN 4768:1990 as the largest maximum height of profile within the evaluation length.

3 CONDITIONS OF MEASUREMENT

Phase correct profile filter according to ISO 11562:1996 must be used.

Specimen	Evaluation length (mm)	λc (µm)	λs (µm)	Measuring force *) (mN)	Speed *) (mm/s)	Sampling spacing (µm)	Tip radius (µm)
629f	4,0	800	2,5	< 1	≤ 0,5	≤ 0,5	2
633g	4,0	800	2,5	< 1	≤ 0,5	≤ 0,5	2
686sg	12,5	2500	8	<1	≤ 0,5	≤ 1,5	2

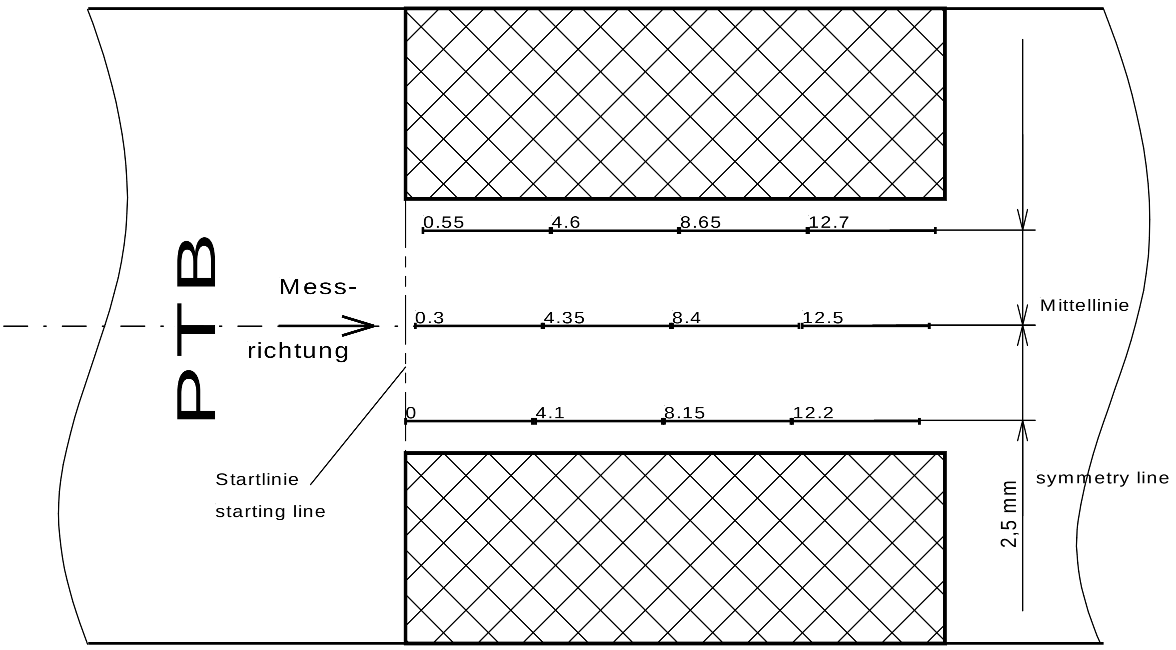
) Please, try to use the conditions mentioned as close as possible, and check your stylus instrument according to the standards carefully!

4 AREAS OF MEASUREMENT

Meßstellenplan für PTB-Rauhnormale (g, m, f), 2

starting points of the evaluation lengths in mm from the starting line

scale 5:1

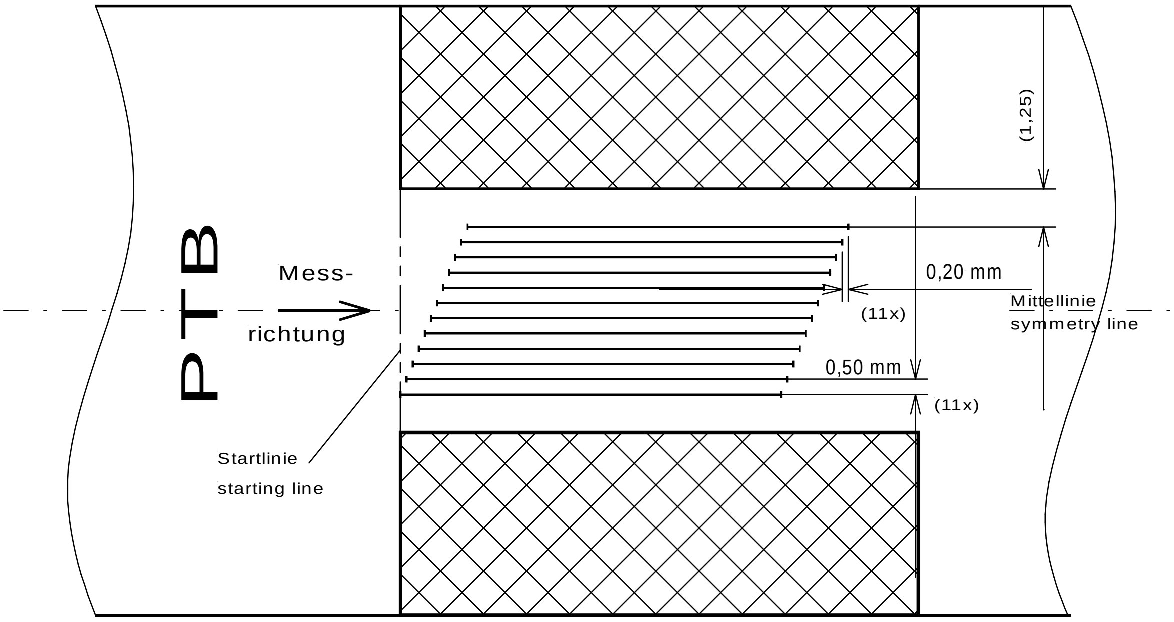


Meßstellenplan für PTB-Rauhnormale (gg), 1

Startpunkte der Meßstrecken in mm von Startlinie

starting points of the evaluation lengths in mm from the starting line

Maßstab 5:1 scale 5:1 $\lambda_c = 2.5$ mm



DATASHEET 4

1 ROUGHNESS STANDARD OF TYPE D2

The superfine roughness standard (Fig. 6) consists of a flat turned cylinder of copper coated with a layer of chemical deposited nickel of amorphous structure. The hardness was determined to 550 HV which is comparable with that of the steel roughness standards. By turning in an ultra precision turning machine, the profile in the flat circle is produced by a controlled movement of a single diamond tip with a radius of 5 µm and tip angle of 60°. This gives a profile that avoids the short and little reproducible wavelengths of the usual ground specimens. The repetition length is 1,25 mm in accordance with the specification for standards of type D2 with a roughness given below.

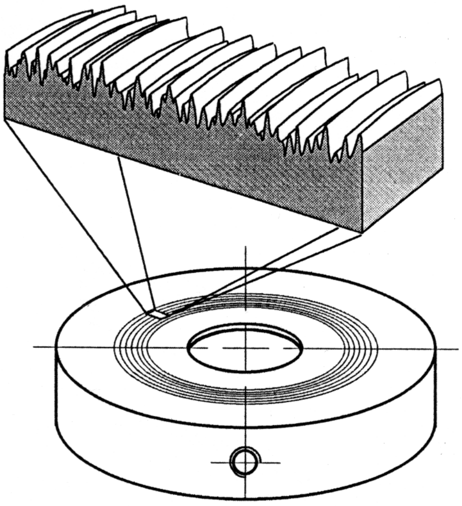


Fig. 6: Superfine roughness standard

A set consists of 3 superfine roughness standards with the following nominal values (in nm):

***Rz**: 150 / 300 / 450*

For the comparison we will use the standard with a nominal value of *Rz* = 150 nm.

2 MEASURANDS

Ra, Rz (ISO 4287:1997) ***Rmax*** (DIN 4768:1990), ***Rpk, Rk, Rvk, Mr1, Mr2*** (ISO 13565-2:1996)
(using λs)

The parameter ***Rmax*** is described in DIN 4768:1990 as the largest maximum height of profile (***Rz***) within the evaluation length.

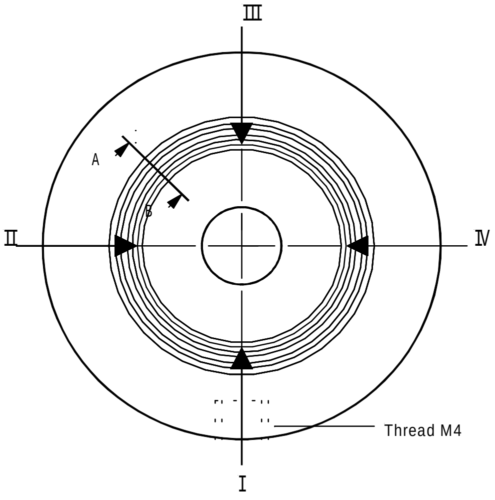
3 CONDITIONS OF MEASUREMENT

Phase correct profile filter according to ISO 11562:1996 must be used.

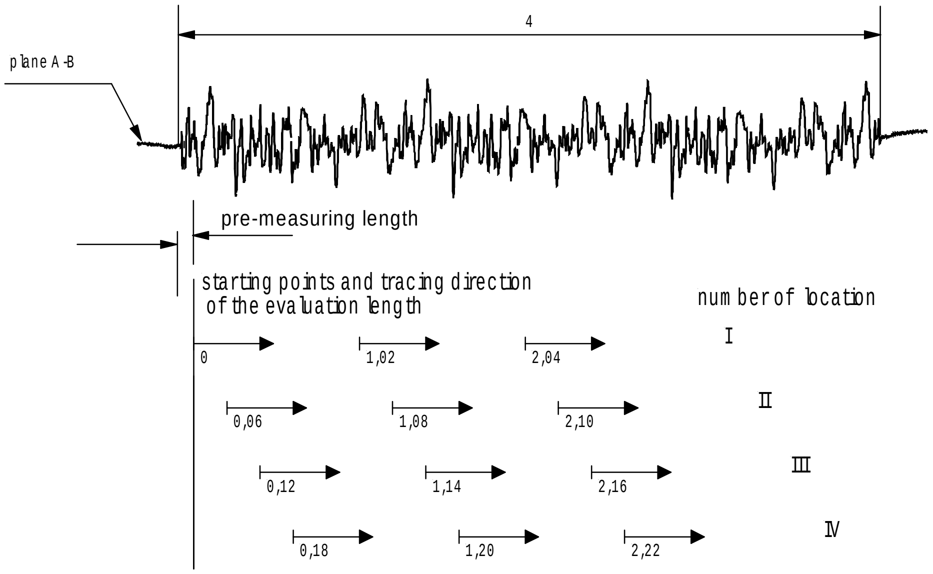
Specimen SF150	Evaluation length (mm)	λc (µm)	λs (µm)	Measuring force *) (mN)	Speed *) (mm/s)	Sampling spacing (µm)	Tip radius (µm)
1.006	1,25	250	2,5	< 0,6	≤ 0,1	≤ 0,5	2

) Please, try to use the conditions mentioned as close as possible, and check your stylus instrument according to the standards carefully!

4 AREA OF MEASUREMENT



location of measurement areas I to IV



n = 4 x 3 = 12 intersection planes

1. Datasheet D5

1.1. Reference Data of Type F1

Reference data are computer data files which represent the total profile in suitable recording medium, a 1,44 MB FD or CD in this case. These data are used to test software by using them as input data into the software.

1.2. Softgauge file format

1.2.1. General

The softgauge file format used in this case is a subset of the softgauge file format specified in ISO 5436-2:2000.

The file extension of this file protocol is `.smd`. The file protocol for the softgauge is divided into four separate sections or records. Each record is composed of lines of information and within each line there are various "fields" in which the information is coded. The file format is in **seven bit ASCII character code**.
Each line is terminated by a carriage return, (`<cr>`), and line feed, (`<lf>`). This is MSDOS typically.
Each record is terminated by an end of record, (`<ASCII 3>`), with a carriage return, (`<cr>`), and line feed,(`<lf>`). The last record is also further terminated by an end of file, (`<ASCII 26>`). For each field the separator is at least one white space.

1.2.2. Record 1 - header

The first record contains a fixed header including the following information:
The revision of the softgauge file format.
The file identifier.
The GPS feature type, number and name of the stored feature - axis information.
The number of data points in the profile.
The scaling of the data points.
The resolution of the data points.

The first line of record 1 contains 2 fields:
`The_revision_number`, and;
`File_identifier.`

Table 1 contains valid options for these fields.

field name	valid options	type	comments
`revision`	‘ISO 5436 – 2000’	string ASCII	
`file identifier`	<filename without extender and path>	string ASCII	must be unique

The second line of record 1 contains 3 fields:
`Feature_type`, and;
`Feature_number`, and;
`Feature_name`.

Table 2 contains valid options for these fields.

Table 2

field name	valid options	type	comments
feature type	‘PRF’	string ASCII	only profile data are allowed
feature number	0	unsigned integer	reserved for future use
feature name	‘PTB_2d_k’ or ‘PTB_2d_p’	string ASCII	‘PTB_2d_k’ is used for cartesian data, ‘PTB_2d_p’ is used for polar data

Each of the remaining lines of record 1 contains at least 6 fields:
`Axis_name`, and;
`Axis_type`, and;
`Number_of_points`, and;
`Units`, and;
`Scale_factor`, and;
`Axis_data_type`.

A seventh field, containing the incremental value is added if the axis type is incremental. Each axis in the softgauge has a line allocated to it. Thus for a profile there will be 2 remaining lines one for the X-axis and one for the Z-axis.
Table 3 contains valid options for these fields.

Table 3

field name	valid options	type	comments
axis name	‘CX’ ‘CZ’ ‘PR’ ‘PA’	string ASCII	Cartesian X axis Cartesian Z axis polar Radius polar Angle
axis type	‘A’ ‘I’ ‘R’	unsigned char	absolute data incremental data relative data
number of points	n	unsigned long integer	number of data points
units	‘m’ ‘mm’ ‘um’ ‘nm’	string ASCII	metres millimetres micrometres nanometres
scale factor	normally 1.0e0	double	scale to indicated units (scientific notation)
axis data type	‘I’ ‘L’ ‘F’ ‘D’	unsigned char	integer long integer float double
incremental value (axis type I only)		double	value of the increment

Example of record 1:

```
ISO 5436 - 2000<0>RN505<0><cr><lf>
PRF<0> 0 PTB_2d_k<0><cr><lf>
CX<0> A 11200 um<0> 1.0e0 D<cr><lf>
CZ<0> A 11200 nm<0> 1.0e0 D<cr><lf>
<3><cr><lf>
```

1.2.3. Record 2 - other Information

The second record must contain some information, some other are mandatory. This information shall start with a key word. The following list of examples is non-exhaustive and new keywords may be specified and used.
NOTE: Information contained in record 2 is intended for information only. However the information may be read and used by computers but it shall be possible to use the data without information from record 2.

Table 4: Examples of keywords in record 2

keyword	type	comments	mandatory
DATE	string ASCII	date of measurement	**NO**
TIME	string ASCII	time of measurement	yes
INSTRUMENT_ID	string ASCII	identification of measuring instrument (manufacturer and model)	yes
LAST_CALIBRATION	sting ASCII	date and time of last calibration	**NO**
PROBING_SYSTEM	see table 5	details of the probe used for the measurement	**NO**
COMMENT	string ASCII (must be delimited by ‘/*’ and ‘*/’; C-comment style)		yes
OFFSET_mm	double	offset of the start of the measurement in mm from the origin	yes
SPEED	double	traverse speed in mm/s	**NO**
PROFILE_FILTER	see table 6		**NO**
PARAMETER_VALUE	see table 7		yes

Table 5: Fields of PROBING_SYSTEM option of record 2

	PROBING_SYSTEM	
probe identification	string ASCII	identification of probe type
probing_system_type	‘contacting’ ‘non_contacting’	probing system which needs material contact probing system which does not need material contact
tip radius value	double	radius value
units	‘m’ ‘mm’ ‘um’ ‘nm’	metres millimetres micrometres nanometres
tip angle	double	angle of the spherical portion of the probe in degrees

Table 6: Fields of FILTER option of record 2

	FILTER	
filter type	‘gauss’ ‘dft’ ‘fft’ ‘2rc’ ‘spline’ ‘motiv’	Type of implementation of ISO 11562:1996 2RC-filter spline-filter motif filter according to ISO 12085:
λs cutoff value	`‘Ls’`<32>double	Value of λs in μm in scientific notation

λc cutoff value	`‘Lc’`<32>double	Value of λc in mm in scientific notation
motif_A	`‘MA’`<32>float	value of A according to ISO 12085
motif_B	`‘MB’`<32>float	value of B according to ISO 12085

Table 7: Fields of PARAMETER_VALUE option of record 2

	PARAMETER_VALUE	
parameter name	string ASCII	Example ‘Wq’
parameter value	double	value of the parameter
units	‘m’ ‘mm’ ‘um’ ‘nm’	metres millimetres micrometres nanometres
uncertainty	double	uncertaity calculated according to GUM

Example of record 2:

```
DATE 21 November 2000<0><cr><lf>
TIME 11:57 AM <0><cr><lf>
CREATED_BY PTB<0><cr><lf>
INSTRUMENT_ID TEST Type A<0><cr><lf>
INSTRUMENT_SERIAL AAA0001 <0><cr><lf>
LAST_CALIBRATION 1 April 2000 <0><cr><lf>
PROBING_SYSTEM FTK50<0>contacting 2.0 um<0> 90.0<cr><lf>
COMMENT /* This is a comment */<0><cr><lf>
OFFSET<0>1.0 <cr><lf>
SPEED<0>0.5 <cr><lf>
PROFILE_FILTER FFT Ls<32>0.25e+1 Lc<32>0.8e+0<cr><lf>
<3><cr><lf>
```

1.2.4. Record 3 - data

The third record contains the data. Each axis, defined in record 1, that is not an incremental axis will require data.

The data in record 3 is written in blocks in the order that the axes are defined in record 1. Each line of record 3 relates to a single data value. It contains 1 field:

`Data_value`.

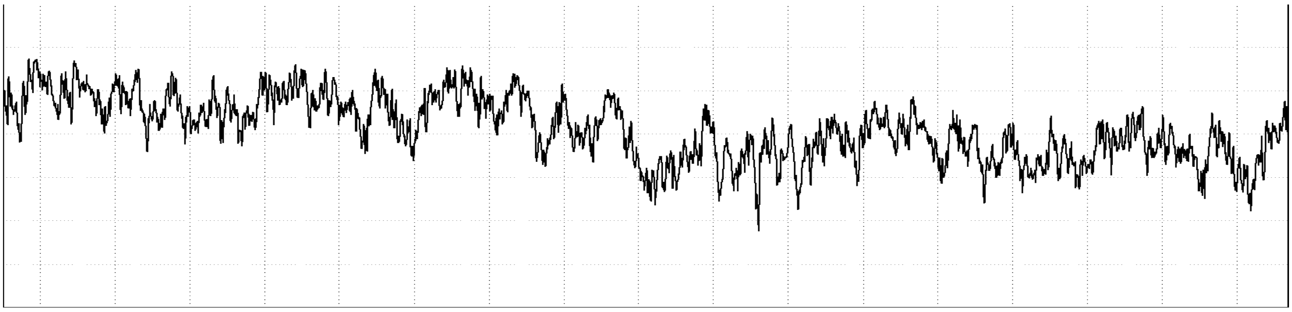
Multiplication of the data value by the scale factor contained in record 1 gives the value in the units specified in record 1.

NOTE The data in record 3 are raw data and have not been adjusted after a calibration.

Example of record 3:

```
0.5<cr><lf>
118.370000<cr><lf>
1.0<cr><lf>
158.865000<cr><lf>
1.5<cr><lf>
171.325000<cr><lf>
.
.
5598.5<cr><lf>
-732.025000<cr><lf>
5599.0<cr><lf>
-747.600000<cr><lf>
5599.5<cr><lf>
-718.007500<cr><lf>
<3><cr><lf>
```

profile unfiltered:



1.2.5. Record 4 - checksum

This record contains a checksum for the data contained in records 1, 2 and 3. Checksums are used to maintain data integrity.
The checksum is obtained by summing all the individual bytes (including `<cr>`, `<lf>` end of records etc.) values over records 1, 2 and 3 to an unsigned long integer, Modulo 65535.

Example of record 4:

```
23243<cr><lf>
<3><cr><lf>
<26>
```

Measurands

We will provide for the software comparison three data sets. Depending on the data set some of the following parameters should be determined:
Ra, Rq, Rz, Rt, Rp, Rv, Rsk, Rku, RSm, Wt, Pt (ISO 4287:1997)
Rmax (DIN 4768:1990),
Rpk, Rk, Rvk, Mr1, Mr2 (ISO 13565-2:1996)

THE PARAMETER ***RMAX*** IS DESCRIBED IN DIN 4768:1990 AS THE LARGEST MAXIMUM HEIGHT OF PROFILE (***RZ***) WITHIN THE EVALUATION LENGTH.

Appendix B1 - REPORTS OF INSTITUTES

COMMENTS OF PARTICIPANTS REGARDING THEIR MEASURED VALUES

CEM

At page 25/33, in Table 7, the comments on our results are true, but it is a little bit difficult to investigate on why such values. Because the existence of other uncertainty components, even when increasing the standard deviation, it is possible to get lower final uncertainty.

The contribution of the standard deviation is very small because it is divided by the number of measurements and this number may be different on different standards. Moreover, the A1 type standard used for adjusting the measurement equipment has different uncertainty depending on the value to be measured and this is another important contribution to the final uncertainty.

With respect to the comment at the end of the paragraph 8.3.2 it would be necessary to investigate much more on this item but unfortunately we did not have to much time to do it.

CGM

We have some comments to our results which we would like to be added to our report.

Our result for the RSm parameter did all come out too small in the report. They were computed by our own developed software RCS4G version 2.0. An investigation of the applied algorithm showed us that there was a systematic error in the calculation of the length of the first profile element. By removing the first profile element from the calculation we obtain the following values for RSm.

RSm values computed with the software after correction:

7070 /PGN 10:	RSm = (199960 +/- 1376) nm
8194 PGN 3:	RSm = (119990 +/- 1125) nm
P114A:	RSm = (50036 +/- 648)nm

Fortunately this has not given us any problems as replacing of customer certificates since we have not been making any with RSm using version 2.0.

Concerning the results we are surprisingly having problem with the coarse type C standard 7070/PGN10 when measuring Rz but not Rzmax. We have no explanation for this at the moment.

CMI

We have found two errors in our measurement report.

1) Depth standard EN 806 R1 0,2 µm.

By mistake we reported the value of our reference standard: 195 nm. The value we measured on Depth standard EN 806 R1 0,2 µm was: 325 nm. The corrected measurement report is attached.

2) the similar mistake we did in the case of Roughness standard 686sg.

By mistake we reported the value of our reference standard
Rz: 13597 nm and Rmax: 15328 nm . The value we measured on Roughness standard 686sg was Rz: 14115 nm and Rmax:15649 nm. The corrected measurement report is attached.

ILM/ISTEC

Comment to our report added after Draft A was published:

Comparing our results with the reference values of Draft A we found that the parameter Ry provided by our instrument using a software based on ISO 4287:1984 is a better approach to Rmax then Rt.

Therefore our new values for type C,D standard are:

Geom. Stan-dard			(Rmax) Rt	**(Rmax) Ry**
Rub	P114A/528-RS 5	value	1,609	**1,605**
		std. dev.	12	**13**
		Meas. Unc.	65	**65**
PTB	7070/PGN10	value	9,767	**9,766**
		std. dev.	66	**70**
		Meas. Unc.	391	**391**
PTB	8194/PGN3	value	3,112	**3,105**
		std. dev.	51	**53**
		Meas. Unc.	125	**124**

Roughn.standard			(Rmax) Rt	**(Rmax) Ry**
very coarse	686sg	value	15,568	**15,531**
		std. dev.	40	**43**
		Meas. Unc.	778	**777**
coarse	633g	value	8,842	**8,821**
		std. dev.	91	**97**
		Meas. Unc.	442	**441**
fine	629f	value	1,512	**1,359**
		std. dev.	49	**29**
		Meas. Unc.	76	**68**
SFRN 150	1.006	value	0,2030	**0,1960**
		std. dev.	15	**24**
		Meas. Unc.	12	**12**

Uncertainty budget doesn't need a new calculation.

IPQ

At page 18/33 we try to answer at your comments about our reported values concerning the Pt and D parameters. With our measuring system we can not measure without the use of one lc filter. Like you say in the report, the use of this filter would strongly influence the profile of the depth setting standard and looking for the position of ours results on the tables of the appendix D1 (results of Pt parameter) we can see that IPQ values are always bigger than the mean. So, perhaps, with the impossibility to remove the lc filter, we are introducing a systematic error. Is not possible, for us, at this moment made a new revaluation of the values, because we do not know what will be the better solution (software or mathematical analyse) to treat the values.

This was the first time that we measure and evaluate this type of standards (Depth setting standards) so this comparison was very important for studying the proceeding of measurement and evaluation of the values.

METAS

To our surprise in a few cases there occurred larger deviations (which even resulted in the failure of the En-criteria) of the following parameters: Pt and D for the R1 and R3 groove of the depth setting standard EN 806 and the RSm values for the roughness standards, type C. As indicated in the measurement report A3, METAS used styli with 60 mm and 20 mm arm length for the measurements. Since the difference of the two styli was well within the given uncertainty range and the fact that the stylus with 60 mm arm length is used for most calibration services, the results given in the report were all from the 60 mm stylus. Unfortunately we found out, that measurements with this stylus contained more noise than the ones obtained with the 20 mm stylus. We underestimated the contribution of noise (which is more significant for small groove depths and maybe not the same everyday) in the uncertainty assessment. On the other hand we would like to indicate the results obtained with the 20 mm stylus would have agreed well with the reference value:
EN 806:
R1: Pt = (292 ± 19) nm; D = (288 ± 19) nm
R2: Pt = (1375 ± 40) nm; D = (1370 ± 40) nm

Our values of the RSm parameters in the report were all computed by the software package Ultra Version 6 except for the RSm value of the data file 7080.SMD where the evaluation was done using our own METAS software (LabView program).
The RSm value for the data file 7080 shows no significant deviation from the reference value (PTB). Evaluating the measured RSm parameters for the roughness standard 7070 / PGN 10 with the METAS software (instead of using UltraVersion 6) leeds to values with much smaller deviations from the reference value. It seems therefore, that Ultra Version 6 does not calculate RSm parameters correctly in some cases while it does sometimes in other cases (see also the strange grouping of values in fig. 5).

RSm values computed with METAS software:
7070 / PGN 10: RSm = (199'987 ± 70) nm
8194 PGN 3: RSm = (119'955 ± 52) nm
P114A: RSm = (50’044 ± 28) nm

Shortly after METAS had made the measurements for the comparison we began to use only values calculated with our own software for certificates.
The implementation of the RSm value seems to be a general problem, as e. g. discussed in: "Ambiguities in the definition of spacing parameters for surface-texture characterization", Richard K Leach and Peter M Harris, Meas. Sci. Technol. 13 (2002) 1924–1930.

NMi-VSL

What we have done so far is to check all relevant measurement data and the uncertainty contributions derived for this comparison. In our case two values were, based on the En critirion, excluded for the calculation of the reference values: Pt for the EN806 depth standard and Rmax for the 686sg roughness standard. After examining the measurement data and the uncertainty calculation for these parameters and we were not able to find any irregularities. However, since Pt is strongly influenced by noise one might argue that we have estimated the uncertainty contribution due to noise a bit on the low side. For Rmax we have measured an exceptionally low standard deviation on the 686sg standard and therefore a low overall measurement uncertainty. This seems to have been measured also by other contributers. So far we can not explain this effect other than that it might be the standard itself.

When looking at the results of the software standards it is surprising to see the variance in the results and in other cases the good agreement without matching the PTB reference value. This might be a starting point for a discussion with the software suppliers in order to reach agreement on the correct implementation on the calculation of the various parameters.

NPL

Please find attached the amended Euromet 600 results.
The following changes were required:
Type A - we found that to calculate Pt we need to level the profiles in a different manner to when we calculate d. We had not come across this, as we never have been asked to quote Pt.
Type C and D - our filter was not operating correctly as NanoSurf IV does not have a uniform sampling rate. This problem is now fixed but it meant that we had to re-analyse the data.
Type F1 - NanoSurf IV requires a *(-1) multiplier. The softgauges do not, so we have had to re-analyse the data.

(Table see below)

Depth standard			Pt	D							lambda-c	lambda-s	Speed
	EN 806										mm	µm	mm/s
R1	0,2 µm	value/µm	0,295	0,283									0,009
		std. dev./nm	3,0	2,8									
		U/nm (k=2)	3,3	7,0									
		D of F	8,9	47,8									
R3	1,5 µm	value/µm	1,375	1,365									0,009
		std. dev./nm	5,4	3,3									
		U/nm (k=2)	5,2	6,2									
		D of F	5,3	38,2									
R6	8 µm	value/µm	8,365	8,351									0,02
		std. dev./nm	15,9	6,3									
		U/nm (k=2)	14,4	11,6									
		D of F	4,1	37,5									
Geom. Standard			Ra	Rz	Rmax	RSm							
Rub	P114A/528-RS 5	value/µm	0,504	1,583	1,591	50,067					0,25	2,5	0,04
		std. dev./nm	1,6	4,5	13,0	19,9							
		U/nm (k=2)	1,7	3,0	7,6	11,6							
		D of F	49,8	17,0	11,7	11,3							
PTB	7070/PGN10	value/µm	2,951	9,625	9,780	200,049					2,5	8	0,09
		std. dev./nm	12,3	38,3	67,5	52,2							
		U/nm (k=2)	7,3	22,2	40,0	30,2							
		D of F	11,8	11,1	11,0	11,0							
PTB	8194/PGN3	value/µm	0,900	3,080	3,097	120,030					0,8	2,5	0,09
		std. dev./nm	8,4	51,3	55,8	43,4							
		U/nm (k=2)	5,1	29,7	32,3	25,1							
		D of F	12,7	11,0	11,0	11,1							

Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed
											mm	µm	mm/s
very coarse	686sg	value/µm	2,345	14,293	15,525	8,078	1,25	3,22	7,55	92,62	2,5	8	0,09
		std. dev./nm	20,7	301,4	46,8	202,3	52,4	303,8	0,81	0,75			
		U/nm (k=2)	12,1	174,1	27,1	116,9	30,3	202,6	1,40	1,39			
		D of F	11,3	11,0	11,1	11,0	11,0	8,0	53,6	52,7			
coarse	633g	value/µm	1,515	7,418	8,868	4,579	0,680	2,263	5,17	82,85	0,8	2,5	0,09
		std. dev./nm	2,1	153,3	126,4	72,4	34,6	54,2	0,29	0,89			
		U/nm (k=2)	1,8	88,6	73,0	41,9	20,1	31,3	1,33	1,42			
		D of F	38,8	11,0	11,0	11,0	11,1	11,0	46,4	54,5			
fine	629f	value/µm	0,148	1,234	1,410	0,451	0,136	0,297	9,87	87,66	0,8	2,5	0,09
		std. dev./nm	3,6	50,8	60,3	14,2	6,4	16,4	0,69	0,52			
		U/nm (k=2)	2,5	29,4	34,9	8,3	4,0	9,6	1,38	1,35			
		D of F	20,8	11,0	11,0	11,6	13,9	11,4	51,9	49,2			
SFRN 150	1.006	value/nm **	25,06	140,91	185,70	79,48	26,21	30,50	11,20	86,22	0,25	2,5	0,04
		std. dev./nm	0,63	4,52	14,97	6,14	3,36	4,13	1,78	1,44			
		U/nm (k=2)	1,37	3,02	8,74	3,79	2,35	2,72	1,67	1,56			
		D of F	51,3	16,6	11,5	14,2	22,3	18,4	46,5	53,4			
Data files			Ra	Rq	Rp	Rv	Rt	Rsk#	Rz	Rku#	Rsm	Rmax	Rpk
			ISO 4287									DIN 4768	ISO 13565-2
file 1	xz7080	value/µm	0,424	0,484	0,754	0,721	1,484	0,010	1,475	1,680	99,825		
file 2	xz1001	value/µm	0,087	0,107	0,232	0,238	0,628	-0,160	0,470	2,710	66,135		
file 3	xz505	value/µm	0,187	0,230	0,498	0,748	1,425	-0,220	1,246	2,680	98,808		

*) ISO 13565-1

#) These parameters do not have units

**) Values for this artefact quoted in nm

SMU

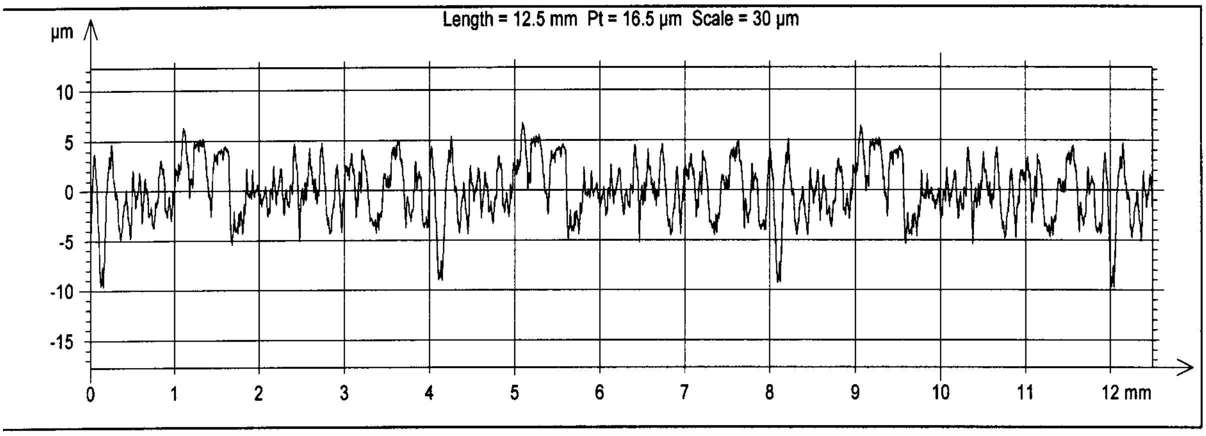
Comments to the Draft 1 – Euromet #600

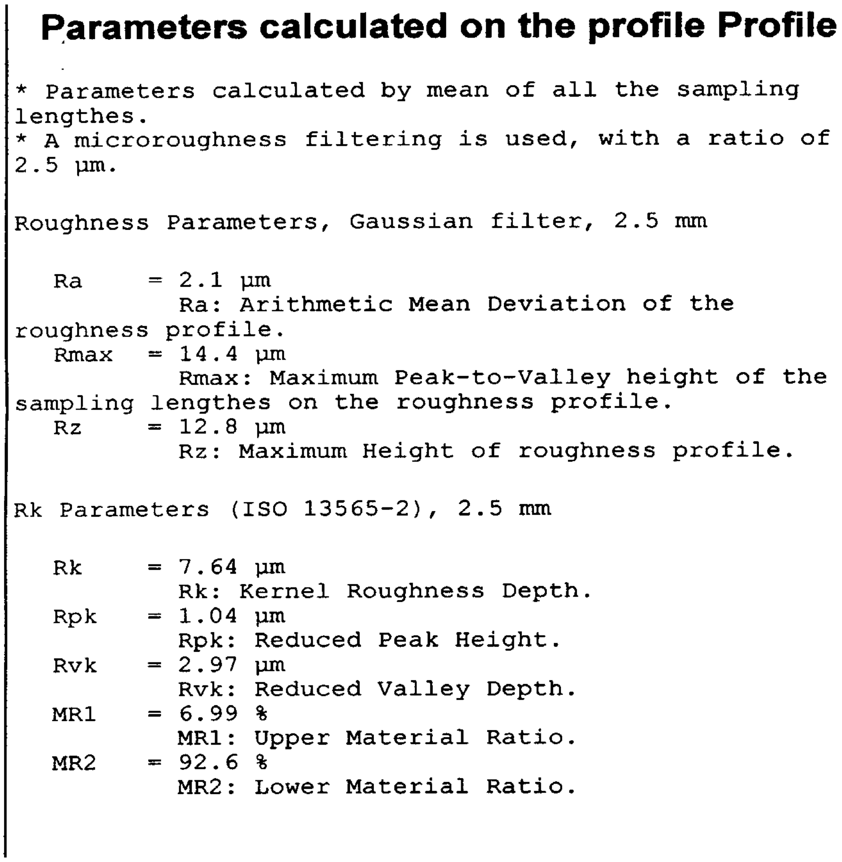
1. Contact profilometer Talysurf 6 works with the programme TalyProfile 3.0.8, which was purchased in 2002 from the company Taylor-Hobson. Programme has it own parameters fixed, which can not be changed, since such a change might effect some other parameters (filtration). Our facility operates at the fixed value of speed 1 mm/s and this fact causes very quick sampling of surface points. In the case of parameters d – groove depth and standards of type D – random profile these have different parameters from the reference value.
2. Values of parameters Pt; RSm; Mr1 and Mr2 were measured by the instrument and their value has been influenced by the large speed of stylus
3. Error sources resulting from the fixed parameters of the measuring programme were not taken into account and our claimed uncertainties were underestimated.

In the following example are given parameters and results of calibration of the D type standard.

Owner of the standard:	PTB Braunsweig
type :	D
manufacturer:	PTB 99/49
serial number:	686 sg
nominal values :	Ra = 2.5 µm; Rz = 14 µm

Conditions of measurement:	
temperature:	20.3 °C
speed:	1 mm/s
magnification:	5000 x
points:	**12500**
stylus tip radius	2 µm
	λc = 2500 µm; λs = 8 µm
length:	12,5 mm





Parameters calculated on the profile Profile

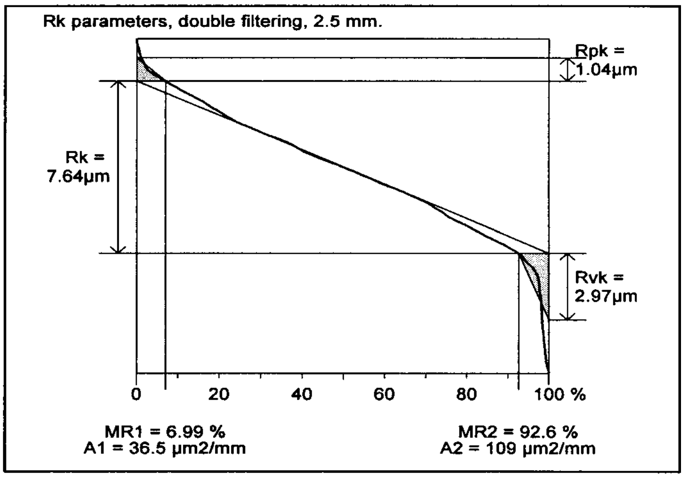
```
* Parameters calculated by mean of all the sampling
lengthes.
* A microroughness filtering is used, with a ratio of
2.5 µm.

Roughness Parameters, Gaussian filter, 2.5 mm

   Ra     = 2.1 µm
            Ra: Arithmetic Mean Deviation of the
roughness profile.
   Rmax   = 14.4 µm
            Rmax: Maximum Peak-to-Valley height of the
sampling lengthes on the roughness profile.
   Rz     = 12.8 µm
            Rz: Maximum Height of roughness profile.

Rk Parameters (ISO 13565-2), 2.5 mm

   Rk     = 7.64 µm
            Rk: Kernel Roughness Depth.
   Rpk    = 1.04 µm
            Rpk: Reduced Peak Height.
   Rvk    = 2.97 µm
            Rvk: Reduced Valley Depth.
   MR1    = 6.99 %
            MR1: Upper Material Ratio.
   MR2    = 92.6 %
            MR2: Lower Material Ratio.
```



SP

We have the following comments regarding the results from SP.

1. Our software uses the wrong definition of the Rt parameter. We think therefore that our results for this parameter should not be used in the calculation of the reference values.

2. The deviation from the reference values of the parameters Rvk and Rpk in our case seem to be slightly dependent on the roughness of the surface. We have not yet found the reason for this, but we suspect it might be a software problem.

3. We have re-evaluated the uncertainty calculations for the parameters RSm, Mr1 and Mr2. In the case of RSm, we had underestimated the effect of the resolution of the x-axis. In the case of Mr1 and Mr2, we did not take into account the effect of truncation in the software. Please find the new values in the attached excel-sheet. We think it would be appropriate to include these new uncertainty-values in draft B of the report.

Geom. Standard			RSm
Rub	P114A/528-RS 5	value/µm	50,03
		std. dev./nm	11
		U/nm (k=2)	50
PTB	7070/PGN10	value/µm	199,94
		std. dev./nm	20
		U/nm (k=2)	51
PTB	8194/PGN3	value/µm	119,98
		std. dev./nm	33
		U/nm (k=2)	54

Roughn.standard			Mr1/%*	Mr2/%*
very coars	686sg	value/µm	6,6	93,6
		std. dev./nm	1,3	0,5
		U/nm (k=2)	2,1	2,0
coarse	633g	value/µm	6	81,6
		std. dev./nm	0,9	0,9
		U/nm (k=2)	2,1	2,1
fine	629f	value/µm	8,4	88,1
		std. dev./nm	0,8	0,8
		U/nm (k=2)	2,1	2,1
SFRN 150	1.006	value/µm	10,8	87,4
		std. dev./nm	1,3	1,9
		U/nm (k=2)	2,1	2,3

UME

(Only part of the comment related to changes of the uncertainty)
1) We calibrated our roughness instrument by using PTB calibrated depth setting standard with six grooves. We used only the deepest groove (Pt = 9870 and D = 9820 nm). The relative uncertainty is % 0.305 . Our uncertainty for R6 groove (D = 8363 nm) of the depth standard EN 806 is 25.6 nm, our relative uncertainty is % 0.306 (Section 3.1–3.3, P:8–10 in UME Report Appendix B1 in Draft A) . As can be seen, our relative uncertainty in the comparison is equal to the uncertainty of our reference standard. This is caused by an error in the uncertainty model used for D parameter. In the model, z values of measured profile were being averaged according to the assumption of randomly distributed z-values. We applied this for the uncertainty of reference standards as well as for our measurements on the sample. But Dr. Koenders explained that the uncertainty of our reference standard was systematic not random. So we can not apply averaging for the uncertainty of reference standard. The corrected uncertainty equations and the budgets for D parameters can be seen in the attachment. According to the equations in the attachment, uncertainties for D parameters were recalculated. The results are as following:

Groove R1 (D = 282 nm), U(D) = 20.2 nm (k = 2)
Groove R3 (D = 1364 nm), U(D) = 24.4 nm (k = 2)
Groove R6 (D = 8363 nm), U(D) = 70.8 nm (k = 2)

2) We calculated the uncertainty only for Rz parameter (Section 3.7–3.13, P:14–20 in UME Report Appendix B1 in Draft A) . And we used this calculated absolute uncertainty for Ra and Rz1max in order to be on a safe side, because background noise level is high in our laboratory (Rzo = 33nm). But our uncertainties for Ra parameters seem very large when compared to other countries in the comparison. So we think that two uncertainty contributions should be changed in the budget. One of them is the systematic deviation (the difference between UME and PTB) and the other is standard deviation of the parameter on the surface. The systematic deviation may be calculated for Ra instead of Rz. Standard deviation of Ra may be used instead of Rz on the surface. The corrected model equation, the uncertainty equation and the budget can be seen in the attachment. According to the equations in the attachment, uncertainties for Ra parameters were calculated. The results are as following:

Geometric Standard P114A	(Ra = 505 nm),	U(Ra) = 20.0 nm (k = 2)
Geometric Standard 7070	(Ra = 2978 nm),	U(Ra) = 46.0 nm (k = 2)
Geometric Standard 8194	(Ra = 901 nm),	U(Ra) = 25.2 nm (k = 2)
Roughness Standard 686sg	(Ra = 2346 nm),	U(Ra) = 73.4 nm (k = 2)
Roughness Standard 633g	(Ra = 1533 nm),	U(Ra) = 30.8 nm (k = 2)
Roughness Standard 629f	(Ra = 147 nm),	U(Ra) = 20.0 nm (k = 2)
Roughness Standard 1.006	(Ra = 24 nm),	U(Ra) = 19.4 nm (k = 2)

Appendix B1

Reports of BEV

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments

The groove depths were measured using an rather old inverse interference microscope of the Linnik type (see figure). A Tl-spectral lamp was used as the light source. Two objectives have been used (10× and 25×) under different numerical apertures (0.04 to 0.28); NA-corrections were applied to the data. The samples have been measured under different orientations, wedge angles, and positions. Only the "*D*" parameter was measured.

The interferogramms were processed as usual (zero-padded, fast-Fourier-transformed, filtered in the vicinity of the relevant spatial frequencies, back-transformed to phase image modulo 2π) using a general purpose computer program (IDEA, http://optics.tu-graz.ac.at/optics/). The so processed images have been measured manually to get the relevant fringe fractions. The fit applied to the groove is not exactly according to ISO 5436, this is accounted for in the uncertainty budget.

Although it is possible to get the integral part of the fringes using these images or the respective white light interferogramms, groove R6 was also checked with a stylus instrument (Taylor-Hobson Talysurf 3). Only a single profile was recorded to save the artefact from scratching.

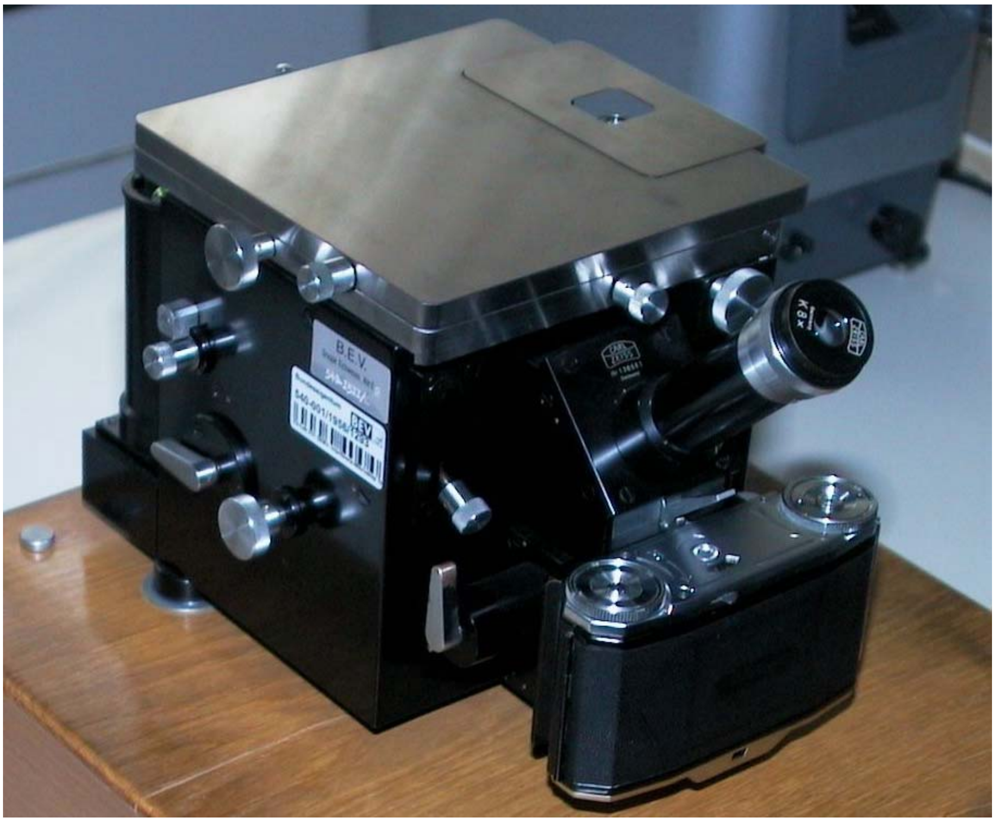


Fig. 1: used microscope

Laboratory: BEV

Date: 14. 12. 2001 Signature: ....

A4 - Uncertainty of measurement

Equation used:

$$d = k \cdot \frac{\lambda}{2} \cdot (F + f) + \delta_{\text{rand}} + \delta_{\text{fit}} + \delta_{\text{form}} \quad \text{with} \quad f = \frac{b}{a}$$

where:

k	**aperture correction factor *)**
λ	**wavelength (535.046 nm)**
F	**integral part of fringes**
a	**distance of two fringes (treated as a length reading)**
b	**deviation of two fringes (treated as a length reading)**
f	**fringe fraction: *f* = *b/a* *)**
δ_{rand}	**random error, for computational reasons separated from *f* *)**
δ_{fit}	**contribution from the difference in the fit algorithm applied (BEV vs. ISO 5436)**
δ_{form}	**form deviation of groove**

*) the uncertainty contributions for these quantities have been evaluated as an appropriate mean of the uncertainties for the individual measurements. For this reason the probability distributions are not of the simple type as anticipated in the footnote of the table.

The aperture correction factor was calculated according to VDE/VDI 2604 from the opening angle. Its uncertainty is taken from the uncertainty of the determination of this angle and a contribution for a possible inhomogenous illumination field.

For $u(\delta_{\text{fit}})$ we use the following estimate for cylindrical grooves: $0.005 \cdot d$ (rectangular distribution).

$u(\delta_{\text{form}})$ is set to the standard deviation of the individual measurements.

Step height standard with a nominal height of 200 nm: identification R1

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
$\boldsymbol{k}$	1.0003 1.0200	0.00015 0.00165	~N	285.0 nm	0.3 nm *)	∞
$\boldsymbol{\lambda}$	535.046 nm	**0.01 nm**	R	0.52	0.0 nm	∞
$\boldsymbol{F}$	1	**0**	exact			
$\boldsymbol{a}$	7 to 40	**0.29**	R	used in the calculation of $u(f)$		∞
$\boldsymbol{b}$	0 to 5	**0.29**	R			∞
$\boldsymbol{f}$	0.04	**0.013**	~T	267.5 nm	3.5 nm *)	∞
$\boldsymbol{\delta}_{\mathbf{form}}$	0 nm	3.5 nm	N	1	3.5 nm	9
$\boldsymbol{\delta}_{\mathbf{rand}}$	0 nm	2.6 nm	N	1	2.6 nm *)	60
$\boldsymbol{\delta}_{\mathbf{fit}}$	0 nm	0.8 nm	R	1	0.8 nm	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.
*) see explanation on the first page

Combined standard uncertainty: $u_c(d)$ = 5.7 nm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 52

Expanded uncertainty: $U(d)$ = 12 nm with a coverage factor
k=2.04

Laboratory: BEV

Date: 14. 12. 2001 Signature: ....

Step height standard with a nominal height of 1500 nm: identification R3

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
$\boldsymbol{k}$	1.0003 1.0200	0.00015 0.00165	~N	1366 nm	1.4 nm *)	∞
$\boldsymbol{\lambda}$	535.046 nm	**0.01 nm**	R	2.53	0.0 nm	∞
$\boldsymbol{F}$	5	**0**	exact			
$\boldsymbol{a}$	8 to 42	**0.29**	R	used in the calculation of $u(f)$		∞
$\boldsymbol{b}$	0 to 4	**0.29**	R			∞
$\boldsymbol{f}$	0.05	**0.015**	~T	267.5 nm	3.9 nm *)	∞
$\boldsymbol{\delta_{\mathrm{form}}}$	0 nm	3.8 nm	N	1	3.8 nm	6
$\boldsymbol{\delta_{\mathrm{rand}}}$	0 nm	3.3 nm	N	1	3.3 nm *)	40
$\boldsymbol{\delta_{\mathrm{fit}}}$	0 nm	3.9 nm	R	1	3.9 nm	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.
*) see explanation on the first page

Combined standard uncertainty: $u_c(d)$ = 7.6 nm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 69

Expanded uncertainty: $U(d)$ = 15 nm with a coverage factor k=2.0

Laboratory: BEV

Date: 14. 12. 2001 Signature: ....

Step height standard with a nominal height of 8000 nm: identification R6

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
$\boldsymbol{k}$	1.0003 1.0037	0.00015 0.00050	~N	8357 nm	2.2 nm *)	∞
$\boldsymbol{\lambda}$	535.046 nm	**0.01 nm**	R	15.7	0.2 nm	∞
$\boldsymbol{F}$	31	**0**	exact			
$\boldsymbol{a}$	4 to 50	**0.29**	R	used in the calculation of $u(f)$		∞
$\boldsymbol{b}$	0 to 10	**0.29**	R			∞
$\boldsymbol{f}$	0.2	**0.03**	~T	267.5 nm	8.5 nm *)	∞
$\boldsymbol{\delta}_{\mathbf{form}}$	0 nm	12.6 nm	N	1	12.6 nm	11
$\boldsymbol{\delta}_{\mathbf{rand}}$	0 nm	5.5 nm	N	1	5.5 nm *)	70
$\boldsymbol{\delta}_{\mathbf{fit}}$	0 nm	24.2 nm	R	1	24.2 nm	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.
*) see explanation on the first page

Combined standard uncertainty: $u_c(d)$ = 29 nm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 271

Expanded uncertainty: $U(d)$ = 58 nm with a coverage factor k=2.0

Laboratory: BEV

Date: 14. 12. 2001 Signature: ....

Appendix B1

Reports of CEM

Centro Español de Metrología

Comparison of Surface Texture Measurements
EUROMET Project: 600

Results obtained by

Stylus Profiler

Emilio Prieto

17th October 2002

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Description of the measurement instrument:

For all measurements it was used a commercial moving stylus profiler **Perthometer Concept** from Mahr™. This instrument works according to the standardized profile method, following the corresponding ISO written standards. It was also used a high precision drive unit PRK and skidless pick-ups with radii indicated in the technical protocol of the comparison.

Isolated measurement area and table along with strict and stable ambient conditions.

To obtain and analize data it was used the Perthometer software plus a Talymap Universal 2.0.

Measurement Method:

There were measured several significant profiles distributed on the standard according to the instructions of the technical report for the different standards.

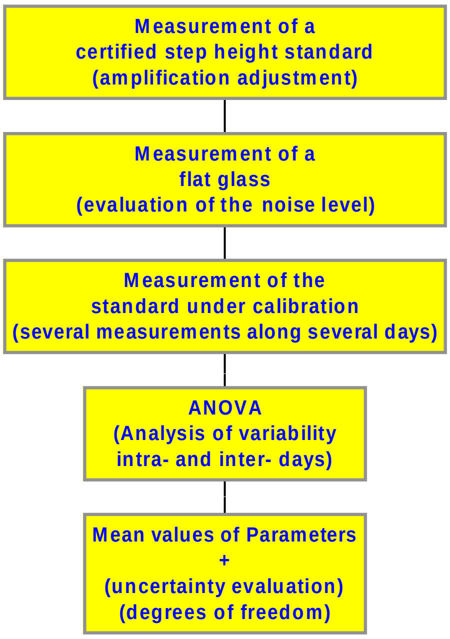
Vertical amplification of the instrument always adjusted by means of a depth setting standard type A1 with a certified value close to the nominal *d*/*Pt* (steps/grooves) or *Rz* (roughness) value of the standard to be measured.

Noise influence evaluated by measuring parameters on a flat glass with the same measurement conditions established as for the different standards.

Before measurements, alignment of the measurement plane of the step/standard with respect to the reference surface, in order to obtain the best internal alignment of all profiles.

Measurement results and uncertainty evaluation following GUM document after applying ANOVA method in order to identify and quantify random individual effects.

Scheme of the measurement process
(for steps, grooves & roughness standards)



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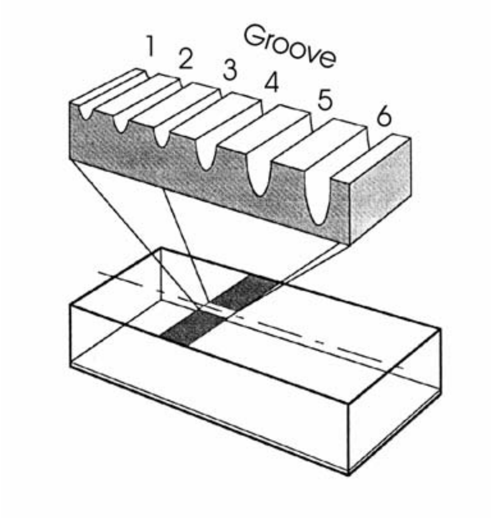
Measurement Report (DATASHEET 1)



Depth setting standard type A2

Measurement conditions (for Groove R1):

According to the technical protocol

- Nominal Value: 0,20 µm
- Tracing Length: 0,30 mm
- Stylus Tracking Force: 0,4 mN
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm
- Stylus Tip radius: 2 µm (diamond)

Other complementary data

- Vertical Range: ±25 µm
- Data Points: 600
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (for Groove R3):

According to the technical protocol

- Nominal Value: 1,50 µm
- Tracing Length: 0,50 mm
- Stylus Tracking Force: 0,4 mN
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm
- Stylus Tip radius: 2 µm (diamond)

Other complementary data

- Vertical Range: ±25 µm
- Data Points: 1000
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (for Groove R6):

According to the technical protocol

- Nominal Value: 8,00 µm
- Tracing Length: 1,00 mm
- Stylus Tracking Force: 0,4 mN
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm
- Stylus Tip radius: 2 µm (diamond)

Other complementary data

- Vertical Range: ±25 µm
- Data Points: 2000
- Temperature: 20 ºC ±0,5 ºC

Measurement results:

Groove R1	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	0,2	0,308	0,030	152
d (µm) (*)				

(*) Waiting for taking new measurements when receiving again the standard.

Groove R3	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	1,5	1,428	0,033	120
d (µm) (*)				

(*) Waiting for taking new measurements when receiving again the standard.

Groove R6	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	8,0	8,152	0,026	28
d (µm) (*)				

(*) Waiting for taking new measurements when receiving again the standard.

Uncertainty of measurement (DATASHEET 1)

Mathematical model:

$\boxed{H = f \cdot h + C_1(N)}$, with $\boxed{f = \frac{h_p}{h_m}}$

$$\boxed{u^2(f) = \left(\frac{\partial f}{\partial h_p}\right)^2 u^2(h_p) + \left(\frac{\partial f}{\partial h_m}\right)^2 u^2(h_m)}$$

$$\boxed{u^2(H) = \left(\frac{\partial H}{\partial f}\right)^2 u^2(f) + \left(\frac{\partial H}{\partial h}\right)^2 u^2(h) + u^2(C_1)}$$

$$\boxed{u^2(H) = \left(\frac{h}{h_m}\right)^2 u^2(h_p) + \left(\frac{h}{h_m}\right)^2 \left(\frac{h_p}{h_m}\right)^2 u^2(h_m) + \left(\frac{h_p}{h_m}\right)^2 u^2(h) + u^2(C_1) \cong u^2(h_p) + u^2(h_m) + u^2(h) + u^2(C_1)}$$

where,

f = calibration factor
h_p = certified value of the step height standard used for adjusting the measuring system
h_m = measured height on the step height standard with a calibration factor $f = 1$
h = measured height on the step/groove under calibration with a calibration factor $f = 1$
C_1 = correction by noise effect

Identification: groove R1

Quantity X_i	**Estimate** x_i	**Uncertainty** $u(x_i)$ **(µm)**	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** u_i *(Pt)* **(µm)**	**Degrees of freedom** ν_i
Amplification					0,0131	101
Calibrated step height standard	$P_t(1)$	0,013	N		0,013	100
Measurement on the groove standard	Pt_m		N		0,001	8
Dispersion	$s(Pt_m(1))$	*0,0013*	*N*			*8*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity	$P_t(2)$			1	0,0054	16
Dispersion	$s(Pt_m(2))$	*0,0054*	*N*			*16*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$C_1(N)$	0,027	R	1	0,027	100

Combined standard uncertainty: $u_c(Pt) = 0{,}030$ µm

Effective degrees of freedom: $\nu_{eff}\ (Pt) = 152$

Expanded uncertainty: ***U(Pt) = 0,060 µm*** with a coverage factor *k*=2

NOTES:

1. **Dispersion includes both homogenity of the sample and measurement repeatability**
2. **In rectangular distributions we always consider DoF =100. Acting so, we try to be conservative and avoiding using DoF = ∞ because its lack of physical meaning.**

Identification: groove R3

Quantity X_i	**Estimate** x_i	**Uncertainty** $u(x_i)$ **(µm)**	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(Pt)$ **(µm)**	**Degrees of freedom** ν_i
Amplification					0,005	103
Calibrated step height standard	*Pt(1)*	0,005	N		0,005	100
Measurement on the groove standard	Pt_m		N		0,001	5
Dispersion	$s(Pt_m(1))$	*0,001*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity					0,0107	16
Dispersion	$s(Pt_m(2))$	*0,0107*	*N*			*16*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$C_1(N)$	0,0310	R	1	0,0310	100

Combined standard uncertainty: $u_c(Pt) = 0,033$ µm

Effective degrees of freedom: $\nu_{eff}\ (Pt) = 120$

Expanded uncertainty: ***U(Pt) = 0,065* µm** with a coverage factor *k*=2

Identification: groove R6

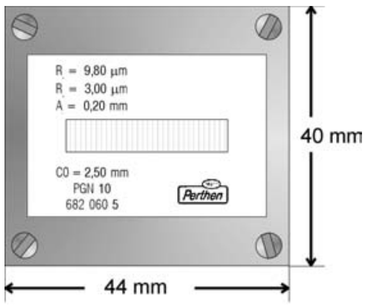
Quantity X_i	**Estimate** x_i	**Uncertainty** $u(x_i)$ **(µm)**	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(Pt)$ **(µm)**	**Degrees of freedom** ν_i
Amplification					0,023	17
Calibrated step height standard	Pt(1)	0,013	N		0,013	100
Measurement on the groove standard	Pt_m		N		0,019	8
Dispersion	$s(Pt_m(1))$	*0,0185*	*N*			*8*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity					0,0109	16
Dispersion	$s(Pt_m(2))$	*0,0109*	*N*			*16*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$C_1(N)$	0,0072	R	1	0,0072	100

Combined standard uncertainty: $u_c(Pt) = 0,026$ µm

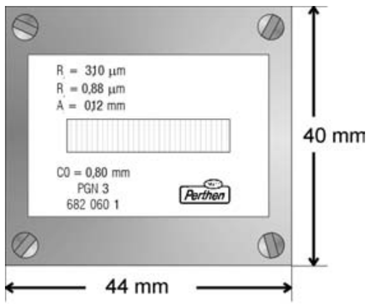
Effective degrees of freedom: $\nu_{eff}\ (Pt) = 28$

Expanded uncertainty: ***U(Pt) = 0,053* µm** with a coverage factor *k*=2

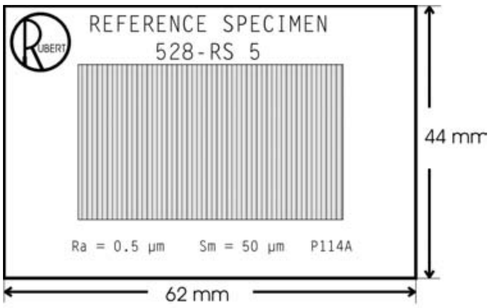
Measurement Report (DATASHEET 2)



Ref. 7070



Ref. 8194



Ref. P114A

Measurement conditions (Specimen 7070):

According to the technical protocol

- Sampling Spacing: 1,50 µm
- Evaluation Length: 12,50 mm
- Scan Speed: 0,50 mm/s
- Stylus Tip radius: 2 µm (diamond)
- Stylus Tracking Force: 0,4 mN
- Cut-off wavelength: 2,5 mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 17,50 mm
- Data Points: 11674
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (Specimen 8194):

According to the technical protocol

- Sampling Spacing: 0,50 µm
- Evaluation Length: 4,00 mm
- Scan Speed: 0,50 mm/s
- Stylus Tip radius: 2 µm (diamond)
- Stylus Tracking Force: 0,4 mN
- Cut-off wavelength: 0,8 mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 5,60 mm
- Data Points: 11200
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (Specimen P114A):

According to the technical protocol

- Sampling Spacing: 0,50 µm
- Evaluation Length: 1,25 mm
- Scan Speed: 0,50 mm/s
- Stylus Tip radius: 2 µm (diamond)
- Stylus Tracking Force: 0,4 mN
- Cut-off wavelength: 0,25 mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 1,75 mm
- Data Points: 3500
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement results:

Specimen 7070	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	3,00	2,909	0,085	94
Rz (µm)	9,80	9,476	0,093	128
Rmax (µm)		9,627	0,375	125
RSm (µm)	200	197,853	1,904	100

Specimen 8194	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	0,88	0,894	0,014	123
Rz (µm)	3,10	3,091	0,054	117
Rmax (µm)		3,113	0,110	104
RSm (µm)	120	118,719	3,427	100

Specimen P114A	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	0,5	0,491	0,002	12
Rz (µm)		1,575	0,017	101
Rmax (µm)		1,588	0,055	198
RSm (µm)	50	49,536	1,430	100

Uncertainty of measurement (Datasheet 2)

General comment:

The mathematical model shown in Datasheet 1 is basically valid for the different parameters obtained on the different standards, because the measurement process is maintained, independently of the sample type. We consider always four main uncertainty components (excluding temperature effects because the stability of the ambient conditions at the Lab.)

These uncertainty components are coming from:

a) a step height standard used for adjusting the amplification of the profiler (certified value)
b) measuring the certified step height standard (resolution + repeatability obtained)
c) measuring the sample (resolution +homogenity + repeatability, for each of the parameters)
d) noise effects (for each of the parameters, measuring on a flat glass, maintaining same measurement conditions as for the sample)

Between steps b) and c) we measure an own certified standard similar to the sample and with parameter values close to those of the sample to be measured in step c) (this is only possible for some typical parameters as *Ra*, *Rz* or *Rmax*. Other parameters are not typically certified).

We take into account any significative difference between the certified value and our result by applying a correction factor, taking also into account a fith uncertainty component due to this difference.

For instance, for a parameter *P*, we calculate the value $\Delta_P = \dfrac{\overline{P} - P_{certif}}{\overline{P}}$,

where

$\overline{P}$ is the mean value of the parameter, obtained on the certified standard, and
P_{certif} is the certified value of the parameter

From here we obtain a correction factor $C_P = \Delta_P \cdot \overline{\overline{P}}$, where $\overline{\overline{P}}$ is the great mean value obtained on the sample along several days. Its contribution to the uncertainty is $u(C_P) = \dfrac{C_P}{\sqrt{12}}$

<u>NOTE:</u> *P* may be *Ra*, *Rz*, *Rmax*, ...

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Uncertainty budgets for *Ra*

Identification: **7070**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0853**	**94**
Calibrated step height standard	P_t *(cert)*	*0,080*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity	**Ra(1)**			**1**	**0,0034**	**44**
Dispersion	$s(Ra_m(1))$	*0,003*	*N*			*44*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0011	R	**1**	**0,0011**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}085$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 94$

Expanded uncertainty: ***U(Ra) = 0,169* µm** with a coverage factor *k*=2

Identification: **8194**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,014**	**110**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,004*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity	**Ra(1)**			**1**	**0,001**	**53**
Dispersion	$s(Ra_m(1))$	*0,001*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,003	R	**1**	**0,003**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}014$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 123$

Expanded uncertainty: ***U(Ra) = 0,027* µm** with a coverage factor *k*=2

Identification: **P114A**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0015**	**6**
Calibrated step height standard	P_t *(cert)*	*0,0005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0014*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogenity	**Ra(1)**			**1**	**0,0004**	**131**
Dispersion	$s(Ra_m(1))$	*0,0003*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0009	R	**1**	**0,0009**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}002$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 12$

Expanded uncertainty: **$U(Ra) = 0{,}004$ µm** with a coverage factor k=2

Uncertainty budgets for *Rz*

Identification: **7070**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,085**	**94**
Calibrated step height standard	*P_t (cert)*	*0,080*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,006**	**47**
Dispersion	*$s(Rz_m(1))$*	*0,006*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,036	R	**1**	**0,036**	**100**

Combined standard uncertainty: $u_c(Rz) = 0{,}093$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rz) = 128$

Expanded uncertainty: ***U(Rz) = 0,182* µm** with a coverage factor *k*=2

Identification: **8194**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,014**	**110**
Calibrated step height standard	*P_t (cert)*	*0,013*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0038*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,007**	**47**
Dispersion	*$s(Rz_m(1))$*	*0,007*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0518	R	**1**	**0,0518**	**100**

Combined standard uncertainty: $u_c(Rz) = 0{,}054$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rz) = 117$

Expanded uncertainty: ***U(Rz) = 0,106* µm** with a coverage factor *k*=2

Identification: **P114A**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0014**	**5**
Calibrated step height standard	P_t *(cert)*	*0,0005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0014*	*N*			*5*
Resolution	*res*	*0,0003*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,0010**	**54**
Dispersion	$s(Rz_m(1))$	*0,0010*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0173	R	**1**	**0,0173**	**100**

Combined standard uncertainty: $u_c(Rz) = 0,017$ µm

Effective degrees of freedom: $\nu_{eff}(Rz) = 101$

Expanded uncertainty: ***U(Rz) = 0,034*** **µm** with a coverage factor *k*=2

Uncertainty budgets for *Rmax*

Identification: **7070**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rmax)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0853**	**94**
Calibrated step height standard	P_t *(cert)*	*0,080*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,3539**	**100**
Dispersion	$s(Rmax_m(1))$	*0,009*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Correction	*C(Rmax)*	*0,3538*				*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,090	R	**1**	**0,0904**	**100**

Combined standard uncertainty: $u_c\,(Rmax) = 0{,}375$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rmax) = 125$

Expanded uncertainty: ***U(Rmax) = 0,735*** **µm** with a coverage factor *k*=2

Identification: **8194**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rmax)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0135**	**110**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0038*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,008**	**47**
Dispersion	$s(Rmax_m(1))$	*0,008*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1086	R	**1**	**0,1086**	**100**

Combined standard uncertainty: $u_c\,(Rmax) = 0{,}110$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rmax) = 104$

Expanded uncertainty: ***U(Rmax) = 0,215*** **µm** with a coverage factor *k*=2

Identification: **P114A**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rmax)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0015**	**6**
Calibrated step height standard	P_t *(cert)*	*0,0005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0014*	*N*			*5*
Resolution	*res*	*2,89E-05*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,0369**	**100**
Dispersion	$s(Rmax_m(1))$	*0,0014*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Correction	*C(Rmax)*	*0,0369*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,0403	R	**1**	**0,0403**	**100**

Combined standard uncertainty: $u_c(Rmax) = 0,055$ µm

Effective degrees of freedom: $\nu_{eff}(Rmax) = 198$

Expanded uncertainty: ***U(Rmax) = 0,107* µm** with a coverage factor *k*=2

Uncertainty budgets for *RSm*

Identification: 7070

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(RSm)$ (µm)	Degrees of freedom ν_i
Sample homogeneity	**RSm(1)**			**1**	**0,0047**	**47**
Dispersion	$s(RSm_m(1))$	*0,005*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
movement accuracy				**1**	**1,9038**	**100**
x-axis		*1,9038*	*R*			

Combined standard uncertainty: $u_c(RSm) = 1,904$ µm

Effective degrees of freedom: ν_{eff} $(RSm) = 100$

Expanded uncertainty: ***U(RSm) = 3,808* µm** with a coverage factor *k*=2

Identification: 8194

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(RSm)$ (µm)	Degrees of freedom ν_i
Sample homogeneity	**RSm(1)**			**1**	**0,0067**	**47**
Dispersion	$s(RSm_m(1))$	*0,007*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
movement accuracy				**1**	**1,1424**	**100**
x-axis		*1,1424*	*R*			

Combined standard uncertainty: $u_c(RSm) = 3,427$ µm

Effective degrees of freedom: ν_{eff} $(RSm) = 100$

Expanded uncertainty: ***U(RSm) = 6,854* µm** with a coverage factor *k*=2

Identification: **P114A**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(RSm)$ (µm)	Degrees of freedom ν_i
Sample homogeneity	**RSm(1)**			**1**	**0,0067**	**44**
Dispersion	$s(RSm_m(1))$	*0,0067*	*N*			*44*
Resolution	*res*	*2,89E-04*	*R*			*100*
movement accuracy				**1**	**1,430**	**100**
x-axis		*1,430*	*R*			

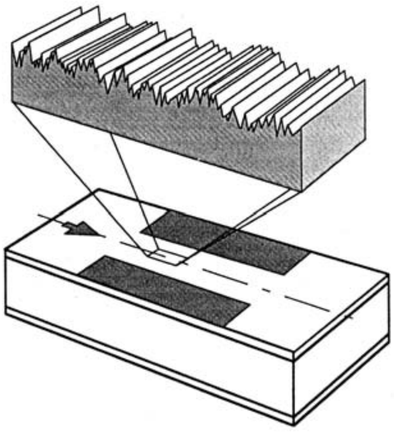
Combined standard uncertainty: $u_c\,(RSm) = 1{,}430$ µm

Effective degrees of freedom: $\nu_{eff}\ (RSm) = 100$

Expanded uncertainty: $U(RSm) = 2{,}860$ **µm** with a coverage factor k=2

Measurement Report (DATASHEET 3)

Roughness Standards of type D1 - Specimens: 629f, 633g and 686sg



Measurement conditions (Specimen: 629f):

According to the technical protocol

- *Sampling Spacing: 0,50* µm
- *Evaluation Length: 4,00* mm
- *Scan Speed: 0,50* mm/s
- *Stylus Tip radius: 2* µm *(diamond)*
- *Stylus Tracking Force: 0,4* mN
- *Cut-off wavelength: 0,8* mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 5,60 mm
- Data Points: 11200
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (Specimen: 633g):

According to the technical protocol

- *Sampling Spacing: 0,50* µm
- *Evaluation Length: 4,00* mm
- *Scan Speed: 0,50* mm/s
- *Stylus Tip radius: 2* µm *(diamond)*
- *Stylus Tracking Force: 0,4* mN
- *Cut-off wavelength: 0,8* mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 5,60 mm
- Data Points: 11200
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (Specimen: 686sg):

According to the technical protocol

- *Sampling Spacing: 1,50* µm
- *Evaluation Length: 12,50* mm
- *Scan Speed: 0,50* mm/s
- *Stylus Tip radius: 2* µm *(diamond)*
- *Stylus Tracking Force: 0,4* mN
- *Cut-off wavelength: 0,25* mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 17,50 mm
- Data Points: 11674
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement results:

Specimen 629f	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	0,2	0,146	0,006	171
Rz (µm)	1,5	1,248	0,052	105
Rmax (µm)		1,428	0,114	122
Rk (µm)		0,442	0,011	163
Rpk (µm)		0,133	0,008	140
Rvk (µm)		0,290	0,009	169

	measured value (%)	uncertainty u_c (%)	eff. DoF ν_{eff}
Mr1 (%)	9,33	0,144	143
Mr2 (%)	87,691	0,166	131

Specimen 633g	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	1,5	1,487	0,023	17
Rz (µm)	8,5	7,397	0,063	157
Rmax (µm)		8,743	0,340	123
Rk (µm)		4,320	0,057	12
Rpk (µm)		0,733	0,056	12
Rvk (µm)		2,433	0,056	12

Specimen 633g	measured value (%)	uncertainty u_c (%)	eff. DoF ν_{eff}
Mr1 (%)	6,311	0,131	118
Mr2 (%)	81,803	0,169	131

Specimen 686sg	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Ra (µm)	2,5	2,303	0,085	94
Rz (µm)	14	14,046	0,097	148
Rmax (µm)		15,297	0,576	109
Rk (µm)		7,930	0,035	50
Rpk (µm)		1,275	0,015	65
Rvk (µm)		3,110	0,029	51

Specimen 686sg	measured value (%)	uncertainty u_c (%)	eff. DoF ν_{eff}
Mr1 (%)	8,065	0,191	111
Mr2 (%)	92,839	0,230	133

Uncertainty of measurement (DATASHEET 3)

Uncertainty budgets for *Ra*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0052**	**104**
Calibrated step height standard	P_t *(cert)*	*0,0050*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0014*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Ra(1)**			**1**	**0,0005**	**103**
Dispersion	$s(Ra_m(1))$	*0,0004*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0031	R	**1**	**0,0031**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}006$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 171$

Expanded uncertainty: ***U(Ra) = 0,012* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0226**	**17**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0185*	*N*			*8*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Ra(1)**			**1**	**0,0014**	**51**
Dispersion	$s(Ra_m(1))$	*0,0014*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0031	R	**1**	**0,0031**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}023$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 17$

Expanded uncertainty: ***U(Ra) = 0,048* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0853**	**94**
Calibrated step height standard	P_t *(cert)*	*0,080*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Ra(1)**			**1**	**0,0044**	**47**
Dispersion	$s(Ra_m(1))$	*0,004*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0011	R	**1**	**0,0011**	**100**

Combined standard uncertainty: $u_c(Ra) = 0{,}085$ µm

Effective degrees of freedom: $\nu_{eff}(Ra) = 94$

Expanded uncertainty: ***U(Ra) = 0,169*** **µm** with a coverage factor *k*=2

Uncertainty budgets for *Rz*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0052**	**104**
Calibrated step height standard	*P_t (cert)*	*0,005*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0014*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,0064**	**47**
Dispersion	*$s(Rz_m(1)$*	*0,006*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0518	R	**1**	**0,0518**	**100**

Combined standard uncertainty: $u_c(Rz) = 0{,}052$ µm

Effective degrees of freedom: ν_{eff} *(Rz) = 105*

Expanded uncertainty: ***U(Rz) = 0,103* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0226**	**17**
Calibrated step height standard	*P_t (cert)*	*0,013*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0185*	*N*			*8*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,028**	**47**
Dispersion	*$s(Rz_m(1)$*	*0,028*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0518	R	**1**	**0,0518**	**100**

Combined standard uncertainty: $u_c(Rz) = 0{,}063$ µm

Effective degrees of freedom: ν_{eff} *(Rz) = 157*

Expanded uncertainty: ***U(Rz) = 0,125* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0853**	**94**
Calibrated step height standard	P_t *(cert)*	*0,080*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,028**	**47**
Dispersion	$s(Rz_m(1))$	*0,028*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C2(N)**	0,0362	R	**1**	**0,0362**	**100**

Combined standard uncertainty: $u_c(Rz) = 0{,}097$ µm

Effective degrees of freedom: $\nu_{eff}(Rz) = 148$

Expanded uncertainty: ***U(Rz) = 0,19* µm** with a coverage factor *k*=2

Uncertainty budgets for *Rmax*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution u_i *(Rmax)* (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0052**	**104**
Calibrated step height standard	*P_t (cert)*	*0,005*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0014*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,0362**	**131**
Dispersion	*$s(Rmax_m(1))$*	*0,0143*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Correction (Rmax)	*C(Rmax)*	*0,0332*	*R*			*100*
Datum/Noise	**C_2(N)**	0,1086	R	**1**	**0,1086**	**100**

Combined standard uncertainty: u_c *(Rmax)* = *0,114* µm

Effective degrees of freedom: ν_{eff} *(Rmax) = 122*

Expanded uncertainty: ***U(Rmax)* = *0,225* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution u_i *(Rmax)* (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,0226**	**17**
Calibrated step height standard	*P_t (cert)*	*0,013*	*N*			*100*
Dispersion	*$s(Pt_m)$*	*0,0185*	*N*			*8*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,3219**	**100**
Dispersion	*$s(Rmax_m(1)$*	*0,018*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Corrección (Rmax)	*C(Rmax)*	*0,3214*	*R*			*100*
Datum/Noise	**C_2(N)**	0,1086	R	**1**	**0,1086**	**100**

Combined standard uncertainty: u_c *(Rmax) = 0,340* µm

Effective degrees of freedom: ν_{eff} *(Rmax) = 123*

Expanded uncertainty: ***U(Rmax) = 0,667* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rmax)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,085**	**94**
Calibrated step height standard	P_t *(cert)*	*0,080*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,0295*	*N*			*5*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**0,5623**	**100**
Dispersion	$s(Rmax_m(1)$	*0,007*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Correccion (Rmax)	*C(Rmax9*	*0,562*	*R*			*100*
Datum/Noise	**C2(N)**	0,0904	R	**1**	**0,0904**	**100**

Combined standard uncertainty: $u_c(Rmax)$ = *0,576* µm

Effective degrees of freedom: ν_{eff} *(Rmax) = 109*

Expanded uncertainty: ***U(Rmax) = 1,129* µm** with a coverage factor *k*=2

Uncertainty budgets for *Rpk*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rpk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rpk(1)**			**1**	**0,001**	**59**
Dispersion	$s(Rpk_m(1)$	*0,001*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0046	R	**1**	**0,0046**	**100**

Combined standard uncertainty: $u_c(Rpk) = 0{,}008$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rpk) = 140$

Expanded uncertainty: ***U(Rpk)* = *0,015* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rpk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,056**	**12**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,054*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rpk(1)**			**1**	**0,005**	**47**
Dispersion	$s(Rpk_m(1)$	*0,005*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0046	R	**1**	**0,0046**	**100**

Combined standard uncertainty: $u_c(Rpk) = 0{,}056$ µm

Effective degrees of freedom: $\nu_{eff}\ (Rpk) = 12$

Expanded uncertainty: ***U(Rpk)* = *0,112* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rpk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rpk(1)**			**1**	**0,014**	**47**
Dispersion	$s(Rpk_m(1))$	*0,014*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,0009	R	**1**	**0,0009**	**100**

Combined standard uncertainty: $u_c(Rpk) = 0{,}015$ µm

Effective degrees of freedom: $\nu_{eff}(Rpk) = 65$

Expanded uncertainty: ***U(Rpk) = 0,030* µm** with a coverage factor *k*=2

Uncertainty budgets for *Rk*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rk(1)**			**1**	**0,001**	**52**
Dispersion	$s(Rk_m(1))$	*0,001*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0095	R	**1**	**0,0095**	**100**

Combined standard uncertainty: $u_c(Rk) = 0{,}011$ µm

Effective degrees of freedom: $\nu_{eff}(Rk) = 163$

Expanded uncertainty: ***U(Rk)* = *0,023* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,056**	**12**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,054*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rk(1)**			**1**	**0,01**	**47**
Dispersion	$s(Rk_m(1))$	*0,01*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0095	R	**1**	**0,0095**	**100**

Combined standard uncertainty: $u_c(Rk) = 0{,}057$ µm

Effective degrees of freedom: $\nu_{eff}(Rk) = 12$

Expanded uncertainty: ***U(Rk)* = *0,115* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rk(1)**			**1**	**0,034**	**47**
Dispersion	$s(Rk_m(1)$	*0,034*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0023	R	**1**	**0,0023**	**100**

Combined standard uncertainty: $u_c(Rk) = 0{,}035$ µm

Effective degrees of freedom: $\nu_{eff}(Rk) = 50$

Expanded uncertainty: ***U(Rk) = 0,070* µm** with a coverage factor *k*=2

Uncertainty budgets for *Rvk*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rvk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rvk(1)**			**1**	**0,001**	**50**
Dispersion	$s(Rvk_m)(1)$	*0,001*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0059	R	**1**	**0,0059**	**100**

Combined standard uncertainty: $u_c(Rvk) = 0{,}009$ µm

Effective degrees of freedom: ν_{eff} $(Rvk) = 169$

Expanded uncertainty: ***U(Rvk)* = *0,017* µm** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rvk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,056**	**12**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,054*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rvk(1)**			**1**	**0,007**	**47**
Dispersion	$s(Rvk_m)(1)$	*0,007*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0059	R	**1**	**0,0059**	**100**

Combined standard uncertainty: $u_c(Rvk) = 0{,}056$ µm

Effective degrees of freedom: ν_{eff} $(Rvk) = 12$

Expanded uncertainty: ***U(Rvk)* = *0,113* µm** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rvk)$ (µm)	Degrees of freedom v_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rvk(1)**			**1**	**0,028**	**47**
Dispersion	$s(Rvk_m)(1)$	*0,028*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0013	R	**1**	**0,0013**	**100**

Combined standard uncertainty: $u_c(Rvk) = 0,029$ µm

Effective degrees of freedom: $\nu_{eff}(Rvk) = 51$

Expanded uncertainty: ***U(Rvk) = 0,057*** µm with a coverage factor *k*=2

Uncertainty budgets for *Mr1*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr1)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	$\mathbf{R_{Mr1}(1)}$			**1**	**0,071**	**47**
Dispersion	$s(RMr_m(1)$	*0,071*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1248	R	**1**	**0,1248**	**100**

Combined standard uncertainty: $u_c(Mr1) = 0{,}144$ %

Effective degrees of freedom: ν_{eff} *(Mr1) = 143*

Expanded uncertainty: ***U(Mr1) = 0,288 %*** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr1)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,021**	**27**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,017*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	$\mathbf{R_{Mr1}(1)}$			**1**	**0,032**	**47**
Dispersion	$s(RMr_m(1)$	*0,032*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1248	R	**1**	**0,1248**	**100**

Combined standard uncertainty: $u_c(Mr1) = 0{,}131$ %

Effective degrees of freedom: ν_{eff} *(Mr1) = 118*

Expanded uncertainty: ***U(Mr1) = 0,26 %*** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr1)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,005**	**106**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	$\mathbf{R_{Mr1}(1)}$			**1**	**0,146**	**47**
Dispersion	$s(RMr_m(1)$	*0,146*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1231	R	**1**	**0,1231**	**100**

Combined standard uncertainty: $u_c(Mr1) = 0{,}191\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr1) = 111$

Expanded uncertainty: ***U(Mr1) = 0,382 %*** with a coverage factor *k*=2

Uncertainty budgets for *Mr2*

Identification: **629f**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr2)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	$\mathbf{R_{Mr2}(1)}$			**1**	**0,067**	**47**
Dispersion	$s(RMr_m(1)$	*0,067*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1519	R	**1**	**0,1519**	**100**

Combined standard uncertainty: $u_c(Mr2) = 0{,}166\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr2) = 131$

Expanded uncertainty: ***U(Mr2) = 0,332 %*** with a coverage factor *k*=2

Identification: **633g**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr2)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,056**	**12**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,054*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	$\mathbf{R_{Mr2}(1)}$			**1**	**0,050**	**47**
Dispersion	$s(RMr_m(1)$	*0,050*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	0,1519	R	**1**	**0,1519**	**100**

Combined standard uncertainty: $u_c(Mr2) = 0{,}169\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr2) = 131$

Expanded uncertainty: ***U(Mr2) = 0,339 %*** with a coverage factor *k*=2

Identification: **686sg**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr2)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,006**	**69**
Calibrated step height standard	P_t *(cert)*	*0,005*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,003*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**$R_{Mr2}(1)$**			**1**	**0,096**	**47**
Dispersion	$s(RMr_m(1))$	*0,096*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**$C_2(N)$**	0,2094	R	**1**	**0,2094**	**100**

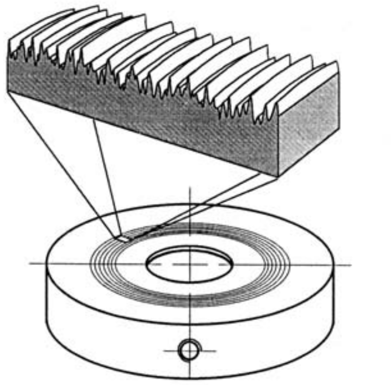
Combined standard uncertainty: $u_c(Mr2) = 0{,}230\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr2) = 133$

Expanded uncertainty: ***U(Mr2) = 0,461 %*** with a coverage factor *k*=2

Measurement Report (DATASHEET 4)

Superfine roughness standard of type D2 - Specimen SF 150



Measurement data (Specimen SF150):

According to the technical protocol

- *Sampling Spacing*: 0,50 µm
- *Evaluation Length*: 1,25 mm
- *Scan Speed*: 0,10 mm/s
- *Stylus Tip radius*: 2 µm *(diamond)*
- *Stylus Tracking Force*: 0,4 mN
- *Cut-off wavelength*: 0,8 mm

Other complementary data

- Vertical Range: ±25 µm
- Tracing Length: 1,75 mm
- Data Points: 3500
- Filter: GAUSS
- Temperature: 20 ºC ±0,5 ºC

Measurement results:

Specimen SF150	measured value (nm)	uncertainty u_c (nm)	eff. DoF ν_{eff}
***Ra* (nm)**	23,52	13	101
***Rz* (nm)**	133,29	16	182
***Rmax* (nm)**	172,90	19	207
***Rk* (nm)**	72,56	13	101
***Rpk* (nm)**	26,10	13	107
***Rvk* (nm)**	29,83	14	138
	measured value (%)	uncertainty u_c (%)	eff. DoF ν_{eff}
***Mr1* (%)**	11,862	0,099	48
***Mr2* (%)**	86,421	0,100	48

Uncertainty of measurement (DATASHEET 4)

Uncertainty budget for *Ra*

Identification: **SF 150**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (nm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Ra)$ (nm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**13,068**	**101**
Calibrated step height standard	P_t *(cert)*	*13,00*	*N*			*100*
Dispersion	$s(Pt_m)$	*1,303*	*N*			*8*
Resolution	*res*	*2,89E-01*	*R*			*100*
Sample homogeneity	**Ra(1)**			**1**	**0,299**	**114**
Dispersion	$s(Ra_m)(1))$	*0,0079*	*N*			*47*
Resolution	*res*	*2,89E-01*	*R*			*100*
Datum/Noise	**C_2(N)**	0,721	R	**1**	**0,721**	**100**

Combined standard uncertainty: $u_c(Ra) = 13{,}09$ *nm*

Effective degrees of freedom: $\nu_{eff}(Ra) = 101$

Expanded uncertainty: ***U(Ra)* = 25,66 nm** with a coverage factor *k*=2

Uncertainty budget for *Rz*

Identification: SF 150

Roughness standard with a nominal value of **Rz = 150 nm**

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (nm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rz)$ (nm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**13,070**	**101**
Calibrated step height standard	P_t *(cert)*	*13,00*	*N*			*100*
Dispersion	$s(Pt_m)$	*1,303*	*N*			*8*
Resolution	*res*	*0,289*	*R*			*100*
Sample homogeneity	**Rz(1)**			**1**	**0,7071**	**66**
Dispersion	$s(Rz_m)(1)$	*0,645*	*N*			*47*
Resolution	*res*	*0,289*	*R*			*100*
Datum/Noise	$\mathbf{C_2(N)}$	9,310	R	**1**	**9,310**	**100**

Combined standard uncertainty: $u_c(Rz) = 16{,}05$ nm

Effective degrees of freedom: $\nu_{eff}(Rz) = 182$

Expanded uncertainty: ***U(Rz) = 31,45*** **nm** with a coverage factor *k*=2

Uncertainty budget for *Rmax*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (nm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rmax)$ (nm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**13,07**	**101**
Calibrated step height standard	P_t *(cert)*	*13,00*	*N*			*100*
Dispersion	$s(Pt_m)$	*1,303*				*8*
Resolution	*res*	*0,289*	*r*			*100*
Sample homogeneity	**Rmax(1)**			**1**	**2,408**	**48**
Dispersion	$s(Rmax_m(1)$	*2,391*	*N*			*47*
Resolution	*res*	*0,289*	*R*			*100*
Datum/Noise	**C_2(N)**	13,40	R	**1**	**13,40**	**100**

Combined standard uncertainty: $u_c(Rmax) = 18{,}87$ nm

Effective degrees of freedom: $\nu_{eff}(Rmax) = 207$

Expanded uncertainty: ***U(Rmax)* = 37 nm** with a coverage factor *k*=2

Uncertainty budget for *Rpk*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rpk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,013**	**101**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rpk(1)**			**1**	**0,0003**	**144**
Dispersion	$s(Rpk_m)(1)$	*0,0002*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0023	R	**1**	**0,0023**	**100**

Combined standard uncertainty: $u_c(Rpk) = 13$ *nm*

Effective degrees of freedom: $\nu_{eff}(Rpk) = 107$

Expanded uncertainty: ***U(Rpk)* =*27* nm** with a coverage factor *k*=2

Uncertainty budget for *Rk*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rk)$ (µm)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,013**	**101**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rk(1)**			**1**	**0,0006**	**83**
Dispersion	$s(Rk_m)(1)$	*0,0005*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0002	R	**1**	**0,0002**	**100**

Combined standard uncertainty: $u_c(Rk) = 13$ *nm*

Effective degrees of freedom: $\nu_{eff}(Rk) = 101$

Expanded uncertainty: ***U(Rk)* = *26* nm** with a coverage factor *k*=2

Uncertainty budgets for *Rvk*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (µm)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Rk)$ (µm)	Degrees of freedom v_i
Amplification	**C1(Ampl)**			**1**	**0,013**	**101**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Rvk(1)**			**1**	**0,0004**	**124**
Dispersion	$s(Rvk_m)(1)$	*0,0003*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0057	R	**1**	**0,0057**	**100**

Combined standard uncertainty: $u_c(Rvk) = 14$ nm

Effective degrees of freedom: $\nu_{eff}(Rvk) = 138$

Expanded uncertainty: ***U(Rvk) = 29 nm*** with a coverage factor k=2

Uncertainty budget for *Mr1*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr1)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,013**	**101**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Mr1(1)**			**1**	**0,099**	**83**
Dispersion	$s(Mr_m)(1)$	*0,0985*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0005	R	**1**	**0,0002**	**100**

Combined standard uncertainty: $u_c(Mr1) = 0{,}099\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr1) = 48$

Expanded uncertainty: ***U(Mr1) = 0,2 %*** with a coverage factor *k*=2

Uncertainty budget for *Mr2*

Identification: SF 150

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$ (%)	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(Mr2)$ (%)	Degrees of freedom ν_i
Amplification	**C1(Ampl)**			**1**	**0,013**	**101**
Calibrated step height standard	P_t *(cert)*	*0,013*	*N*			*100*
Dispersion	$s(Pt_m)$	*0,001*	*N*			*11*
Resolution	*res*	*2,89E-04*	*R*			*100*
Sample homogeneity	**Mr2(1)**			**1**	**0,099**	**83**
Dispersion	$s(Mr_m)(1)$	*0,0994*	*N*			*47*
Resolution	*res*	*2,89E-04*	*R*			*100*
Datum/Noise	**C_2(N)**	0,0005	R	**1**	**0,0002**	**100**

Combined standard uncertainty: $u_c(Mr2) = 0{,}1\ \%$

Effective degrees of freedom: $\nu_{eff}\ (Mr2) = 48$

Expanded uncertainty: ***U(Mr2) = 0,2 %*** with a coverage factor *k*=2

Laboratory: Centro Español de Metrología (CEM) - SPAIN

Date: March 2002

Signature:

Nuria Galán

Nuria Galán
Lab. Technician

Revised and Approved:

Emilio Prieto
Head of Length Area

17/10/2002

Centro Español de Metrología

Comparison of Surface Texture Measurements

EUROMET Project: 600

Results obtained by

Stylus Profiler

New measurements on grooves R1, R3 and R6

(Parameters ***Pt*** and ***d***)

Emilio Prieto

24th March 2003

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Description of the measurement instruments:

There were used two commercial contact-stylus profilers, a **Perthometer Concept** from Mahr™ and a **Dektak-3ST** from Veeco™; the last one exclusively for measuring R1, R3 and R6 grooves. These instruments work according to the standardized profile method, following approved written standards.

Along with the Perthometer it was used a high precision drive unit PRK and skidless pick-ups with radii indicated in the technical protocol of the comparison. With the Dektak there was used a 2,5 µm stylus, the closest one to the value indicated in the technical protocol.

It was also used an isolated measurement area and table along with strict and stable ambient conditions.

To obtain and analize data there were used the instruments' resident software plus a Talymap Universal 2.0.

Measurement Method:

There were measured several significant profiles distributed on the standard according to the instructions of the technical report for the different standards.

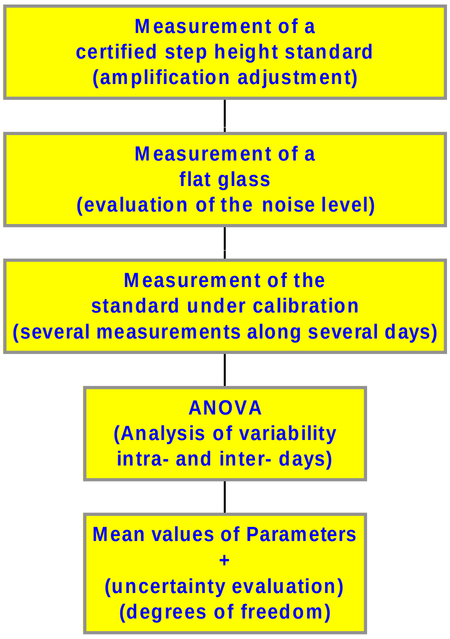
Vertical amplification of the instrument always adjusted by means of a depth setting standard type A1 with a certified value close to the nominal *d*/*Pt* (steps/grooves) or *Rz* (roughness) value of the standard to be measured.

Noise influence evaluated by measuring parameters on a flat glass with the same measurement conditions established as for the different standards.

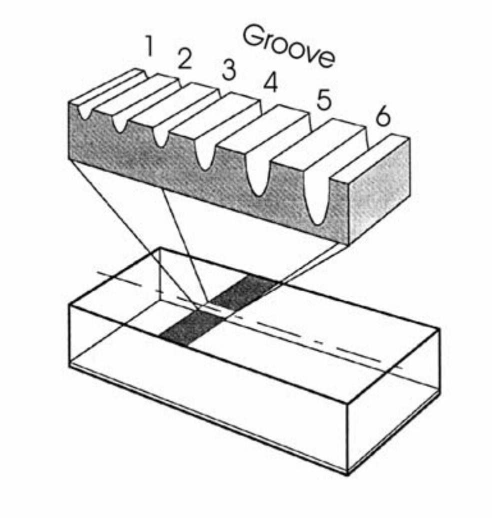
Before measurements, alignment of the measurement plane of the step/standard with respect to the reference surface, in order to obtain the best internal alignment of all profiles.

Measurement results and uncertainty evaluation following GUM document after applying ANOVA method in order to identify and quantify random individual effects.

Scheme of the measurement process
(for steps, grooves & roughness standards)



Measurement Report (DATASHEET 1)



Depth setting standard type A2

Measurement conditions (for Groove R1):

According to the technical protocol

- Nominal Value: 0,20 µm
- Tracing Length: 0,30 mm
- Stylus Tracking Force: **0,9 mN**
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm

Stylus Tip radius: **2,5 µm** (diamond)

Other complementary data

- Vertical Range: 65,5 µm
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (for Groove R3):

According to the technical protocol

- Nominal Value: 1,50 µm
- Tracing Length: 0,50 mm
- Stylus Tracking Force: **0,9 mN**
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm

Stylus Tip radius: **2,5 µm** (diamond)

Other complementary data

- Vertical Range: 65,5 µm
- Temperature: 20 ºC ±0,5 ºC

Measurement conditions (for Groove R6):

According to the technical protocol

- Nominal Value: 8,00 µm
- Tracing Length: 1,00 mm
- Stylus Tracking Force: **0,9 mN**
- Scan Speed: 0,10 mm/s
- Sampling Spacing: 0,50 µm
- Stylus Tip radius: **2,5 µm** (diamond)

Other complementary data

- Vertical Range: 65,5 µm
- Temperature: 20 ºC ±0,5 ºC

Measurement results:

Groove R1	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	0,2	0,284	0,005	107
d (µm)		0,277	0,005	107

Groove R3	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	1,5	1,360	0,005	103
d (µm)		1,358	0,005	103

Groove R6	nominal value (µm)	measured value (µm)	uncertainty u_c (µm)	eff. DoF ν_{eff}
Pt (µm)	8,0	8,329	0,006	150
d (µm)		8,315	0,006	150

Uncertainty of measurement (DATASHEET 1)

Mathematical model:

$$Pt = C_1(Adjust.) + \mathrm{Pt}(1) + C_2(N)$$

C_1(*Adjust.*) = Correction by equipment adjustment (calibration data of the step standard plus measurement results)
Pt(1) or *d*(1) = mean value obtained when measuring the step/groove under calibration
C_2(N) = correction by noise effects (after measuring a flat glass)

Identification: groove R1

Quantity X_i	symbol	value	units	probability distribution	standard uncertainties		degrees of freedom, υ		sensitivity coefficients	uncertainty contribution to		degrees of freedom υ	relative weight (in %)
					$u(x_i)$	$u_c(x_i)$	partial	total		$u_i(Pt)$	units		
C_1 Equipment adjustment						0,005 µm		102	1	0,005	µm	102	97,36
step certified value	hp	0,01	µm	normal (k=2)	0,005 µm		100						
dispersion	s(hm)	1,00E-03	µm	normal	4,47E-04 µm		5						
resolution	r(eq)	0,001	µm	rectangular	2,89E-04 µm		100						
Sample homogenity						0,001 µm		13	1	0,001	µm	13	2,32
dispersion and homogenity	s(Pt(1))	0,002	µm	normal	0,001 µm		10						
resolution	r(eq)	0,001	µm	rectangular	2,89E-04 µm		100						
C_2 (noise)	C_2 (N)	0,001	µm	rectangular		0,000 µm	100	100	1	0,000	µm	100	0,32
										u_c = 0,005		**υ = 107**	Σ = 100,00

Combined standard uncertainty: $u_c\,(Pt\,/\,d) = 0{,}005$ µm

Effective degrees of freedom: $\nu_{eff}\ (Pt\,/\,d) = 107$

Expanded uncertainty: **$U(Pt\,/\,d) = 0{,}01$ µm** with a coverage factor k = 2

NOTES:

1. **Dispersion includes both homogenity of the sample and measurement repeatability**
2. **In rectangular distributions we always consider DoF =100. Acting so, we try to be conservative and avoiding using DoF = ∞ because its lack of physical meaning.**

Identification: groove R3

Quantity X_i	symbol	value	units	probability distribution	standard uncertainties		degrees of freedom, υ		sensitivity coefficients	uncertainty contribution to		degrees of freedom	relative weight
					$u(x_i)$	$u_c(x_i)$	partial	total		$u_i(Pt)$	units	υ	(in %)
C_1 Equipment adjustment						0,005 µm		102	1	0,005	µm	102	99,35
step certified value	hp	0,01	µm	normal(k=2)	0,01 µm		100						
dispersion	s(hm)	1,00E-03	µm	normal	4,47E-04 µm		5						
resolution	r(eq)	0,001	µm	rectangular	2,89E-04 µm		100						
Sample homogenity						0,000 µm		100	1	0,000	µm	100	0,33
dispersion and homogenity	s(Pt(1))	0,000	µm	normal	0,000 µm		9						
resolution	r(eq)	0,001	µm	rectangular	2,89E-04 µm		100						
C_2 (noise)	C_2 (N)	0,001	µm	rectangular		0,000 µm	100	100	1	0,000	µm	100	0,33

Σ = 100,00

u_c = 0,005	υ = 103

Combined standard uncertainty: $u_c\,(Pt\,/\,d) = 0{,}005$ µm

Effective degrees of freedom: $\nu_{eff}\;(Pt\,/\,d) = 103$

Expanded uncertainty: ***U(Pt / d) = 0,01 µm*** with a coverage factor *k* = 2

Identification: groove R6

Quantity X_i	symbol	value	units	probability distribution	standard uncertainties		degrees of freedom, υ		sensitivity coefficients	uncertainty contribution to		degrees of freedom	relative weight
					$u(x_i)$	$u_c(x_i)$	partial	total		$u_i(Pt)$	units	υ	(in %)
C_1 Equipment adjustment						0,005 µm		102	1	0,005	µm	102	63,24
step certified value	hp	0,01	µm	normal(k=2)	0,01 µm		100						
dispersion	s(hm)	1,00E-03	µm	normal	4,47E-04 µm		5						
resolution	r(eq)	0,001	µm	rectangular	2,89E-04 µm		100						
Sample homogenity						0,004 µm		49	1	0,004	µm	49	36,55
dispersion and homogenity	s(Pt(1))	0,008	µm	normal	0,003 µm		11						
resolution	r(eq)	0,010	µm	rectangular	2,89E-03 µm		100						
C_2 (noise)	C_2 (N)	0,001	µm	rectangular		0,000 µm	100	100	1	0,000	µm	100	0,21

Σ = 100,00

u_c = 0,006	υ = 150

Combined standard uncertainty: $u_c\,(Pt\,/\,d) = 0{,}006$ µm

Effective degrees of freedom: $\nu_{eff}\;(Pt\,/\,d) = 150$

Expanded uncertainty: ***U(Pt / d) = 0,012 µm*** with a coverage factor *k* = 2

Comment from CEM

At page 25/33, in Table 7, the comments on our results are true, but it is a little bit difficult to investigate on why such values. Because the existence of other uncertainty components, even when increasing the standard deviation, it is possible to get lower final uncertainty.

The contribution of the standard deviation is very small because it is divided by the number of measurements and this number may be different on different standards. Moreover, the A1 type standard used for adjusting the measurement equipment has different uncertainty depending on the value to be measured and this is another important contribution to the final uncertainty.

With respect to the comment at the end of the paragraph 8.3.2 it would be necessary to investigate much more on this item but unfortunately we did not have to much time to do it.

Appendix B1

Reports of CGM

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments ....

....

Instrument: Taylor Hobson Talysurf 5-120 stylus instrument equipped with a Heidenhain scale on x-axis enabling sampling on position. PC based acquisition and control system with 12-Bit A/D converter and a capacity of 10200 samples in one trace.

Working principle: Continuously moving stylus

Data Collection: 2 µm radius stylus tip, sampling is made while stylus moving at equal steps in x- position. 10 different analog vertical measuring ranges, the range is chosen for each task as the minimum possible taken waviness and form error into account.

Data Evaluation: Data is evaluated as evaluated as “raw data” that is; no compensation for reference plane and linearity correction is made. The software used is in the evaluation: RCS4G ver 2.0 “Roughness Calibration Software” developed by CGM.

Characteristion of instrument: The instrument has a background noise level Rzo between 30 and 58 nm measured on an optical flat depending on measuring range and speed.................

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Environmental characterisation: **The instrument is placed in a clima controlled measuring lab situated basement level the measurement table is mounted on its own ground vibration isolated from the floor and walls in the room.**

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A4 - Uncertainty of measurement

Step height standard with a nominal height of 1.5 µm:
Identification: EN 806 Groove 1

Equation used: $d = C*(d_{meas}) + \partial(d)_{unlinarity} + \partial(d)_{resol} + \partial(d)_{residual}$

$$u^2(d) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta_d)$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ nm	degrees of freedom v_i
Dref	155	3.5	normal	1	3.5	∞
ΔDlocus	2	1.155	rectangular	1	1.2	∞
ΔDrepeat	0.31	0.31	normal	1	0.3	11
δunlinarity	9.6	6	rectangular	1	5.5	∞
δresol	0.10	0	digital	1	0.0	∞
δresidual	53	15	triangular	1	15.3	5
δ (d)	4	2	normal	1	1.8	4

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 17

Effective degree of freedom: $v_{eff}(d)$ = ∞

Expanded uncertainty: $U(d)$ = **34** with a coverage factor k=2

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A4 - Uncertainty of measurement

Step height standard with a nominal height of 1.5 µm:
Identification: EN 806 Groove 3

Equation used: $d = C * (d_{meas}) + \partial(d)_{unlinarity} + \partial(d)_{resol} + \partial(d)_{residual}$

$$u^2(d) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta_d)\ ^{\mathrm{i}}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ nm	degrees of freedom v_i
Dref	1110	6	normal	1	6.0	∞
ΔDlocus	3	1.732	rectangular	1	1.7	∞
ΔDrepeat	2.22	2.22	normal	1	2.2	11
δunlinarity	24.452	14	rectangular	1	14.1	∞
δresol	0.49	0	digital	1	0.1	∞
δresidual	50	14	triangular	1	14.4	5
δ (d)	5	2	normal	1	2.2	4

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 21

Effective degree of freedom: $v_{eff}\ (d)$ = ∞

Expanded uncertainty: $U(d)$ = **43** with a coverage factor k=2

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A4 - Uncertainty of measurement

Step height standard with a nominal height of 8_ nm: Identification: EN 806 Groove 6

Equation used: $d = C*(d_{meas}) + \partial(d)_{unlinarity} + \partial(d)_{resol} + \partial(d)_{residual}$

$$u^2(d) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta_d)$$ [ii]

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14	rectangular	1	14.5	∞
δresol	4.88	1	digital	1	1.4	∞
δresidual	68	20	triangular	1	19.6	5
δ (d)	16	7	normal	1	7.2	4

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 34

Effective degree of freedom: $v_{eff}(d)$ = ∞

Expanded uncertainty: $U(d)$ = **69** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Ra of 0.5 µm:
Identification: P114A/528-RS

Equation used: $Ra = C*(Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom v_i
Dref	2682	12.5	normal	1	12.5	∞
ΔDlocus	15	8.660	rectangular	1	8.7	∞
ΔDrepeat	5.364	5.364	normal	1	5.4	11
δunlinarity	11.50	6.6	rectangular	1	6.6	∞
δresol	0.98	0.3	digital	1	0.3	∞
δresidual	9	2.6	triangular	1	2.6	5
δ (Ra)	2	0.6	normal	1	0.6	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra) = 18$

Effective degree of freedom: $v_{\text{eff}}\,(Ra) = \infty$

Expanded uncertainty: $U(Ra) = $ **35** with a coverage factor k=2

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[i] A4 - Uncertainty of measurement

Geometri standard with a nominal Rz of 1.6 µm:
Identification: P114A/528-RS

Equation used: $Rz = C*(Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	2682	10	normal	1	10.0	∞
ΔDlocus	15	8.660	rectangular	1	8.7	∞
ΔDrepeat	5.364	5.364	normal	1	5.4	11
δunlinarity	11.50	6.6	rectangular	1	6.6	∞
δresol	0.98	0.3	digital	1	0.3	∞
δresidual	56	16.2	triangular	1	16.2	5
δ (Rz)	6	1.7	normal	1	1.7	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 23$

Effective degree of freedom: $v_{eff}(Rz) = \infty$

Expanded uncertainty: $U(Rz) =$ **45** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Rsm of 50 µm:
Identification: P114A/528-RS

Equation used: $Rsm = \frac{1}{n} \cdot \sum_n \Delta x_n$

$$u^2(Rsm) = 2*\{\ u^2(Rsm, ref)\ +\ u^2(Rsm, resol)\ +\ \frac{1}{12} \cdot s^2(\overline{Rsm})\ +\ \frac{1}{12} \cdot (\frac{w}{h} \cdot Rz_0)^2\ + \frac{1}{12} \cdot (\frac{1}{4} \cdot \frac{w}{h} \cdot Wt_0)^2\ \}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rsm)$ nm	degrees of freedom ν_i
Rsm,ref	10000	200	normal	1.00	200.0	11
Rsm,resol	200	57.7	digital	1	57.7	∞
Wto	150	43.3	rectangular	1.00	43.3	∞
Rzo	56	64.7	rectangular	1.00	64.7	∞
S(Rsm)	191	55.1	normal	1.00	55.1	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rsm)$= 324

Effective degree of freedom: ν_{eff} (Rsm)= ∞

Expanded uncertainty: $U(sm)$ = **648** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Ra of 3 µm:
Identification: 7070/PGN10

Equation used: $Ra = C*(Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14	rectangular	1	14.5	∞
δresol	4.88	1	digital	1	1.4	∞
δresidual	10	3	triangular	1	2.9	5
δ (Ra)	10	4	normal	1	4.5	4

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra)$ = 28

Effective degree of freedom: v_{eff} (Ra)= ∞

Expanded uncertainty: $U(Ra)$ = **56** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Rz of 10 µm:
Identification: 7070/PGN10

Equation used: $Rz = C*(Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14.5	rectangular	1	14.5	∞
δresol	4.88	1.4	digital	1	1.4	∞
δresidual	68	19.6	triangular	1	19.6	5
δ (Rz)	34	9.8	normal	1	9.8	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 35$

Effective degree of freedom: $v_{eff}(Rz) = \infty$

Expanded uncertainty: $U(Rz) = \mathbf{70}$ with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Rsm of 200 µm:
Identification: 7070/PGN10

Equation used: $Rsm = \frac{1}{n} \cdot \sum_{n} \Delta x_n$

$$u^2(Rsm) = 2*\{\ u^2(Rsm, ref) + u^2(Rsm, resol) + \frac{1}{12} \cdot s^2(\overline{Rsm}) + \frac{1}{12} \cdot (\frac{w}{h} \cdot Rz_0)^2 + \frac{1}{12} \cdot (\frac{1}{4} \cdot \frac{w}{h} \cdot Wt_0)^2\ \}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rsm)$ nm	degrees of freedom ν_i
Rsm,ref	10000	200	normal	1	200.0	11
Rsm,resol	1500	433.0	digital	1	433.0	∞
Wto	150	43.3	rectangular	1	43.3	∞
Rzo	68	78.5	rectangular	1	78.5	∞
S(Rsm)	140	40.4	normal	1	40.4	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rsm) = 689$

Effective degree of freedom: $\nu_{\text{eff}}\ (Rsm) = \infty$

Expanded uncertainty: $U(sm) = \mathbf{1377}$ with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Ra of 0.9 µm:
Identification: 8194/PGN3

Equation used: $Ra = C*(Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom ν_i
Dref	5803	10	normal	1	10.0	∞
ΔDlocus	6.5	3.753	rectangular	1	3.8	∞
ΔDrepeat	11.606	11.606	normal	1	11.6	11
δunlinarity	34.10	19.7	rectangular	1	19.7	∞
δresol	1.95	0.6	digital	1	0.6	∞
δresidual	8	2.3	triangular	1	2.3	5
δ (Ra)	10	2.9	normal	1	2.9	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra) = 26$

Effective degree of freedom: $\nu_{eff}\ (Ra) = \infty$

Expanded uncertainty: $U(Ra) =$ **51** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Rz of 3 µm:
Identification: 8194/PGN3

Equation used: $Rz = C*(Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	5803	10	normal	1	10.0	∞
ΔDlocus	6.5	3.753	rectangular	1	3.8	∞
ΔDrepeat	11.606	11.606	normal	1	11.6	11
δunlinarity	34.10	19.7	rectangular	1	19.7	∞
δresol	1.95	0.6	digital	1	0.6	∞
δresidual	49	14.1	triangular	1	14.1	5
δ (Rz)	48	13.9	normal	1	13.9	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 32$

Effective degree of freedom: $v_{eff}(Rz) = \infty$

Expanded uncertainty: $U(Rz) = $ **64** with a coverage factor k=2

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A4 - Uncertainty of measurement

Geometri standard with a nominal Rsm of 118 µm:
Identification: 8194/PGN3

Equation used: $Rsm = \frac{1}{n} \cdot \sum_{n} \Delta x_n$

$$u^2(Rsm) = 2*\{\ u^2(Rsm, ref)\ +\ u^2(Rsm, resol)\ +\ \frac{1}{12} \cdot s^2(\overline{Rsm})\ \ +\ \frac{1}{12} \cdot (\frac{w}{h} \cdot Rz_0)^2\ +$$
$$\frac{1}{12} \cdot (\frac{1}{4} \cdot \frac{w}{h} \cdot Wt_0)^2\ \}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rsm)$ nm	degrees of freedom v_i
Rsm,ref	10000	200	normal	1	200.0	11
Rsm,resol	500	144.3	digital	1	144.3	∞
Wto	150	43.3	rectangular	1	43.3	∞
Rzo	49	56.6	rectangular	1	56.6	∞
S(Rsm)	1052	303.7	normal	1	303.7	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rsm)$= 562

Effective degree of freedom: $v_{eff}\ (Rsm)$= ∞

Expanded uncertainty: $U(sm)$ = **1125** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Ra of 0.15 µm:
Identification: 629f

Equation used: $Ra = C * (Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Dref	2682	12.5	normal	1	12.5	∞
ΔDlocus	15	8.660	rectangular	1	8.7	∞
ΔDrepeat	5.364	5.364	normal	1	5.4	11
δunlinarity	11.50	6.6	rectangular	1	6.6	∞
δresol	0.98	0.3	digital	1	0.3	∞
δresidual	9	2.6	triangular	1	2.6	5
δ (Ra)	4	1.2	normal	1	1.2	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra)$ = 18

Effective degree of freedom: ν_{eff} (Ra)= ∞

Expanded uncertainty: $U(Ra)$ = **35** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 1.2 µm: Identification: 629f

Equation used: $Rz = C * (Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	2682	10	normal	1	10.0	∞
ΔDlocus	15	8.660	rectangular	1	8.7	∞
ΔDrepeat	5.364	5.364	normal	1	5.4	11
δunlinarity	11.50	6.6	rectangular	1	6.6	∞
δresol	0.98	0.3	digital	1	0.3	∞
δresidual	56	16.2	triangular	1	16.2	5
δ (Rz)	41	11.8	normal	1	11.8	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz)$ = 25

Effective degree of freedom: v_{eff} (Rz)= ∞

Expanded uncertainty: $U(Rz)$ = **51** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 1.24 µm:
Identification: 629f Rk

Equation used: $Rk = C * (Rk_{meas}) + \partial(Rk)_{unlinarity} + \partial(Rk)_{resol} + \partial(Rk)_{residual}$

$$u^2(Rk) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rk))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	Sensitivity coefficient c_i	uncertainty contribution $u_i(Rk)$ nm	degrees of freedom v_i
Dref	2682	12.5	normal	1	12.5	∞
ΔDlocus	15	8.660	rectangular	1	8.7	∞
ΔDrepeat	5.364	5.364	normal	1	5.4	11
δunlinarity	11.50	6.6	rectangular	1	6.6	∞
δresol	0.98	0.3	digital	1	0.3	∞
δresidual	26	7.5	triangular	1	7.5	5
δ (Rk)	12	3.5	normal	1	3.5	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rk) = 19$

Effective degree of freedom: $v_{eff}(Rk) = \infty$

Expanded uncertainty: $U(Rk)$ = **39** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Ra of 1.5 µm:
Identification: 633g

Equation used: $Ra = C * (Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom ν_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14.5	rectangular	1	14.5	∞
δresol	4.88	1.4	digital	1	1.4	∞
δresidual	10	2.9	triangular	1	2.9	5
δ (Ra)	4	1.2	normal	1	1.2	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra) = 28$

Effective degree of freedom: $\nu_{eff}(Ra) = \infty$

Expanded uncertainty: $U(Ra) = 55$ with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 7.45 µm:
Identification: 633g

Equation used: $Rz = C * (Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14.5	rectangular	1	14.5	∞
δresol	4.88	1.4	digital	1	1.4	∞
δresidual	68	19.6	triangular	1	19.6	5
δ (Rz)	259	74.8	normal	1	74.8	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 42$

Effective degree of freedom: $v_{eff}(Rz) = \infty$

Expanded uncertainty: $U(Rz) = $ **84** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 7.5 µm:
Identification: 633g Rk

Equation used: $Rk = C*(Rk_{meas}) + \partial(Rk)_{unlinarity} + \partial(Rk)_{resol} + \partial(Rk)_{residual}$

$$u^2(Rk) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rk))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	Sensitivity coefficient c_i	uncertainty contribution $u_i(Rk)$ nm	degrees of freedom ν_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.05	14.5	rectangular	1	14.5	∞
δresol	4.88	1.4	digital	1	1.4	∞
δresidual	34	9.8	triangular	1	9.8	5
δ (Rk)	19	5.5	normal	1	5.5	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rk) = 30$

Effective degree of freedom: $\nu_{eff}\ (Rk) = \infty$

Expanded uncertainty: $U(Rk)$ = **59** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Ra of 2.34 µm:
Identification: 686sg

Equation used: $Ra = C * (Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.90	15.0	rectangular	1	15.0	∞
δresol	9.77	2.8	digital	1	2.8	∞
δresidual	9	2.6	triangular	1	2.6	5
δ (Ra)	19	5.5	normal	1	5.5	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra) = 28$

Effective degree of freedom: $v_{eff}(Ra) = \infty$

Expanded uncertainty: $U(Ra) = $ **57** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 14 µm:
Identification: 686sg

Equation used: $Rz = C*(Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom v_i
Dref	9300	12.5	Normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	Normal	1	18.6	11
δunlinarity	25.90	15.0	rectangular	1	15.0	∞
δresol	9.77	2.8	Digital	1	2.8	∞
δresidual	68	19.6	Triangular	1	19.6	5
δ (Rz)	326	94.1	normal	1	94.1	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 100$

Effective degree of freedom: $v_{eff}(Rz) = \infty$

Expanded uncertainty: $U(Rz) = \mathbf{200}$ with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard with a nominal Rz of 14 µm:
Identification: 686sg Rk

Equation used: $Rk = C*(Rk_{meas}) + \partial(Rk)_{unlinarity} + \partial(Rk)_{resol} + \partial(Rk)_{residual}$

$$u^2(Rk) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rk))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	Sensitivity coefficient c_i	uncertainty contribution u_i(Rk) nm	degrees of freedom v_i
Dref	9300	12.5	normal	1	12.5	∞
ΔDlocus	10	5.774	rectangular	1	5.8	∞
ΔDrepeat	18.6	18.6	normal	1	18.6	11
δunlinarity	25.90	15.0	rectangular	1	15.0	∞
δresol	9.77	2.8	digital	1	2.8	∞
δresidual	34	9.8	triangular	1	9.8	5
δ (Rk)	109	31.5	normal	1	31.5	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rk) = 43$

Effective degree of freedom: $v_{eff}\ (Rk) = \infty$

Expanded uncertainty: $U(Rk) =$ **86** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard type D2 with a Ra of 0.026 µm:
Identification: SFRN 150

Equation used: $Ra = C * (Ra_{meas}) + \partial(Ra)_{unlinarity} + \partial(Ra)_{resol} + \partial(Ra)_{residual}$

$$u^2(Ra) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Ra))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom v_i
Dref	416	4	normal	1	4.0	∞
ΔDlocus	1	0.577	rectangular	1	0.6	∞
ΔDrepeat	0.832	0.832	normal	1	0.8	11
δunlinarity	9.60	5.5	rectangular	1	5.5	∞
δresol	0.20	0.1	digital	1	0.1	∞
δresidual	8	2.3	triangular	1	2.3	5
δ (Ra)	1	0.3	normal	1	0.3	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Ra) = 7$

Effective degree of freedom: $v_{eff}(Ra) = \infty$

Expanded uncertainty: $U(Ra) = 15$ with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard type D2 with a nominal Rz of 0.14 µm:
Identification: SFRN 150

Equation used: $Rz = C * (Rz_{meas}) + \partial(Rz)_{unlinarity} + \partial(Rz)_{resol} + \partial(Rz)_{residual}$

$$u^2(Rz) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rz))$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$ nm	degrees of freedom ν_i
Dref	416	4	normal	1	4.0	∞
ΔDlocus	1	0.577	rectangular	1	0.6	∞
ΔDrepeat	0.832	0.832	normal	1	0.8	11
δunlinarity	9.60	5.5	rectangular	1	5.5	∞
δresol	0.20	0.1	digital	1	0.1	∞
δresidual	44	12.7	triangular	1	12.7	5
δ (Rz)	6	1.7	normal	1	1.7	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rz) = 15$

Effective degree of freedom: $\nu_{\text{eff}}\ (Rz) = \infty$

Expanded uncertainty: $U(Rz)$ = **29** with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness standard type D2 with a Rk of 0.076 µm:
Identification: SFRN 150

Equation used: $Rk = C*(Rk_{meas}) + \partial(Rk)_{unlinarity} + \partial(Rk)_{resol} + \partial(Rk)_{residual}$

$$u^2(Rk) = u^2(D_{ref}) + u^2(\Delta D_{locus}) + u^2(\Delta D_{repeat}) + u^2(\delta_{unlinarity}) + u^2(\delta_{resol}) + u^2(\delta_{residual}) + u^2(\delta(Rk))$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	Sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$ nm	degrees of freedom v_i
Dref	416	4	normal	1	4.0	∞
ΔDlocus	1	0.577	rectangular	1	0.6	∞
ΔDrepeat	0.832	0.832	normal	1	0.8	11
δunlinarity	9.60	5.5	rectangular	1	5.5	∞
δresol	0.20	0.1	digital	1	0.1	∞
δresidual	23	6.6	triangular	1	6.6	5
δ (Rk)	6	1.7	normal	1	1.7	11

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Rk) = 10$

Effective degree of freedom: $v_{eff}(Rk) = \infty$

Expanded uncertainty: $U(Rk) =$ **19** with a coverage factor k=2

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CGM

We have some comments to our results which we would like to be added to our report.

Our result for the RSm parameter did all come out too small in the report. They were computed by our own developed software RCS4G version 2.0. An investigation of the applied algorithm showed us that there was a systematic error in the calculation of the length of the first profile element. By removing the first profile element from the calculation we obtain the following values for RSm.

RSm values computed with the software after correction:
7070 /PGN 10: RSm = (199960 +/- 1376) nm
8194 PGN 3: RSm = (119990 +/- 1125) nm
P114A: RSm = (50036 +/- 648)nm

Fortunately this has not given us any problems as replacing of customer certificates since we have not been making any with RSm using version 2.0.

Concerning the results we are surprisingly having problem with the coarse type C standard 7070/PGN10 when measuring Rz but not Rzmax. We have no explanation for this at the moment.

Appendix B1

Reports of CMI

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments

1. TYPE OF INSTRUMENT

The measurement was carried out by surface tracing device HOMMEL TESTER T8000 made by the firm Hommelwerke GmbH. This equipment consists of the own apparatus HOMMEL TESTER T8000 of serial number 44731 with the absolute taking-off device TKL 100s of serial number 76151 with the diamond tip of radius of curvature 2 μm.

2. KIND OF OPERATION

The measurement was performed by the surface tracing method. It deals with inductive system of measurement of traversing lenght. The diamond tip is led along the measured surface. The measured sample is placed on the table and the taking-off arm with the diamond tip is moving.

3. CONDITIONS OF DATA COLLECTION

Data are collected by that system automatically by means of the hardware and software components. The hardware and software components at the heart of the system are provided by an intelligent PC slot card together with the TURBO Roughness for Windows software. These meet the very latest requirements in terms of on-line roughness measurement technology.

4. CONDITIONS OF EVALUATION

THE EQUIPMENT WAS CALIBRATED BY MEANS OF THE FOLLOWING SET OF STANDARDS:

1 piece of standard A2 of serial number 0909
1 piece of standard D of serial number 0764
1 piece of standard D of serial number 0906
1 piece of standard D of serial number 0889

These standards were calibrated in the PTB.

The calibration was taken into consideration by the evaluation of results of measurement comparison.

5. CHARAKTERISATION OF INSTRUMENT NOISE AND DEVIATION OF IDEAL BEHAVIOUR

Within the framework of calibration the measurement by means of flat glass was caried out. The deviations determined in this way are deviations produced by instrument noise. The equipment setting up in the laboratory doesn´t allow to give rise to other undesirable deviations.

6. ENVIROMENT CHARACTERISATION

The apparatus is placed in the laboratory on the granite board, which is put on the own basis (without basis of building) because of vibration isolation. In that laboratory there is an air-conditioning, which keeps the temperature within ±1˚C and the air humidity below 65 %.

7. THE MEASUREMENT UNCERTAINTIES

The uncertainties of measurement are divided into two parts:

1. part – the uncertainty caused by standard, which is measured.

This uncertainty is given by the quality of standard surface. It is the type A uncertainty, evaluted according to the relation:

$$u_1 = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{i=n}(x_i - \bar{x})^2}$$

n is the number of measurements
x_i is the single value of measurement
is the average calculated according to the relation:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{i=n} x_1$$

This uncerntainty is introduced in the first line of the tables.

2. part – the uncertainty caused by the method. This uncertainty is given by sum of the uncertainties caused by the following influences:

- the uncertainty given by the radius of curvature r (μm) of the diamond tip
- the uncertainty of standard used for calibration of device
- the uncertainty determined at the calibration of device
    - the uncertainty given by homogeneity of standard used
    - the uncertainty determined at the calibration of device from the standard deviation of the average of the single measured values
- the uncertainty given by the deviation of the measured length from its nominal value
- the uncertainty given by the deviation of the force from its nominal value.

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Date: .22.8.2001..................... Signature:…Jiří BOROVSKÝ..

A4 - Uncertainty of measurement

Step height standard with a nominal height of _5__ nm: Pt identification EN 806 R1

Equation used:

$$d = f(x_i)$$

$d = f(Pt_1; r; u_e; Pt_2; h; l; F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Pt_1 [µm]		0,002	N	1	0,002	9
R [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,009	N	1	0,009	4
Pt_2 [µm]		0,03	N	1	0,03	4
h [µm]	0,056	0,016	R	1	0,016	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}036$ µm

Effective degree of freedom: $v_{eff}(d) = 8$

Expanded uncertainty: $U(d) = 0{,}072$ µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: D identification EN 806 R1

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(D_1; r; u_e; D_2; h; l; F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
D_1 [µm]		0,002	N	1	0,002	9
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,009	N	1	0,009	4
D_2 [µm]		0,022	N	1	0,022	4
h [µm]	0,128	0,037	R	1	0,037	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 45 µm

Effective degree of freedom: $\nu_{\mathrm{eff}}\,(d)$ = 59

Expanded uncertainty: $U(d)$ = 90 µm with a coverage factor k=2

Step height standard with a nominal height of _78_ nm: Pt identification EN806 R3

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Pt}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Pt}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Pt_1 [µm]		0,03	N	1	0,03	9
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,01	N	1	0,01	4
Pt_2 [µm]		0,024	N	1	0,024	4
h [µm]	0,13	0,037	R	1	0,037	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,046 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 53

Expanded uncertainty: $U(d)$ = 0,092 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: D identification EN 806 R3

Equation used:

$$d = f(x_i)$$

d = f (D_1; r; u_e; D_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
D_1 [µm]		0,008	N	1	0,008	9
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,01	N	1	0,01	4
D_2 [µm]		0,033	N	1	0,033	4
h [µm]	0,167	0,048	R	1	0,048	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 60 µm

Effective degree of freedom: $\nu_{eff}(d)$ = 42

Expanded uncertainty: $U(d)$ = 120 µm with a coverage factor k=2

Step height standard with a nominal height of _353_ nm: Pt identification EN806 R6

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Pt}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Pt}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Pt_1 [µm]		0,007	N	1	0,007	9
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,04	N	1	0,04	4
Pt_2 [µm]		0,027	N	1	0,027	4
h [µm]	0,15	0,04	R	1	0,04	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}065$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 24$

Expanded uncertainty: $U(d) = 0{,}130$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: D identification EN 806 R6

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (D_1; r; u_e; D_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
D_1 [µm]		0,007	N	1	0,007	9
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,04	N	1	0,04	4
D_2 [µm]		0,019	N	1	0,019	4
h [µm]	0,120	0,035	R	1	0,035	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 57 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 76

Expanded uncertainty: $U(d)$ = 114 µm with a coverage factor k=2

Step height standard with a nominal height of _1_ nm: Ra identification P114A

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Ra}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Ra}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ra_1 [µm]		0,0006	N	1	0,0006	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,01	N	1	0,01	11
Ra_2 [µm]		0,0008	N	1	0,0008	14
h [µm]	0,01	0,003	R	1	0,003	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,012 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 26

Expanded uncertainty: $U(d)$ = 0,024 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rz identification P114A

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rz}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rz}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,002	N	1	0,002	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathrm{u_e}$ [µm]		0,06	N	1	0,06	11
Rz_2 [µm]		0,006	N	1	0,006	14
h [µm]	0,072	0,021	R	1	0,021	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,064 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 14

Expanded uncertainty: $U(d)$ = 0,128 µmwith a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification P114A

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rmax$_1$; r; u$_e$; Rmax$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rmax$_1$ [µm]		0,003	N	1	0,003	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,07	N	1	0,07	11
Rmax$_2$ [µm]		0,008	N	1	0,008	14
h [µm]	0,103	0,030	R	1	0,030	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,077 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 16

Expanded uncertainty: $U(d)$ = 0,154 µm with a coverage factor k=2

Step height standard with a nominal height of _200_ nm: RSm identification P114A

Equation used:

$$d = f(x_i)$$

d = f (RSm$_1$; r; u$_e$; RSm$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
RSm$_1$ [µm]		0,348	N	1	0,0003	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		6,0	N	1	0,006	11
RSm$_2$ [µm]		0,447	N	1	0,0003	14
h [µm]	0,0025	0,722	R	1	0,0007	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 6,1 µm

Effective degree of freedom: $v_{\text{eff}}(d)$ = 4

Expanded uncertainty: $U(d)$ = 12,2 µm with a coverage factor k=2

Step height standard with a nominal height of _60_ nm: Ra identification 7070

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Ra$_1$; r; u$_e$; Ra$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ra$_1$ [µm]		0,002	N	1	0,002	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,02	N	1	0,02	11
Ra$_2$ [µm]		0,003	N	1	0,003	14
h [µm]	0,29	0,08	R	1	0,08	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,086 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 3826

Expanded uncertainty: $U(d)$ = 0,172 µm with a coverage factor k=2

Step height standard with a nominal height of _253_ nm: Rz identification 7070

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rz_1; r; u_e; Rz_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,005	N	1	0,005	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,11	N	1	0,11	11
Rz_2 [µm]		0,02	N	1	0,02	14
h [µm]	0,19	0,05	R	1	0,05	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,124 µm

Effective degree of freedom: $v_{eff}(d)$ = 18

Expanded uncertainty: $U(d)$ = 0,248 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification 7070

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rmax}_1;\ r;\ u_e;\ \mathrm{Rmax}_2;\ h;\ l;\ F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rmax₁ [µm]		0,01	N	1	0,01	11
r [µm]	0,01	0,006	R	1	0,006	∞
uₑ [µm]		0,14	N	1	0,14	11
Rmax₂ [µm]		0,008	N	1	0,008	14
h [µm]	0,108	0,03	R	1	0,03	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}144\ \mu\mathrm{m}$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 12$

Expanded uncertainty: $U(d) = 0{,}288\ \mu\mathrm{m}$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: RSm identification 7070

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (RSm_1; r; u_e; RSm_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
RSm_1 [µm]		0,0	N	1	0,0	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		2,0	N	1	0,002	11
RSm_2 [µm]		0,447	N	1	0,0003	14
h [µm]	0,003	0,866	R	1	0,0009	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 2,2 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 6

Expanded uncertainty: $U(d)$ = 4,4 µm with a coverage factor k=2

Step height standard with a nominal height of _14_ nm: Ra identification 8194

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Ra$_1$; r; u$_e$; Ra$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ra$_1$ [µm]		0,002	N	1	0,002	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,022	N	1	0,022	11
Ra$_2$ [µm]		0,001	N	1	0,001	14
h [µm]	0,013	0,004	R	1	0,004	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,023 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 14

Expanded uncertainty: $U(d)$ = 0,046 µm with a coverage factor k=2

Step height standard with a nominal height of _44_ nm: Rz identification 8194

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rz}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rz}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,01	N	1	0,01	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,12	N	1	0,12	11
Rz_2 [µm]		0,01	N	1	0,01	14
h [µm]	0,18	0,05	R	1	0,05	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,132 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 16

Expanded uncertainty: $U(d)$ = 0,264 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification 8194

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rmax}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rmax}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rmax_1 [µm]		0,01	N	1	0,01	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathrm{u_e}$ [µm]		0,14	N	1	0,14	11
Rmax_2 [µm]		0,03	N	1	0,03	14
h [µm]	0,363	0,1	R	1	0,1	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}178\ \mu\mathrm{m}$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 29$

Expanded uncertainty: $U(d) = 0{,}356\ \mu\mathrm{m}$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: RSm identification 8194

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{RSm}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{RSm}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
RSm_1 [µm]		0,538	N	1	0,0005	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathrm{u_e}$ [µm]		2,0	N	1	0,002	11
RSm_2 [µm]		0,224	N	1	0,0001	14
h [µm]	0,0012	0,346	R	1	0,0003	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 2{,}1\ \mu\mathrm{m}$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 5$

Expanded uncertainty: $U(d) = 4{,}2\ \mu\mathrm{m}$ with a coverage factor k=2

Step height standard with a nominal height of _172_ nm: Ra identification 686sg

Equation used:

$$d= \mathrm{f}(x_\mathrm{i})$$

$d = \mathrm{f}\ (\mathrm{Ra}_1; \mathrm{r}; \mathrm{u}_\mathrm{e}; \mathrm{Ra}_2; \mathrm{h}; \mathrm{l}; \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_\mathrm{i}(d)$	degrees of freedom v_i
Ra_1 [µm]		0,010	N	1	0,010	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,02	N	1	0,02	11
Ra_2 [µm]		0,003	N	1	0,003	14
h [µm]	0,29	0,084	R	1	0,084	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,087 µm

Effective degree of freedom: $v_\mathrm{eff}\ (d)$ = 3688

Expanded uncertainty: $U(d)$ = 0,174 µm with a coverage factor k=2

Step height standard with a nominal height of _403_ nm: Rz identification 686sg

Equation used:

$$d = f(x_i)$$

d = f (Rz_1; r; u_e; Rz_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,13	N	1	0,13	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,11	N	1	0,11	11
Rz_2 [µm]		0,015	N	1	0,015	14
h [µm]	0,19	0,055	R	1	0,055	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,177 µm

Effective degree of freedom: v_{eff} (d) = 27

Expanded uncertainty: $U(d)$ = 0,354 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification 686sg

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rmax$_1$; r; u$_e$; Rmax$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rmax$_1$ [µm]		0,018	N	1	0,018	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,15	N	1	0,15	11
Rmax$_2$ [µm]		0,008	N	1	0,008	14
h [µm]	0,109	0,031	R	1	0,031	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,155 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 12

Expanded uncertainty: $U(d)$ = 0,310 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rk identification 686sg

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rk}_1;\ r;\ u_e;\ \mathrm{Rk}_2;\ h;\ l;\ F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rk$_1$ [µm]		0,070	N	1	0,070	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,8	N	1	0,8	11
Rk$_2$ [µm]		0,010	N	1	0,010	14
h [µm]	0,95	0,274	R	1	0,274	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}849\ \mu\mathrm{m}$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 14$

Expanded uncertainty: $U(d) = 1{,}698\ \mu\mathrm{m}$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rpk identification 686sg

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rpk$_1$; r; u$_e$; Rpk$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rpk$_1$ [µm]		0,017	N	1	0,017	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,023	N	1	0,023	11
Rpk$_2$ [µm]		0,008	N	1	0,008	14
h [µm]	0,35	0,101	R	1	0,101	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,106 µm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 3715

Expanded uncertainty: $U(d)$ = 0,212µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rvk identification 686sg

Equation used:

$$d = f(x_i)$$

$d = f\,(Rvk_1;\ r;\ u_e;\ Rvk_2;\ h;\ l;\ F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rvk_1 [µm]		0,105	N	1	0,105	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,07	N	1	0,07	11
Rvk_2 [µm]		0,008	N	1	0,008	14
h [µm]	0,102	0,029	R	1	0,029	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,130 µm

Effective degree of freedom: $\nu_{eff}\,(d)$ = 22

Expanded uncertainty: $U(d)$ = 0,260 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr1 identification 686sg

Equation used:

$$d= \mathrm{f}(x_\mathrm{i})$$

$d = \mathrm{f}\ (\mathrm{Mr1}_1;\ \mathrm{r};\ \mathrm{u}_\mathrm{e};\ \mathrm{Mr1}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_\mathrm{i}(d)$	degrees of freedom v_i
$\mathbf{Mr1_1}$ [µm]		0,231	N	1	0,231	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathbf{u_e}$ [µm]		0,44	N	1	0,44	11
$\mathbf{Mr1_2}$ [µm]		0,145	N	1	0,145	14
h [µm]	0,85	0,245	R	1	0,245	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}6\ \%$

Effective degree of freedom: $v_\mathrm{eff}\ (d) = 29$

Expanded uncertainty: $U(d) = 1{,}2\ \%$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr2 identification 686sg

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\ (\mathrm{Mr2}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Mr2}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$\mathrm{Mr2}_1$ [µm]		0,260	N	1	0,260	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,99	N	1	0,99	11
$\mathrm{Mr2}_2$ [µm]		0,310	N	1	0,310	14
h [µm]	0,75	0,217	R	1	0,217	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 1{,}1\ \%$

Effective degree of freedom: $v_{\mathrm{eff}}\ (d) = 16$

Expanded uncertainty: $U(d) = 2{,}2\ \%$ with a coverage factor k=2

Step height standard with a nominal height of _13_ nm: Ra identification 633g

Equation used:

$$d= \mathrm{f}(x_\mathrm{i})$$

d = f (Ra$_1$; r; u$_e$; Ra$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_\mathrm{i}(d)$	degrees of freedom v_i
Ra$_1$ [µm]		0,007	N	1	0,007	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,02	N	1	0,02	11
Ra$_2$ [µm]		0,003	N	1	0,003	14
h [µm]	0,29	0,084	R	1	0,084	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,087 µm

Effective degree of freedom: $v_\mathrm{eff}\,(d)$ = 3822

Expanded uncertainty: $U(d)$ = 0,174 µm with a coverage factor k=2

Step height standard with a nominal height of _1200_ nm: Rz identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rz}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rz}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,060	N	1	0,060	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,11	N	1	0,11	11
Rz_2 [µm]		0,015	N	1	0,015	14
h [µm]	0,19	0,055	R	1	0,055	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}138$ µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 25$

Expanded uncertainty: $U(d) = 0{,}276$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rmax$_1$; r; u$_e$; Rmax$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rmax$_1$ [µm]		0,038	N	1	0,038	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,15	N	1	0,15	11
Rmax$_2$ [µm]		0,008	N	1	0,008	14
h [µm]	0,109	0,031	R	1	0,031	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,158 µm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 14

Expanded uncertainty: $U(d)$ = 0,316µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rk identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rk}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Rk}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$\mathbf{Rk_1}$ [µm]		0,036	N	1	0,036	11
r [µm]	0,0	0,006	R	1	0,006	∞
$\mathbf{u_e}$ [µm]		0,8	N	1	0,8	11
$\mathbf{Rk_2}$ [µm]		0,010	N	1	0,010	14
h [µm]	0,95	0,274	R	1	0,274	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,847 µm

Effective degree of freedom: $v_{\text{eff}}\,(d)$ = 14

Expanded uncertainty: $U(d)$ = 1,694 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rpk identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rpk_1; r; u_e; Rpk_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rpk_1 [µm]		0,019	N	1	0,019	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,023	N	1	0,023	11
Rpk_2 [µm]		0,008	N	1	0,008	14
h [µm]	0,35	0,101	R	1	0,101	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,106 µm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 3389

Expanded uncertainty: $U(d)$ = 0,212 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rvk identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rvk$_1$; r; u$_e$; Rvk$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rvk$_1$ [µm]		0,044	N	1	0,044	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,07	N	1	0,07	11
Rvk$_2$ [µm]		0,008	N	1	0,008	14
h [µm]	0,102	0,029	R	1	0,029	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,088 µm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 24

Expanded uncertainty: $U(d)$ = 0,176 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr1 identification 633g

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f ($\mathrm{Mr1}_1$; r; u_e; $\mathrm{Mr1}_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$\mathrm{Mr1}_1$ [µm]		0,087	N	1	0,087	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,44	N	1	0,44	11
$\mathrm{Mr1}_2$ [µm]		0,145	N	1	0,145	14
h [µm]	0,85	0,245	R	1	0,245	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,5 %

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 23

Expanded uncertainty: $U(d)$ = 1,0 % with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr2 identification 633g

Equation used:

$$d = f(x_i)$$

d = f (Mr2$_1$; r; u$_e$; Mr$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Mr2$_1$ [µm]		0,173	N	1	0,173	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,99	N	1	0,99	11
Mr2$_2$ [µm]		0,310	N	1	0,310	14
h [µm]	0,75	0,217	R	1	0,217	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 1,1 %

Effective degree of freedom: $v_{eff}(d)$ = 15

Expanded uncertainty: $U(d)$ = 2,2 % with a coverage factor k=2

Step height standard with a nominal height of _58_ nm: Ra identification 629f

Equation used:

$$d = f(x_i)$$

d = f (Ra_1; r; u_e; Ra_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ra_1 [µm]		0,0009	N	1	0,0009	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,0049	N	1	0,0049	11
Ra_2 [µm]		0,0005	N	1	0,0005	14
h [µm]	0,007	0,0020	R	1	0,0020	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,009 µm

Effective degree of freedom: $v_{eff}(d)$ = 99

Expanded uncertainty: $U(d)$ = 0,018µm with a coverage factor k=2

Step height standard with a nominal height of _328_ nm: Rz identification 629f

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rz}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rz}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,016	N	1	0,016	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,04	N	1	0,04	11
Rz_2 [µm]		0,012	N	1	0,012	14
h [µm]	0,165	0,048	R	1	0,048	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}066$ µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 77$

Expanded uncertainty: $U(d) = 0{,}132$ µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification 629f

Equation used:

$$d = f(x_i)$$

d = f (Rmax$_1$; r; u$_e$; Rmax$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rmax$_1$ [µm]		0,026	N	1	0,026	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,046	N	1	0,046	11
Rmax$_2$ [µm]		0,020	N	1	0,020	14
h [µm]	0,288	0,083	R	1	0,083	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,101 µm

Effective degree of freedom: $v_{eff}(d)$ = 224

Expanded uncertainty: $U(d)$ = 0,202 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rk identification 629f

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rk}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Rk}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rk_1 [µm]		0,0026	N	1	0,0026	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,006	N	1	0,006	11
Rk_2 [µm]		0,0008	N	1	0,0008	14
h [µm]	0,085	0,0245	R	1	0,0245	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}026$ µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 3885$

Expanded uncertainty: $U(d) = 0{,}052$ µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rpk identification 629f

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rpk}_1;\ r;\ u_e;\ \mathrm{Rpk}_2;\ h;\ l;\ F)$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rpk_1 [µm]		0,0020	N	1	0,0020	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,002	N	1	0,002	11
Rpk_2 [µm]		0,0005	N	1	0,0005	14
h [µm]	0,005	0,0014	R	1	0,0014	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}007\ \mu\mathrm{m}$

Effective degree of freedom: $v_{\mathrm{eff}}\,(d) = 960$

Expanded uncertainty: $U(d) = 0{,}014\ \mu\mathrm{m}$ with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rvk identification 629f

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Rvk$_1$; r; u$_e$; Rvk$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rvk$_1$ [µm]		0,0052	N	1	0,0052	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,008	N	1	0,008	11
Rvk$_2$ [µm]		0,0013	N	1	0,0013	14
h [µm]	0,06	0,0173	R	1	0,0173	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,021 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 433

Expanded uncertainty: $U(d)$ = 0,042 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr1 identification 629f

Equation used:

$$d = \mathrm{f}(x_i)$$

d = f (Mr1_1; r; u_e; Mr1_2; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Mr1_1 [µm]		0,173	N	1	0,173	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,25	N	1	0,25	11
Mr1_2 [µm]		0,065	N	1	0,065	14
h [µm]	0,4	0,115	R	1	0,115	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,3 %

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 28

Expanded uncertainty: $U(d)$ = 0,6 % with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr2 identification 629f

Equation used:

$$d = f(x_i)$$

d = f (Mr2$_1$; r; u$_e$; Mr2$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Mr2$_1$ [µm]		0,2021	N	1	0,2021	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,45	N	1	0,45	11
Mr2$_2$ [µm]		0,2453	N	1	0,2453	14
h [µm]	0,55	0,1588	R	1	0,1588	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,6 %

Effective degree of freedom: $v_{eff}(d)$ = 26

Expanded uncertainty: $U(d)$ = 1,2 % with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Ra identification Sf150

Equation used:

$$d = f(x_i)$$

d = f (Ra$_1$; r; u$_e$; Ra$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ra$_1$ [µm]		0,0003	N	1	0,0003	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,0049	N	1	0,0049	11
Ra$_2$ [µm]		0,0005	N	1	0,0005	14
h [µm]	0,007	0,0020	R	1	0,0020	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,009 µm

Effective degree of freedom: $v_{\text{eff}}(d)$ = 97

Expanded uncertainty: $U(d)$ = 0,018 µm with a coverage factor k=2

Step height standard with a nominal height of _4_ nm: Rz identification Sf150

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rz}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rz}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Rz_1 [µm]		0,0026	N	1	0,0026	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,04	N	1	0,04	11
Rz_2 [µm]		0,0119	N	1	0,0119	14
h [µm]	0,165	0,0476	R	1	0,0476	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,064 µm

Effective degree of freedom: $v_{\mathrm{eff}}\,(d)$ = 70

Expanded uncertainty: $U(d)$ = 0,128 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rmax identification Sf150

Equation used:

$$d = \mathrm{f}(x_\mathrm{i})$$

d = f (Rmax$_1$; r; u$_e$; Rmax$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_\mathrm{i}(d)$	degrees of freedom v_i
Rmax$_1$ [µm]		0,0040	N	1	0,0040	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,046	N	1	0,046	11
Rmax$_2$ [µm]		0,0204	N	1	0,0204	14
h [µm]	0,288	0,0831	R	1	0,0831	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,098 µm

Effective degree of freedom: $v_{\mathrm{eff}}(d)$ = 215

Expanded uncertainty: $U(d)$ = 0,196 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rk identification Sf150

Equation used:

$$d = f(x_i)$$

d = f (Rk$_1$; r; u$_e$; Rk$_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rk$_1$ [µm]		0,0014	N	1	0,0014	11
r [µm]	0,01	0,006	R	1	0,006	∞
u$_e$ [µm]		0,006	N	1	0,006	11
Rk$_2$ [µm]		0,0008	N	1	0,0008	14
h [µm]	0,085	0,0245	R	1	0,0245	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,026 µm

Effective degree of freedom: $\nu_{eff}(d)$ = 3954

Expanded uncertainty: $U(d)$ = 0,052 µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rpk identification Sf150

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Rpk}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Rpk}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Rpk_1 [µm]		0,0014	N	1	0,0014	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathrm{u_e}$ [µm]		0,002	N	1	0,002	11
Rpk_2 [µm]		0,0005	N	1	0,0005	14
h [µm]	0,005	0,0014	R	1	0,0014	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}007$ µm

Effective degree of freedom: $\nu_{\mathrm{eff}}\,(d) = 1427$

Expanded uncertainty: $U(d) = 0{,}014$ µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Rvk identification Sf150

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\ (\mathrm{Rvk}_1;\ \mathrm{r};\ \mathrm{u}_e;\ \mathrm{Rvk}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$\mathbf{Rvk_1}$ [µm]		0,0017	N	1	0,0017	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathbf{u_e}$ [µm]		0,008	N	1	0,008	11
$\mathbf{Rvk_2}$ [µm]		0,0013	N	1	0,0013	14
h [µm]	0,006	0,0017	R	1	0,0017	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d) = 0{,}011$ µm

Effective degree of freedom: $v_{\mathrm{eff}}\ (d) = 35$

Expanded uncertainty: $U(d) = 0{,}022$ µm with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr1 identification Sf150

Equation used:

$$d = f(x_i)$$

d = f ($Mr1_1$; r; u_e; $Mr1_2$; h; l; F)

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$Mr1_1$ [µm]		0,548	N	1	0,548	11
r [µm]	0,01	0,006	R	1	0,006	∞
u_e [µm]		0,25	N	1	0,25	11
$Mr1_2$ [µm]		0,065	N	1	0,065	14
h [µm]	0,4	0,115	R	1	0,115	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,6 %

Effective degree of freedom: $v_{eff}(d)$ = 17

Expanded uncertainty: $U(d)$ = 1,2 % with a coverage factor k=2

Step height standard with a nominal height of ___ nm: Mr2 identification Sf150

Equation used:

$$d = \mathrm{f}(x_i)$$

$d = \mathrm{f}\,(\mathrm{Mr2}_1;\ \mathrm{r};\ \mathrm{u_e};\ \mathrm{Mr2}_2;\ \mathrm{h};\ \mathrm{l};\ \mathrm{F})$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
$\mathrm{Mr2}_1$ [µm]		0,491	N	1	0,491	11
r [µm]	0,01	0,006	R	1	0,006	∞
$\mathrm{u_e}$ [µm]		0,45	N	1	0,45	11
$\mathrm{Mr2}_2$ [µm]		0,245	N	1	0,245	14
h [µm]	0,55	0,159	R	1	0,159	∞
l [mm]	0,005	0,003	R	1	0,003	∞
F [mN]	0,002	0,001	R	1	0,001	∞

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 0,7 %

Effective degree of freedom: $v_{eff}\,(d)$ = 30

Expanded uncertainty: $U(d)$ = 1,4 % with a coverage factor k=2

Laboratory: ....CMI-LFM Prague ....

Date: ....22.8.2001…............... Signature:..Jiří BOROVSKÝ....................................

Comment from CMI

We have found two errors in our measurement report.

1) Depth standard EN 806 R1 0,2 µm.

By mistake we reported the value of our reference standard: 195 nm. The value we measured on Depth standard EN 806 R1 0,2 µm was: 325 nm. The corrected measurement report is attached.

2) the similar mistake we did in the case of Roughness standard 686sg.

By mistake we reported the value of our reference standard
Rz: 13597 nm and Rmax: 15328 nm . The value we measured on Roughness standard 686sg was Rz: 14115 nm and Rmax:15649 nm. The corrected measurement report is attached.

Appendix B1

Reports of GUM

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments:

In the **Central Office of Measures (GUM)** was used a commercial stylus instrument, a Rank Taylor Hobson Form Talysurf, Series 2 (1996).

- **Type of instrument:** The stylus instrument – Form Talysurf Series 2, 120*i*, equipped with a standard inductive pick-up and 120 mm traverse unit.
- Kind of operation: **The traverse unit with the inductive pick-up and moving stylus was mounted at a motorised column (up/down and tilt movement) with the granite base, where was placed a x-y axis table.**
- Conditions of data collection: **The probe tip radius was *r* = 2 µm**, **the measuring force <1 mN (about 0,7 mN), the sampling interval 0,25 µm and the vertical resolution 0,64 nm by 0,04 mm gauge range. The measuring speed of gauge was 0,5 mm/sec. The pick-up was used without a nose piece, in the skidless condition.**
- Conditions of evaluation: **The instrument was calibrated (made corrections) using a sphere of known radius – about 12,5 mm; but for measurements of roughness parameters values of calibration factors were determined by using roughness standards type A1, traceable to the PTB.**
- Characterisation of instrument noise and deviation of ideal behaviour: **The instrument noise was checked by using a flat glass and with the movement of gauge (see below table).**

Rz_{DIN}/std. dev. [nm]	Rt/std. dev. [nm]	Rq/std. dev. [nm]	Notes
–	61,0/4,7	8,7/0,8	No filter, lp = 2 mm
32,6/2,3	41,5/4,0	6,6/0,4	λc = 0,08 mm, λs = 1,25 µm, ln = 0,4 mm, Gauss filter
36,2/1,6	44,1/3,3	6,6/0,4	λc = 0,25 mm, λs = 2,5 µm, ln = 1,25 mm, Gauss filter
41,5/2,6	52,6/7,8	6,4/0,4	λc = 0,8 mm, λs = 2,5 µm, ln = 4,0 mm, Gauss filter
39,0/3,3	52,3/6,0	6,0/0,4	λc = 2,5 mm, λs = 8 µm, ln = 12,5 mm, Gauss filter

A mean value of the parameter Wt obtained from the optical surface is given below:

Wz_{DIN}/std. dev. [nm]	Wt/std. dev. [nm]	Wq/std. dev. [nm]	Notes
8,0/1,8	14,5/4,6	4,3/1,5	λc = 0,8 mm, ln = 4,0 mm, Gauss filter

- **Environment characterisation:** The measurements were performed in the laboratory, where was an air-conditioning with a thermal stability ±0,5 °C. The base of the instrument was a commercial epoxy granite construction on antivibration mounts.

Note:

The instrument was not able to read data in .smd format, therefore it was impossible to check of software.

Laboratory: Central Office of Measures (Glowny Urzad Miar GUM)
Length and Angle Division, Surface Texture Measurements Laboratory
2 Elektoralna St., 00-950 Warsaw, POLAND

Date: 27th June 2002 Signature: Barbara Smereczynska

Depth standard EN 806

Table 1. **R1** – parameter Pt

Type A2; EN 806; R1 = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Pt)$	degrees of freedom ν_i
Pt_n	0,3614 µm	2,5 nm	N	1	2,5 nm	100
ΔPt	0	0,29 nm	R	1	0,29 nm	8
b	0	1,64 nm	N	1	1,64 nm	9
z_t	0	0,62 nm	N	1	0,62 nm	14
z_{ref}	0	4,18 nm	R	1	4,18 nm	8
z_0	0	10,45 nm	R	1	10,45 nm	9
z_g	0	11,70 nm	N	2^0,5	16, 50 nm	54,29
A	0	2,89 nm	R	1	2,89 nm	8
Pt	0,287 µm				16,75 nm	57,30
$u_c(Pt)$ = 16,5 nm; U(Pt) = 34 nm ; ν_{eff} = 57; k = 2,0						

Table 2. **R3** – parameter Pt

Type A2; EN 806; R3 = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Pt)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
ΔPt	0	0,58 nm	R	1	0,58 nm	8
b	0	1,42 nm	N	1	1,42 nm	9
z_t	0	0,75 nm	N	1	0,75 nm	14
z_{ref}	0	4,18 nm	R	1	4,18 nm	8
z_0	0	10,45 nm	R	1	10,45 nm	9
z_g	0	13,67nm	N	2^0,5	19,28 nm	99,00
A	0	2,89 nm	R	1	2,89 nm	8
Pt	1,379 µm				19,49 nm	102,86
$u_c(Pt)$ = 19,5 nm; U(Pt) = 39nm ; ν_{eff} = 102; k = 2,0						

Table 3. **R6** – parameter Pt

Type A2; EN806; R6 = 8 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Pt)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	3	22,5 nm	100
ΔPt	0	0,58 nm	R	3	1,74 nm	8
b	0	1,42 nm	N	3	4,26 nm	9
z_t	0	1,76 nm	N	1	1,76 nm	14
z_{ref}	0	4,18 nm	R	1	4,18 nm	8
z_0	0	10,45 nm	R	1	10,45 nm	99
z_g	0	25,76 nm	N	2^0,5	36,25 nm	435,78
A	0	2,89 nm	R	1	2,89 nm	8
Pt	8,312 µm				36,37 nm	440,36
$u_c(Pt)$ = 36,4nm; U(Pt) = 73 nm ; ν_{eff} = 440; k = 2,0						

Table 4. **R1 –** parameter D

<table>
<tr><td colspan="7">Type A2; EN 806; R1 = 0,2 µm</td></tr>
<tr><td>quantity X_i</td><td>estimate x_i</td><td>uncertainty $u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient c_i</td><td>uncertainty contribution $u_i(D)$</td><td>degrees of freedom ν_i</td></tr>
<tr><td>Pt_n</td><td>0,3614 µm</td><td>2,5 nm</td><td>N</td><td>1</td><td>2,5 nm</td><td>100</td></tr>
<tr><td>ΔPt</td><td>0</td><td>0,29 nm</td><td>R</td><td>1</td><td>0,29 nm</td><td>8</td></tr>
<tr><td>b</td><td>0</td><td>1,64 nm</td><td>N</td><td>1</td><td>1,64 nm</td><td>9</td></tr>
<tr><td>z_t</td><td>0</td><td>0,70 nm</td><td>N</td><td>1</td><td>0,70 nm</td><td>14</td></tr>
<tr><td>z_{ref}</td><td>0</td><td>4,18 nm</td><td>R</td><td>1</td><td>4,18 nm</td><td>8</td></tr>
<tr><td>z_0</td><td>0</td><td>1,02 nm</td><td>R</td><td>1</td><td>1,02 nm</td><td>9</td></tr>
<tr><td>A</td><td>0</td><td>1,44 nm</td><td>R</td><td>1</td><td>1,44 nm</td><td>8</td></tr>
<tr><td>D</td><td>0,266 µm</td><td colspan="3"></td><td>5,49 nm</td><td>22,63</td></tr>
<tr><td colspan="7">$u_c(D)$ = 5,5 nm; U(D) = 12 nm ; ν_{eff} = 22; k = 2,12</td></tr>
</table>

Table 5. **R3** – parameter D

<table>
<tr><td colspan="7">Type A2; EN 806; R1 = 1,5 µm</td></tr>
<tr><td>quantity X_i</td><td>estimate x_i</td><td>uncertainty $u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient c_i</td><td>uncertainty contribution $u_i(D)$</td><td>degrees of freedom ν_i</td></tr>
<tr><td>Pt_n</td><td>2,657 µm</td><td>7,5 nm</td><td>N</td><td>1</td><td>7,5 nm</td><td>100</td></tr>
<tr><td>ΔPt</td><td>0</td><td>0,58 nm</td><td>R</td><td>1</td><td>0,58 nm</td><td>8</td></tr>
<tr><td>b</td><td>0</td><td>1,42 nm</td><td>N</td><td>1</td><td>1,42 nm</td><td>9</td></tr>
<tr><td>z_t</td><td>0</td><td>0,59 nm</td><td>N</td><td>1</td><td>0,59 nm</td><td>14</td></tr>
<tr><td>z_{ref}</td><td>0</td><td>4,18 nm</td><td>R</td><td>1</td><td>4,18 nm</td><td>8</td></tr>
<tr><td>z_0</td><td>0</td><td>0,78 nm</td><td>R</td><td>1</td><td>0,78 nm</td><td>9</td></tr>
<tr><td>A</td><td>0</td><td>1,44 nm</td><td>R</td><td>1</td><td>1,44 nm</td><td>8</td></tr>
<tr><td>D</td><td>1,355 µm</td><td colspan="3"></td><td>8,89 nm</td><td>88,32</td></tr>
<tr><td colspan="7">$u_c(D)$ = 8,9 nm; U(D) = 18 nm ; ν_{eff} = 88; k = 2,0</td></tr>
</table>

Table 6. **R6** – parameter D

<table>
<tr><td colspan="7">Type A2; EN 806; R1 = 8 µm</td></tr>
<tr><td>quantity X_i</td><td>estimate x_i</td><td>uncertainty $u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient c_i</td><td>uncertainty contribution $u_i(D)$</td><td>degrees of freedom ν_i</td></tr>
<tr><td>Pt_n</td><td>2,657 µm</td><td>7,5 nm</td><td>N</td><td>3</td><td>22,5 nm</td><td>100</td></tr>
<tr><td>ΔPt</td><td>0</td><td>0,58 nm</td><td>R</td><td>3</td><td>1,74 nm</td><td>8</td></tr>
<tr><td>b</td><td>0</td><td>1,42 nm</td><td>N</td><td>3</td><td>4,26 nm</td><td>9</td></tr>
<tr><td>z_t</td><td>0</td><td>1,50 nm</td><td>N</td><td>1</td><td>1,50 nm</td><td>14</td></tr>
<tr><td>z_{ref}</td><td>0</td><td>4,18 nm</td><td>R</td><td>1</td><td>4,18 nm</td><td>8</td></tr>
<tr><td>z_0</td><td>0</td><td>0,55 nm</td><td>R</td><td>1</td><td>0,55 nm</td><td>9</td></tr>
<tr><td>A</td><td>0</td><td>1,44 nm</td><td>R</td><td>1</td><td>1,44 nm</td><td>8</td></tr>
<tr><td>D</td><td>8,283 µm</td><td colspan="3"></td><td>23,44 nm</td><td>114,40</td></tr>
<tr><td colspan="7">$u_c(D)$ = 23,4 nm; U(D) = 47 nm ; ν_{eff} = 114; k = 2,0</td></tr>
</table>

1 GEOMETRICAL STANDARD P114A

Table 1. Parameter Ra

<table>
<tr><td colspan="7">Type C; P114A; Ra = 0,5 µm</td></tr>
<tr><td>quantity
X_i</td><td>estimate
x_i</td><td>uncertainty
$u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient
c_i</td><td>uncertainty contribution
$u_i(Ra)$</td><td>degrees of freedom
ν_i</td></tr>
<tr><td>Pt_n</td><td>2,657 µm</td><td>7,5 nm</td><td>N</td><td>1</td><td>7,5 nm</td><td>100</td></tr>
<tr><td>Ra_t</td><td>0</td><td>0,25 nm</td><td>N</td><td>1</td><td>0,25 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>11,5 nm</td><td>R</td><td>1</td><td>11,5 nm</td><td>9</td></tr>
<tr><td>Ra_s</td><td>0</td><td>2,72 nm</td><td>R</td><td>1</td><td>2,72 nm</td><td>8</td></tr>
<tr><td>Ra</td><td>0,500 µm</td><td colspan="3"></td><td>14,00 nm</td><td>19,38</td></tr>
<tr><td colspan="7">$u_c(Ra)$ = 14,0 nm; U(Ra) = 29 nm ; ν_{eff} = 19; k = 2,09</td></tr>
</table>

Table 2. Parameter Rz

<table>
<tr><td colspan="7">Type C; P114A; Ra = 0,5 µm</td></tr>
<tr><td>quantity
X_i</td><td>estimate
x_i</td><td>uncertainty
$u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient
c_i</td><td>uncertainty contribution
$u_i(Rz)$</td><td>degrees of freedom
ν_i</td></tr>
<tr><td>Pt_n</td><td>2,657 µm</td><td>7,5 nm</td><td>N</td><td>1</td><td>7,5 nm</td><td>100</td></tr>
<tr><td>Rz_t</td><td>0</td><td>0,80 nm</td><td>N</td><td>1</td><td>0,80 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>11,5 nm</td><td>R</td><td>1</td><td>11,5 nm</td><td>9</td></tr>
<tr><td>Rz_s</td><td>0</td><td>6,84 nm</td><td>R</td><td>1</td><td>6,84 nm</td><td>8</td></tr>
<tr><td>Rz</td><td>1,576 µm</td><td colspan="3"></td><td>15,36 nm</td><td>24,75</td></tr>
<tr><td colspan="7">$u_c(Rz)$ = 15,4 nm; U(Rz) = 32 nm ; ν_{eff} = 24; k = 2,07</td></tr>
</table>

Table 3. Parameter Rmax

<table>
<tr><td colspan="7">Type C; P114A; Ra = 0,5 µm</td></tr>
<tr><td>quantity
X_i</td><td>estimate
x_i</td><td>uncertainty
$u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient
c_i</td><td>uncertainty contribution
$u_i(Rmax)$</td><td>degrees of freedom
ν_i</td></tr>
<tr><td>Pt_n</td><td>2,657 µm</td><td>7,5 nm</td><td>N</td><td>1</td><td>7,5 nm</td><td>100</td></tr>
<tr><td>$Rmax_t$</td><td>0</td><td>1,78 nm</td><td>N</td><td>1</td><td>1.78 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>11,5 nm</td><td>R</td><td>1</td><td>11,5 nm</td><td>9</td></tr>
<tr><td>$Rmax_s$</td><td>0</td><td>6,94 nm</td><td>R</td><td>1</td><td>6,94 nm</td><td>8</td></tr>
<tr><td>Rmax</td><td>1,589 µm</td><td colspan="3"></td><td>15,49 nm</td><td>25,39</td></tr>
<tr><td colspan="7">$u_c(Rmax)$ = 15,5 nm; U(Rmax) = 32 nm ; ν_{eff} = 25; k = 2,06</td></tr>
</table>

Table 4. Parameter RSm

Type C; P114A; Ra = 0,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(RSm)$	degrees of freedom ν_i
RSm_n	0	150 nm	N	1	150 nm	100
RSm_t	0	1,63 nm	N	1	1,63 nm	35
RSm	50,03 µm				150,01 nm	100,02
$u_c(RSm)$ = 150,0 nm; U(RSm) = 300 nm ; ν_{eff} = 100; k = 2,0						

Geometrical standard 7070

Table 1. Parameter Ra

Type C; 7070; Ra = 3,00 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Ra_t	0	2,07 nm	N	1	2,07 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Ra_s	0	12,1 nm	R	1	12,1 nm	8
Ra	2,944 µm				18,29 nm	24,76
$u_c(Ra)$ = 18,3 nm; U(Ra) = 38 nm ; ν_{eff} = 24; k = 2,05						

Table 2. Parameter Rz

Type C; 7070; Ra = 3,00 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rz_t	0	7,58 nm	N	1	7,58 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rz_s	0	37,8 nm	R	1	37,8 nm	8
Rz	9,614 µm				40,87 nm	10,85
$u_c(Rz)$ = 40,9 nm; U(Rz) = 91 nm ; ν_{eff} = 10; k = 2,23						

Table 3. Parameter Rmax

Type C; 7070; Ra = 3,00 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rmax)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
$Rmax_t$	0	9,6 nm	N	1	9,6 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
$Rmax_s$	0	38,6 nm	R	1	38,6 nm	8
Rmax	9,808 µm				42,02 nm	11,16
$u_c(Rmax)$ = 42,0 nm; U(Rmax) = 92 nm ; ν_{eff} = 11; k = 2,20						

Table 4. Parameter RSm

Type C; 7070; Ra = 3,00 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(RSm)$	degrees of freedom ν_i
RSm_n	0	150 nm	N	1	150 nm	100
RSm_t	0	5,7 nm	N	1	3,31 nm	35
RSm	199,94 µm				150,04 nm	100,10
$u_c(RSm)$ = 150 nm; U(RSm) = 300 nm ; ν_{eff} = 100; k = 2,0						

2 GEOMETRICAL STANDARD 8194

Table 1. Parameter Ra

Type C; 8194; Ra = 0,88 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Ra_t	0	1,08 nm	N	1	1,08 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Ra_s	0	4,22 nm	R	1	4,22 nm	8
Ra	0,891 µm				14,81 nm	20,23
$u_c(Ra)$ = 14,8 nm; U(Ra) = 31 nm ; ν_{eff} = 20; k = 2,09						

Table 2. Parameter Rz

Type C; 8194; Ra = 0,88 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rz_t	0	8,92 nm	N	1	8,92 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rz_s	0	12,6 nm	R	1	12,6 nm	8
Rz	3,061 µm				20,94 nm	33,94
$u_c(Rz)$ = 20,9 nm; U(Rz) = 42 nm ; ν_{eff} = 33; k = 2,03						

Table 3. Parameter Rmax

Type C; 8194; Ra = 0,88 µm						
quantity	estimate	uncertainty	probability distribution	sensitivity coefficient	uncertainty contribution	degrees of freedom
X_i	x_i	$u(x_i)$		c_i	$u_i(Rmax)$	ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
$Rmax_t$	0	0,95 nm	N	1	0,95 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
$Rmax_s$	0	12,7 nm	R	1	12,7 nm	8
Rmax	3,081 µm				19,04 nm	23,51
u_c(Rmax) = 19,0 nm; U(Rmax) = 39 nm ; ν_{ef}f = 23; k = 2,07						

Table 4. Parameter RSm

Type C; 8194; Ra = 0,88 µm						
quantity	estimate	uncertainty	probability distribution	sensitivity coefficient	uncertainty contribution	degrees of freedom
X_i	x_i	$u(x_i)$		c_i	$u_i(RSm)$	ν_i
RSm_n	0	150 nm	N	1	150 nm	100
RSm_t	0	4,85 nm	N	1	4,85 nm	35
RSm	119,99 µm				150,08 nm	100,29
u_c(RSm) = 150,1 nm; U(RSm) = 300 nm ; ν_{eff} = 100; k = 2,0						

Roughness standard 629f

Table 1. Parameter Ra

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Ra_t	0	0,35 nm	N	1	0,35 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Ra_s	0	1,33 nm	R	1	1,33 nm	8
Ra	0,147µm				14,22 nm	17,49
$u_c(Ra)$ = 14,2 nm; U(Ra) = 30 nm ; ν_{eff} = 17; k = 2,11						

Table 2. Parameter Rz

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rz_t	0	5,70 nm	N	1	5,70 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rz_s	0	5,59 nm	R	1	5,59 nm	8
Rz	1,252 µm				16,25 nm	28,01
$u_c(Rz)$ = 16,3 nm; U(Rz) = 33 nm ; ν_{eff} = 28; k = 2,05						

Table 3. Parameter Rmax

Type D; 629f; Ra=0,2 µm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rmax)	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
$Rmax_t$	0	12,5 nm	N	1	12,5 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
$Rmax_s$	0	6,36 nm	R	1	6,36 nm	8
Rmax	1,423 µm				19,92 nm	48,67

u_c(Rmax) = 19,9 nm; U(Rmax) = 40 nm ; ν_{eff} = 48; k = 2,01

Table 4. Parameter Rk

Type D; 629f; Ra = 0,2 µm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rk)	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rk_t	0	2,65 nm	N	1	2,65 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rk_s	0	2,50 nm	R	1	2,50 nm	50
Rk	0,456 µm				14,61 nm	19,50

u_c(Rk) = 14,6 nm; U(Rk) = 31 nm ; ν_{eff} = 19; k = 2,09

Table 5. Parameter Rpk

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rpk)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rpk_t	0	1,53 nm	N	1	1,53 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rpk_s	0	1,39 nm	R	1	1,39 nm	50
Rpk	0,162 µm				14,30 nm	17,91
$u_c(Rpk)$ = 14,3 nm; U(Rpk) = 30 nm ; ν_{eff} = 17; k = 2,10						

Table 6. Parameter Rvk

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rvk)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rvk_t	0	3,03 nm	N	1	3,03 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rvk_s	0	1,91 nm	R	1	1,91 nm	50
Rvk	0,302 µm				14,60nm	19,42
$u_c(Rvk)$ = 14,6 nm; U(Rvk) = 31 nm ; ν_{eff} = 19; k = 2,09						

Table 7. Parameter Mr1

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Mr1)	degrees of freedom ν_i
Pt_n	2,657 µm	0,5 %	N	1	0,5 %	100
$Mr1_t$	0	0,08 %	N	1	0,08 %	35
z_0	0	0,84 %	R	1	0,84 %	24
$Mr1_s$	0	0,29 %	R	1	0,29 %	50
Mr1	8,3 %				1,02 %	50,87
u_c(Mr1) = 1,0 %; U(Mr1) = 2,0 % ; ν_{eff} = 50; k = 2,0						

Table 8. Parameter Mr2

Type D; 629f; Ra = 0,2 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Mr2)	degrees of freedom ν_i
Pt_n	2,657 µm	0,5 %	N	1	0,5 %	100
$Mr2_t$	0	0,10 %	N	1	0,10 %	35
z_0	0	0,84 %	R	1	0,84 %	24
$Mr2_s$	0	0,29 %	R	1	0,29 %	50
Mr2	87,5 %				1,02 %	51,22
u_c(Mr2 = 1,0 %; U(Mr2) = 2,0 % ; ν_{eff} = 51; k = 2,0						

3 ROUGHNESS STANDARD 633G

Table 1. Parameter Ra

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Ra_t	0	0,35 nm	N	1	0,35 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Ra_s	0	6,53 nm	R	1	6,53 nm	8
Ra	1,500 µm				15,59 nm	23,04
$u_c(Ra)$ = 15,6 nm; U(Ra) = 32 nm ; ν_{eff} = 23; k = 2,07						

Table 2. Parameter Rz

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rz_t	0	24,45 nm	N	1	24,45 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rz_s	0	29,5 nm	R	1	29,5 nm	8
Rz	7,473 µm				40,84 nm	25,96
$u_c(Rz)$ = 40,8 nm; U(Rz) = 84 nm ; ν_{eff} = 25; k = 2,06						

Table 3. Parameter Rmax

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rmax)	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
$Rmax_t$	0	14,85 nm	N	1	14,85 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
$Rmax_s$	0	34,5 nm	R	1	34,5 nm	8
Rmax	8,752 µm				40,14 nm	14,35
u_c(Rmax) = 40,1 nm; U(Rmax) = 86 nm ; ν_{eff} = 14; k = 2,14						

Table 4. Parameter Rk

Type D; 633g; Ra =1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rk)	degrees of freedom ν_i
Pt_n	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rk_t	0	22,7 nm	N	1	22.7 nm	35
z_0	0	11,3 nm	R	1	12.0 nm	9
Rk_s	0	17,5 nm	R	1	17,5 nm	50
Rk	4,371 µm				31,97 nm	88,50
u_c(Rk) = 32,0 nm; U(Rk) = 64 nm ; ν_{eff} = 88; k = 2,0						

Table 5. Parameter Rpk

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rpk)$	degrees of freedom ν_i
Pt_n	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rpk_t	0	8,68 nm	N	1	8,68 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rpk_s	0	4,05 nm	R	1	4,05 nm	50
Rpk	0,833 µm				17,09 nm	34,06
$u_c(Rpk)$ = 17,1 nm; U(Rpk) = 35 nm ; ν_{eff} = 34; k = 2,03;						

Table 6. Parameter Rvk

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rvk)$	degrees of freedom ν_i
Pt_n	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rvk_t	0	18,83 nm	N	1	18,83 nm	35
z_0	0	12,0 nm	R	1	12,0 nm	9
Rvk_s	0	11,4 nm	R	1	11,4 nm	50
Rvk	2,735 µm				26,17 nm	74,84
$u_c(Rvk)$ = 26,2 nm; U(Rvk) = 52 nm ; ν_{eff} = 74; k = 2,0;						

Table 7. Parameter Mr1

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr1)$	degrees of freedom ν_i
Pt_n	2,657 µm	0,09 %	N	1	0,09 %	100
$Mr1_t$	0	0,08 %	N	1	0,08 %	35
z_0	0	0,14 %	R	1	0,14 %	9
$Mr1_s$	0	0,29 %	R	1	0,29 %	8
Mr1	6,5 %				0,34 %	73,42
$u_c(Mr1)$ = 0,34 %; U(Mr1) = 1,0 % ; ν_{eff} = 73; k = 2,0						

Table 8. Parameter Mr2

Type D; 633g; Ra = 1,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr2)$	degrees of freedom ν_i
Pt_n	2,657 µm	0,09 %	N	1	0,09 %	100
$Mr2_t$	0	0,07 %	N	1	0,07 %	35
z_0	0	0,14 %	R	1	0,14 %	9
$Mr2_s$	0	0,29 %	R	1	0,29 %	8
Mr2	79,5 %				0,34 %	75,13
$u_c(Mr2)$ = 0,34 %; U(Mr2) = 1,0 % ; ν_{eff} = 75; k = 2,0						

4 ROUGHNESS STANDARD 686SG

Table 1. Parameter Ra

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Ra_t	0	3,52 nm	N	1	3,52 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Ra_s	0	9,65 nm	R	1	9,65 nm	8
Ra	2,321 µm				17,01 nm	28,58
$u_c(Ra)$ = 17,0 nm; U(Ra) = 35 nm ; ν_{eff} = 28; k = 2,05						

Table 2. Parameter Rz

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rz_t	0	48,6 nm	N	1	48,6 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rz_s	0	55,5 nm	R	1	55,5 nm	8
Rz	14,22 µm				75,01 nm	23,50
$u_c(Rz)$ = 75,0 nm; U(Rz) = 160 nm ; ν_{eff} = 23; k = 2,07						

Table 3. Parameter Rmax

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rmax)	degrees of freedom ν_i
Pt$_n$	2,657 µm	7,5 nm	N	1	7,5 nm	100
Rmax$_t$	0	5,0 nm	N	1	5,0 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rmax$_s$	0	60,1 nm	R	1	60,1 nm	8
Rmax	15,38 µm				61,81 nm	8,94
u_c(Rmax) = 61,8 nm; U(Rmax) = 140 nm ; ν_{eff} = 8 ; k = 2,20						

Table 4. Parameter Rk

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(Rk)	degrees of freedom ν_i
Pt$_n$	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rk$_t$	0	9,37 nm	N	1	9,37 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rk$_s$	0	31,8 nm	R	1	31,8 nm	50
Rk	8,051 µm				35,82 nm	73,11
u_c(Rk) = 35,8 nm; U(Rk) = 72 nm ; ν_{eff} = 73; k = 2,0						

Table 5. Parameter Rpk

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rpk)$	degrees of freedom ν_i
Pt_n	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rpk_t	0	8,62 nm	N	1	8,62 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rpk_s	0	6,18 nm	R	1	6,18 nm	50
Rpk	1,390 µm				17,22 nm	42,88
$u_c(Rpk)$ = 17,2 nm; U(Rpk) = 35 nm ; ν_{eff} = 42; k = 2,01						

Table 6. Parameter Rvk

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rvk)$	degrees of freedom ν_i
Pt_n	2,657 nm	7,5 nm	N	1	7,5 nm	100
Rvk_t	0	56,53 nm	N	1	56,53 nm	35
z_0	0	11,3 nm	R	1	11,3 nm	9
Rvk_s	0	13,12nm	R	1	13,12 nm	50
Rvk	3,21 µm				59,60 nm	42,88
$u_c(Rvk)$ = 59,6 nm; U(Rvk) = 120 nm ; ν_{eff} = 42; k = 2,02						

Table 7. Parameter Mr1

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr1)$	degrees of freedom ν_i
Pt_n	2,657 µm	0,05 %	N	1	0,05 %	100
$Mr1_t$	0	0,06 %	N	1	0,06 %	35
z_0	0	0,07 %	R	1	0,07 %	9
$Mr1_s$	0	0,29 %	R	1	0,29 %	8
Mr1	7,2 %				0,31 %	62,56
$u_c(Mr1)$ = 0,31 %; U(Mr1) = 1,0 % ; ν_{eff} = 62; k = 2,0						

Table 8. Parameter Mr2

Type D; 686sg; Ra = 2,5 µm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr2)$	degrees of freedom ν_i
Pt_n	2,657 µm	0,05 %	N	1	0,05 %	100
$Mr1_t$	0	0,09 %	N	1	0,09 %	35
z_0	0	0 07 %	R	1	0 07 %	9
$Mr1_s$	0	0 29 %	R	1	0 29 %	8
Mr1	91,7 %				0,32 %	67,92
$u_c(Mr2)$ = 0,32 %; U(Mr2) = 1,0 % ; ν_{eff} = 67; k = 2,0						

5 ROUGHNESS STANDARD 1006

Table 1. Parameter Ra

Type D; 1006; Rz = 150 nm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Ra)$	degrees of freedom ν_i
Pt_n	0,3614 µm	2,5 nm	N	1	2,5 nm	100
Ra_t	0	0,10 nm	N	1	0,10 nm	35
z_0	0	8,7 nm	R	1	8,7 nm	24
Ra_s	0	0,87 nm	R	1	0,87 nm	8
Ra	0,024 µm				9,09 nm	28,60
$u_c(Ra)$ = 9,1 nm; U(Ra) = 19 nm ; ν_{eff} = 28; k = 2,05						

Table 2. Parameter Rz

Type D; 1006; Rz = 150 nm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Rz)$	degrees of freedom ν_i
Pt_n	0,3614 µm	2,5 nm	N	1	2,5 nm	100
Rz_t	0	0,54 nm	N	1	0,54 nm	35
z_0	0	8,7 nm	R	1	8,7 nm	24
Rz_s	0	1,30 nm	R	1	1,30 nm	8
Rz	0,138 µm				9,16 nm	29,41
$u_c(Rz)$ = 9,2 nm; U(Rz) = 19 nm ; ν_{eff} = 29; k = 2,05						

Table 3. Parameter Rmax

<table>
<tr><td colspan="7">Type D; 1006; Rz = 150 nm</td></tr>
<tr><td>quantity X_i</td><td>estimate x_i</td><td>uncertainty $u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient c_i</td><td>uncertainty contribution u_i(Rmax)</td><td>degrees of freedom ν_i</td></tr>
<tr><td>Pt_n</td><td>0,3614 µm</td><td>2,5 nm</td><td>N</td><td>1</td><td>2,5 nm</td><td>100</td></tr>
<tr><td>$Rmax_t$</td><td>0</td><td>1,62 nm</td><td>N</td><td>1</td><td>1,62 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>8,7 nm</td><td>R</td><td>1</td><td>8,7 nm</td><td>24</td></tr>
<tr><td>$Rmax_s$</td><td>0</td><td>1,45 nm</td><td>R</td><td>1</td><td>1,45 nm</td><td>8</td></tr>
<tr><td>Rmax</td><td>0,171 µm</td><td colspan="3"></td><td>9,31 nm</td><td>31,32</td></tr>
<tr><td colspan="7">u_c(Ra) = 9,3 nm; U(Ra) = 19 nm ; ν_{eff} = 31; k = 2,03</td></tr>
</table>

Table 4. Parameter Rk

<table>
<tr><td colspan="7">Type D; 1006; Rz = 150 nm</td></tr>
<tr><td>quantity X_i</td><td>estimate x_i</td><td>uncertainty $u(x_i)$</td><td>probability distribution</td><td>sensitivity coefficient c_i</td><td>uncertainty contribution u_i(Rk)</td><td>degrees of freedom ν_i</td></tr>
<tr><td>Pt_n</td><td>0,3614 nm</td><td>2,5 nm</td><td>N</td><td>1</td><td>2,5 nm</td><td>100</td></tr>
<tr><td>Rk_t</td><td>0</td><td>0,53 nm</td><td>N</td><td>1</td><td>0,53 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>8,7 nm</td><td>R</td><td>1</td><td>8,7 nm</td><td>24</td></tr>
<tr><td>Rk_s</td><td>0</td><td>1,04 nm</td><td>R</td><td>1</td><td>1,04 nm</td><td>50</td></tr>
<tr><td>Rk</td><td>0,075 µm</td><td colspan="3"></td><td>9,13 nm</td><td>29,02</td></tr>
<tr><td colspan="7">u_c(Rk) = 9,1 nm; U(Rk) = 19 nm ; ν_{eff} = 29; k = 2,04</td></tr>
</table>

Table 5. Parametr Rpk

<table>
<tr><th colspan="7">Type D; 1006; Rz = 150 nm</th></tr>
<tr><th>quantity
X_i</th><th>estimate
x_i</th><th>uncertainty
$u(x_i)$</th><th>probability distribution</th><th>sensitivity coefficient
c_i</th><th>uncertainty contribution
$u_i(Rpk)$</th><th>degrees of freedom
ν_i</th></tr>
<tr><td>Pt_n</td><td>0,3614 nm</td><td>2,5 nm</td><td>N</td><td>1</td><td>2,5 nm</td><td>100</td></tr>
<tr><td>Rpk_t</td><td>0</td><td>0,48 nm</td><td>N</td><td>1</td><td>0,48 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>8,7 nm</td><td>R</td><td>1</td><td>8,7 nm</td><td>24</td></tr>
<tr><td>Rpk_s</td><td>0</td><td>0,87 nm</td><td>R</td><td>1</td><td>0,87 nm</td><td>50</td></tr>
<tr><td>Rpk</td><td>0,028 µm</td><td colspan="3"></td><td>9,11 nm</td><td>28,76</td></tr>
<tr><td colspan="7">$u_c(Rpk)$ = 9,1 nm; U(Rpk) = 19 nm ; ν_{eff} = 29; k = 2,05</td></tr>
</table>

Table 6. Parameter Rvk

<table>
<tr><th colspan="7">Type D; 1006; Rz=150 nm</th></tr>
<tr><th>quantity
X_i</th><th>estimate
x_i</th><th>uncertainty
$u(x_i)$</th><th>probability distribution</th><th>sensitivity coefficient
c_i</th><th>uncertainty contribution
$u_i(Rvk)$</th><th>degrees of freedom
ν_i</th></tr>
<tr><td>Pt_n</td><td>0,3614 nm</td><td>2,5 nm</td><td>N</td><td>1</td><td>2,5 nm</td><td>100</td></tr>
<tr><td>Rvk_t</td><td>0</td><td>0,73 nm</td><td>N</td><td>1</td><td>0,73 nm</td><td>35</td></tr>
<tr><td>z_0</td><td>0</td><td>8,7 nm</td><td>R</td><td>1</td><td>8,7 nm</td><td>24</td></tr>
<tr><td>Rvk_s</td><td>0</td><td>0,87 nm</td><td>R</td><td>1</td><td>0,87 nm</td><td>50</td></tr>
<tr><td>Rvk</td><td>0,032 µm</td><td colspan="3"></td><td>9,12 nm</td><td>29,97</td></tr>
<tr><td colspan="7">uc(Rvk) = 9,1 nm; U(Rvk) = 19 nm ; ν_{eff} = 29; k = 2,04</td></tr>
</table>

Table 7. Parameter Mr1

Type D; 1006; Rz = 150 nm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr1)$	degrees of freedom ν_i
Pt_n	0,3614 µm	1,46 %	N	1	1,46 %	100
$Mr1_t$	0	0,23 %	N	1	0,23 %	35
z_0	0	2,5 %	R	1	2,5 %	24
$Mr1_s$	0	0,29 %	R	1	0,29 %	50
Mr1	10,8%				2,92 %	43,37
$u_c(Mr1)$ = 2,9 %; U(Mr2) = 5,8 %; ν_{eff} = 43; k = 2,01						

Table 8. Parameter Mr2

Type D; 1006; Rz = 150 nm						
quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(Mr2)$	degrees of freedom ν_i
Pt_n	0,3614 µm	1,46 %	N	1	1,46 %	100
$Mr2_t$	0	0,21 %	N	1	0,21 %	35
z_0	0	2,5 %	R	1	2,5 %	24
$Mr2_s$	0	0,29 %	R	1	0,29 %	50
Mr2	81,4 %				2,92 %	43,37
$u_c(Mr2)$ = 2,9 %; U(Mr2) = 5,8 % ; ν_{eff} = 43; k = 2,01						

Appendix B1

Reports of ILM

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments ....

The surface profiling instrument in use at ILM is a Form Talysurf 120 with a laser interferometric unit for measuring vertical pick-up to 6.0 mm tip radius 2µm. The range-to-resolution ratio is of 600000:1 which corrisponds to a resolution of 10 nm. The instrument is autoranging. The traverse unit moves the stylus laterally ap to 120 mm with deviations from straightness within 0.1 µm over any 20 mm in the traverse range, as specified by the manufacturer. The instrument used a computer-based control for data acquisition, data analysis and measurements control, software version. 4.0.. The instrument is placed in a room with temperature control(± 1 C°) over a anti-vibration table to minimise vibration noise. .. ..

For standards of type A2 the condition of evaluation are : ....

unfiltered, manual properly alignment and manual measurements. The software in accordance with ISO 5346 is not available. ....

For Standards of type C3,D1,D2 the condition of evaluation are :

phase correct profile filter according ISO 11562, least square reference. ....

....

The values of roughness parameters on flat glass are :

Ra=0.002µm, Rt=0.018µm,Wa=0.003µm,Wt=0.012µm. **…**

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Laboratory: **...Istituto Lavorazione Metalli**...

Date: ..2002/04/22..........................   Signature:....Cuppini Dario..

A4 - Uncertainty of measurement

Step height standard with a nominal height of 200 nm:
identification A2 depth-setting standard s/n EN 806 / PTB 99 073 groove R1

Equation used:

$$d = d_0 \cdot f_c \cdot f_{st}$$

d = 290 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ nm	degrees of freedom ν_i
Profile evaluation	d_0	6 nm	N	1	6	4
Repeatability	f_c	0,011	N	$d_0 \cdot f_{st}$	3,19	6
DPT calib. standard	f_{st}	0,0035	N	$d_0 \cdot f_c$	1,02	20

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 7 nm

Effective degree of freedom: $\nu_{eff}(d)$ = 7

Expanded uncertainty: $U(d)$ = 17 nm with a coverage factor k=2

Laboratory:**Istituto Lavorazione Metalli**..

Date: .2002/04/22.......................... Signature:....Cuppini Dario...

A4 - Uncertainty of measurement

Step height standard with a nominal height of 1500 nm: identification

Equation used:

$$d = f(x_i)$$

$d = d_0 * f_c$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Profile evaluation	d_0	3 nm	N	1	3 nm	4
Calibration factor	f_c	0,008	N	1500nm	12nm	5
DPT calib. standard	f_c	0,0011	N	1500nm	2nm	20

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 13 nm

Effective degree of freedom: $\nu_{\text{eff}}(d)$ = 9

Expanded uncertainty: $U(d)$ = 30 nm with a coverage factor k=2

Laboratory: .**Istituto Lavorazione Metalli**...

Date: 2002/04/22............................ Signature:...Cuppini Dario..

A4 - Uncertainty of measurement

Step height standard with a nominal height of 8000 nm: identification

Equation used:

$$d = f(x_i)$$

$d = d_0 * f_c$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Profile evaluation	d_0	4 nm	N	1	4 nm	4
Calibration factor	f_c	0,003	N	8000nm	24nm	8
DPT calib. standard	f_c	0,0011	N	8000nm	9nm	20

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 26 nm

Effective degree of freedom: $\nu_{eff}(d)$ = 9

Expanded uncertainty: $U(d)$ = 60 nm with a coverage factor k=2

Laboratory: ...**Istituto Lavorazione Metalli**...

Date: .2002/04/22............................ Signature:....Cuppini Dario...

Comment from ILM/ISTEC

Comment to our report added after Draft A was published:

Comparing our results with the reference values of Draft A we found that the parameter Ry provided by our instrument using a software based on ISO 4287:1984 is a better approach to Rmax then Rt.

Therefore our new values for type C,D standard are:

Geom. Standard			(Rmax) Rt	**(Rmax) Ry**
Rub	P114A/528-RS 5	value	1,609	**1,605**
		std. dev.	12	**13**
		Meas. Unc.	65	**65**
PTB	7070/PGN10	value	9,767	**9,766**
		std. dev.	66	**70**
		Meas. Unc.	391	**391**
PTB	8194/PGN3	value	3,112	**3,105**
		std. dev.	51	**53**
		Meas. Unc.	125	**124**

Roughn.standard			(Rmax) Rt	**(Rmax) Ry**
very coarse	686sg	value	15,568	**15,531**
		std. dev.	40	**43**
		Meas. Unc.	778	**777**
coarse	633g	value	8,842	**8,821**
		std. dev.	91	**97**
		Meas. Unc.	442	**441**
fine	629f	value	1,512	**1,359**
		std. dev.	49	**29**
		Meas. Unc.	76	**68**
SFRN 150	1.006	value	0,2030	**0,1960**
		std. dev.	15	**24**
		Meas. Unc.	12	**12**

Uncertainty budget doesn't need a new calculation.

Appendix B1

Reports of IMGC

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments

The roughness and groove standards have been measured at IMGC using a stylus profilometer (Talystep 1, Taylor Hobson- RTH). The instrument works with a PC control (RTH Talystep PC software 0,01 SP) for data acquisition, calibration and setting of measurement parameters. The surface profiles have been analysed using the software RTH – Groove (3.02P IMGC), which calculates the step-height according the ISO 5436.
The instrument has a traverse scan range of ### 2 mm and a measuring pick-up vertical range of ### 12 µm at the lowest magnification, down to a range of ### 30 nm at the highest magnification. Since at this high magnification, vibration, acoustic noise and thermal drift may seriously affect measurement results, our instrument is placed on a massive table with inner air tubes for vibration isolation, in a room with air temperature control. In addition, the instrument itself is equipped with an antivibration base platform and is placed in a insulating box.

Talystep 1 has been calibrated by means of two displacement piezo-capacitive transducers (DPT-10 from Queensgate) which , in turns, have been calibrated using a heterodyne interferometer, namely by sampling the displacements of the transducer at steps of ###/4 in order to minimize the non-linearity error of the interferometer. By correcting the observed non-linearity of the transducer, the resulting expanded uncertainty of the transducer displacements is thus estimated as $0,7\text{nm} + 1\cdot 10^{-4} \times d/\text{nm}$.
By driving the DPT with a low-frequency square-wave AC signal we produced corresponding vertical displacements of the Talystep pick-up in contact with an optical flat mirror glued to the moving part of the transducer. In this way, the pick-up vertical displacements resulted in a recorded profile having a rectangular shape and a definite step height.
The instruments is not calibrated for the lateral displacements of the tip when scanning the sample surface.

All the measurements on the circulating standards have been taken with a stylus tip having a pyramidal shape with angles at the vertex from 90° to 120°, truncated to nominal radii of 0,2 x 2,5 µm. The stylus is mounted so that the larger dimension of the tip is perpendicular to the direction of pick-up traverse movements. The xy stage of the instrument has been used for levelling and positioning the sample.
The measurements have been taken at a room temperature of (20 ± 0.3) °C.

The instrument works with the RTH Talystep PC software 0,01 SP, which does not read the format of the circulating data files. In addition, not all the required roughness parameters are available with the above-mentioned software.

Laboratory: ....IMGC – Istituto di Metrologia “G. Colonnetti”

Date: .....May 15, 2002.......................... Signature:............Gian Bartolo Picotto

A4 - Uncertainty of measurement

Step height standard with a nominal height of 200 nm:

identification A2 depth-setting standard s/n EN 806 / PTB 99 073 groove R1

Equation used:

$$d = d_o \cdot f_c \cdot f_{st}$$

d = 283 nm

quantity X_i		estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ / nm	degrees of freedom ν_i
Instrument calibration	**Uncertainty of the DPT transducer**	f_{st}	0,0012	N	$d_o \cdot f_c$	0,35	10
	repeatability	f_c	0,0025	N	$d_o \cdot f_{st}$	0,71	32
Profile evaluation		d_o	2,5 nm	N	1	2,5	50

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 2,6 nm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 60

Expanded uncertainty: $U(d)$ = 5,5 nm with a coverage factor k=2

Laboratory: ....IMGC - Istituto di Metrologia “G. Colonnetti”...

Date: ....May 15, 2002........................... Signature:........Gian Bartolo Picotto......................

A4 - Uncertainty of measurement

Step height standard with a nominal height of 1500 nm:

identification A2 depth-setting standard s/n EN 806 / PTB 99 073 groove R3

Equation used:

$$d = d_o \cdot f_c \cdot f_{st}$$

d = 1367 nm

quantity X_i		estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ / nm	degrees of freedom ν_i
Instrument calibration	**Uncertainty of the DPT transducer**	f_{st}	0,00028	N	$d_o \cdot f_c$	0,38	10
	repeatability	f_c	0,002	N	$d_o \cdot f_{st}$	2,7	32
Profile evaluation		d_o	2,5 nm	N	1	2,5	50

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 3,7 nm

Effective degree of freedom: $\nu_{\text{eff}}(d)$ = 76

Expanded uncertainty: $U(d)$ = 8 nm with a coverage factor k=2

Laboratory: ....IMGC - Istituto di Metrologia “G. Colonnetti”...

Date: ....May 15, 2002........................... Signature:........Gian Bartolo Picotto.......................

A4 - Uncertainty of measurement

Step height standard with a nominal height of 8000 nm:

identification A2 depth-setting standard s/n EN 806 / PTB 99 073 groove R6

Equation used:

$$d = d_o \cdot f_c \cdot f_{st}$$

d = 8357 nm

quantity X_i		estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$ / nm	degrees of freedom ν_i
Instrument calibration	**Uncertainty of the DPT transducer**	f_{st}	0,00015	N	$d_o \cdot f_c$	1,2	10
	repeatability	f_c	0,0015	N	$d_o \cdot f_{st}$	12,5	32
Profile evaluation		d_o	5 nm	N	1	5	50

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(d)$ = 13,5 nm

Effective degree of freedom: $\nu_{\mathrm{eff}}(d)$ = 44

Expanded uncertainty: $U(d)$ = 28 nm with a coverage factor k=2

Laboratory: ....IMGC - Istituto di Metrologia “G. Colonnetti”...

Date: ....May 15, 2002........................... Signature:........Gian Bartolo Picotto......................

Appendix B1

Reports of IPQ

Instituto Português da Qualidade

Measurement Report

EUROMET SUPPLEMENTARY COMPARISON

SURFACE TEXTURE

Project No. 600

By: Mrs. Fernanda Saraiva
Mrs. Sílvia Gentil
Ms. Maria João Santos

August – November 2002

INTRODUCTION

The EUROMET Project No. 600, Comparison of Surface Texture Measurements, is a supplementary comparison in the field of Length under in the scope of the framework of the Mutual Recognition Arrangement (MRA) of the Metre Convention.

The intercomparison addresses the subject “Measurements on Surface Roughness Standards” and it aims to compare the measurements on roughness standards of type B, C and D, as well on the depth setting standard (type A), as described in the ISO 5436-1, with a stylus instrument.

The measurements started at PTB (one of the pilot labs) in Spring 2001. IPQ received the standards in August 2002 and completed the measurements in September and sent the standards to the last participating laboratory (SMU).

1. Measuring Instruments

Stylus Instrument – Perthometer S8P, Mahr

Drive Unit - PRK

Pick-up RFHTB-50

1.1. Software

Software Perthometer version 1.1.

Note: With this version of Perthometer Software we weren't able to:

- evaluate de *D* parameter (depth of the groove as described in ISO 5436-1) because, even after the transference of data to Excel spreadsheet and Microcal Origin 5.0, the values obtained were incoherent with the expected ones.
- select the *λs filter* and the *sampling spacing*, although we verified that the other required conditions mentioned in each datasheet were in accordance to ISO 3274, item 4.4
- test the software by using the input data from the 3 files for software check (Datasheet 5)

2. Kind of Operation

Moving stylus.

3. Conditions of Data Collection

- Vertical measuring range: 62,5 µm
- Stylus tip radius: 2 µm;
- Measuring force: 0,4 mN

4. Conditions of Evaluation

The conditions required in each datasheet were followed, except what concerns the software restrictions (mentioned above).

5. Characterisation of Instrument Noise and Deviation of Ideal Behaviour

- Background Noise: we used the mean value obtained from five measurements of R-parameters (R-profile) performed over an optical flat
- Straightness Deviation: to evaluate the influences due to deviations from straightness we used an optical flat and measured it five times at the same point to evaluate Wt (waviness parameter). This deviation was only used in the calculation of the depth-setting standard.

6. Environment Characterisation

Laboratory environment with a gradient temperature of 0,03 °C.
All the standards were measured at a reference temperature between 20,02 °C and 20,05 °C.

7. Uncertainty Budget

The uncertainty budget was calculated following a Working Instructions Document from PTB regarding Surface Texture Analysis.

7.1 Uncertainty of Measurement for the Total Height of Profile, Pt

In this item is presented the detailed calculation of the uncertainty for the Pt parameter.

7.1.1. Input Quantities and their Contribution to the Uncertainty Budget:

- **Reference Standard**

According to the calibration certificate, the uncertainty of the reference standard (depth-setting standard calibrated by PTB) is U_n = 40 nm, at k=2.

$$u^2(Pt_n) = \frac{U_n^{\,2}}{4} = \frac{40^2}{4} = 400\ nm^2$$

- **Difference Measuring Point**

Regarding the deviation of trace positioning (a_y) and the gradient in the direction of the groove $\left(G = {\partial P_t}/{\partial y}\right)$ it as been considered a_y = 100 µm and G = 40 nm/mm.

$$u^2\left(Pt_{m\,y}\right) = \frac{a_y{}^2 \times G^2}{3} = \frac{\left[\left(100\times 10^3\right)^2 \times \left(\frac{40}{10^6}\right)\right]^2}{3} = 5{,}33\ nm^2$$

- **Repeatability**

For the repeatability evaluated from five measurements it was obtained a standard deviation of 10 nm.

$$u^2(b) = \frac{s^2(Pt_m)}{m} = s^2\left(\overline{Pt_m}\right) = 10^2 = 100\ nm^2$$

- **Topography (Depth Standard EN 806)**

R1: $u^2(z_e) = s^2(Pt) = 10^2 = 100\ nm^2$

R3: $u^2(z_e) = s^2(Pt) = 20^2 = 400\ nm^2$

R6: $u^2(z_e) = s^2(Pt) = 20^2 = 400\ nm^2$

- **Straightness Deviation of Device**

$$u^2\left(z_{ref}\right) = \frac{Wt_0^2}{12} = \frac{(140)^2}{12} = 1633{,}33\ nm^2$$

- **Background Noise**

$$u^2(z_0) = \frac{\left(\overline{Rz_0}\right)^2}{12} = \frac{100^2}{12} = 833.33\ nm^2$$

7.1.2 Uncertainty of Points of Overall Profile:

$$u^2\left(z_g\right) = u^2(Pt_n) + u^2(Pt_{ny}) + u^2(b) + u^2(z_e) + u^2(z_{ref}) + u^2(z_0)$$

$$u^2\left(z_g\right) = \frac{U_n^2}{4} + \frac{a_y{}^2 \times G^2}{3} + \frac{s^2\left(Pt_m\right)}{m} + s^2(Pt) + \frac{Wt_0{}^2}{12} + \frac{Rz_0{}^2}{12}$$

R1: $u^2(z_g) = 400 + 5{,}33 + 100 + 100 + 1633{,}33 + 833{,}33 = 3071{,}99\ nm^2$

$u(z_g) = 55{,}42\ nm$

R3: $u^2(z_g) = 400 + 5{,}33 + 100 + 400 + 1633{,}33 + 833{,}33 = 3371{,}99\ nm^2$

$u(z_g) = 58{,}07\ nm$

R6: $u^2(z_g) = 400 + 5{,}33 + 100 + 400 + 1633{,}33 + 833{,}33 = 3371{,}99\ nm^2$

$u(z_g) = 58{,}07\ nm$

- **Unknown Systematic Deviations**

$u_v^2(Pt)$ - unknown systematic deviations, this input was evaluated by rectangular distribution (Type B).

7.1.3 Uncertainty of Measurement:

$$u^2(Pt) = u^2(z_g) + \left(\frac{u(Pt_n) \times Pt_m}{Pt_n} \right)^2 + u_v^2(Pt)$$

Pt_n - known from the calibration certificate of the depth-setting standard (reference standard)

Pt_m - parameter Pt measured by us (reference standard)

R1: $u^2(Pt) = (55{,}42)^2 + \left[\frac{20 \times (9{,}16 \times 10^3)}{(9{,}11 \times 10^3)} \right]^2 + 75 = 3550{,}78\,nm^2 \Rightarrow u(Pt) = 59{,}59\,nm$

R3: $$u^2(Pt) = (58{,}07)^2 + \left[\frac{20\times\left(9{,}16\times10^3\right)}{\left(9{,}11\times10^3\right)}\right]^2 + 1408 = 5184{,}53\ nm^2 \Rightarrow u(Pt) = 72{,}00\ nm$$

R6: $$u^2(Pt) = (58{,}07)^2 + \left[\frac{20\times\left(9{,}16\times10^3\right)}{\left(9{,}11\times10^3\right)}\right]^2 + 75 = 3851{,}53\ nm^2 \Rightarrow u(Pt) = 62{,}06\ nm$$

With the coverage factor k=2 the resulting expanded uncertainty of measurement is:

$$U(Pt) = u(Pt)\times 2$$

	R1	**R3**	**R6**
U (Pt)	119,18 nm	144,00 nm	124,12 nm

7.2 Uncertainty of Measurement for Surface Parameters

7.2.1. Input quantities and their contribution to the uncertainty budget:

- **Reference standard (Depth Setting Standard)**

  The uncertainty of measurement (U_n) for the total height of profile Pt_n of the reference standard is stated in the calibration certificate with the coverage factor k=2.

$$u^2(Pt_n) = \frac{1}{4}\times U_n^2$$

- **Statistic on Surface**

$s^2(R_x)$, this input quantity was evaluated from the standard deviation of the R-parameters (R_a, R_z, R_{z1max}, R_k, R_{pk}, R_{vk}), determined by 12 measurements.

- **Residual Noise of the Reference Guide of the Stylus Instrument**

$\frac{Rx_0^2}{12}$, this input quantity was evaluated from the standard deviation of the R-parameters (R_a, R_z, R_{z1max}, R_k, R_{pk}, R_{vk}) measured in an optical flat.

- **Unknown Systematic Deviations**

$u_v^2(R_x)$ - unknown systematic deviations, this input was evaluated using a rectangular distribution (Type B).

7.2.2. Expanded Uncertainty

For the calculation of Expanded Uncertainty with the coverage factor k=2, we used the following approximation:

$$U(R_x) \leq 2\times\sqrt{\left(\frac{1}{4}\times Un^2\right)+s^2(R_x)+\frac{Rx_0^2}{12}+u_v^2(R_x)}$$

NOTES:

- Due to insufficient knowledge of the calculation procedure for the uncertainty budget of the parameters Mr1, Mr2, A1 and A2, we do not present the associated uncertainties.
- The optical flat used was not a reference one. It was only used to get values for Wt_0 and R_{a0}, R_{z0}, R_{z1max0}, R_{k0}, R_{pk0}, R_{vk0} parameters.
- Regarding the RS_m parameter evaluated for the standards P114A, PGN10 and PGN3, we believe the values presented in the table "Results and Measurement Conditions" (see Annex) are not representative of the mean width of the profile elements because, for each standard, this parameter got only two values (see table below), where one of them seems to be caused by the presence of defects in the samples (that's why it was obtained a high standard deviation).

Standard	**RS_m (µm)**	
P114A	50,00	48,08
PGN10	201,60	198,41
PGN3	121,21	117,60

A4 - Uncertainty of measurement

Step height standard with a nominal height of 9100 nm
Identification: Setting master PEN 10-1 (Mahr-Perthen)

Equation used: $u^2(Pt) = u^2(z_g) + \left(\frac{u(Pt_n) \times Pt_m}{Pt_n} \right)^2 + u_v{}^2(Pt)$

$$U(Pt) = u(Pt) \times 2$$

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(h)$	Degrees of freedom v_i
Reference standard	40 nm	20 nm	N	1	20 nm	50
Difference measuring point	a_y = 100 µm G = 40 nm/mm	2,31 nm	R	1	2,31 nm	50
Repeatability	10 nm	10 nm	N	1	10 nm	4
Topography	20 nm	20 nm	N	1	20 nm	4
Straightness deviation of device	140 nm	40,41 nm	R	1	40,41 nm	50
Background noise	100 nm	28,87 nm	R	1	28,87 nm	50
Unknown deviations	65 nm	37,53 nm	R	1	37,53 nm	50
Uncertainty of total height of profile	u (Pt) = 20 nm	20,11 nm			20,11 nm	50

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty: $u_c(Pt)$ = 72,00 nm

Effective degree of freedom: $v_{\mathrm{eff}}(Pt)$ = 158,30

Expanded uncertainty: $U(Pt)$ = 144,00 nm with a coverage factor k=2

Laboratory: INSTITUTO PORTUGUÊS DA QUALIDADE

Date: 2002-11-27 Signature:..

Comment from IPQ

At page 18/33 we try to answer at your comments about our reported values concerning the Pt and D parameters. With our measuring system we can not measure without the use of one lc filter. Like you say in the report, the use of this filter would strongly influence the profile of the depth setting standard and looking for the position of ours results on the tables of the appendix D1 (results of Pt parameter) we can see that IPQ values are always bigger than the mean. So, perhaps, with the impossibility to remove the lc filter, we are introducing a systematic error. Is not possible, for us, at this moment made a new revaluation of the values, because we do not know what will be the better solution (software or mathematical analyse) to treat the values.

This was the first time that we measure and evaluate this type of standards (Depth setting standards) so this comparison was very important for studying the proceeding of measurement and evaluation of the values.

Appendix B1

Reports of METAS

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments used at METAS
For the surface texture measurements we used a Form Talysurf FTS 120L series instrument made by Rank Taylor Hobson Company. Profile analysis according to standards finally occured with the software package Ultra Version 6 and were verified by an additional evaluation using an own METAS software.

The Form Talysurf has a precise reference plane. The scanning arm deflection is detected by a laser interferometer while the lateral position is measured by a glass scale. For the measurements a stylus with an arm length of 60 mm is used. We also used a stylus with an arm length of 20 mm to obtain an additional validation of our results. The results of the mostly independent measurements with the short stylus were well within the given uncertainties. The diamond tips of both scanning arm lengths have a nominal tip radius of 2 µm and a nominal tip angle of 90°. These values were verified by AFM measurements and resulted in a radius of 2.7 µm and a tip angle of 90.5° for the long arm stylus and 2.0 µm and 96° for the short arm stylus. These shape differences of the stylus tips had only a minor influence on the results because the measurement standards have almost no amplitude in the very small wavelength range. The calibration of the styli was carried out by means of reference spheres with a radius of 22 mm for the 60 mm stylus arm and 10 mm for the 20 mm stylus arm. The values given in the report are those obtained by the long stylus. The static measurement force was 0.72 µN. Data points were taken every 0.25 µm.

All results were evaluated according to the required international standards.
The softgauge files could not be imported directly into the Ultra software. In our opinion the data in the soft gauge files is not exactly arranged according to the standard ISO 5436-2. After an offline conversion considering also the scaling factors, the files could be imported but the result was still not very satisfying probably because the data spacing is different from native Ultra files. Therefore the softgauge files were evaluated with an independent LabView program made by ourselves at METAS. This software is also used to evaluate the profiles for the regular calibration work performed with our FTS profiler. Using native FTS Ultra files our own program showed only minor differences to the Ultra evaluation. The uncertainty budget contains also a contribution due to this software performance.
The groove depths of the depth setting standard (type A2) were evaluated according to ISO 5436-1 (1999), i.e. a segment of a circle was fitted to the groove. This evaluation was made using a METAS Igor macro.

The uncertainty budget contains five main influence quantities: Repeatability and uniformity of standards, noise measured on an optical flat, static calibration of the FTS stylus, transfer function of the instrument (dynamic behaviour and filtering), reference surface flatness for groove depth, temperature deviation and finally a contribution of the evaluation software. The dynamic transfer function of the instrument was determined using a piezo actuator with a capacitive displacement sensor placed below the tip. The largest contributions to the total uncertainty were the transfer function of the instrument, the uniformity of the standards and additionally for the groove depths (type A2) the flatness of the reference plane (see also section A4, “uncertainty of measurement”).

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 200 nm: identification R1 (groove number)

Equation used:

$$Pt = \sum c_i \cdot x_i$$

Pt = 321 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity o standard (nm	321	7.603	N	1	7.603	5
z-calibration (rel.) static	0	1.00E-04	N	321	3.21E-02	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	321	0.32	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 9.76

Effective degree of freedom: v_{eff} (h) = 13

Expanded uncertainty (nm): $U(h)$ = 20 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 200 nm: identification R1 (groove number)

Equation used:

$$D = \sum c_i \cdot x_i$$

$D =$ 304 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution $u_\mathrm{i}(\mathrm{h})/\mathrm{nm}$	degrees of freedom v_i
repeatability uniformity	304	5.814	N	1	5.814	5
standard (nm calibration (rel.) static	0	1.00E-04	N	304	3.04E-02	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	304	0.30	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 8.44

Effective degree of freedom: v_eff (h) = 21

Expanded uncertainty (nm): $U(h)$ = 17 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 1500 nm: identification R3 (groove number)

Equation used:

$$Pt = \sum c_i \cdot x_i$$

Pt = 1408 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity o standard (nm	1408	4.025	N	1	4.025	5
z-calibration (rel.) static	0	1.00E-04	N	1408	1.41E-01	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	1408	1.41	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 7.46

Effective degree of freedom: ν_{eff} (h) = 48

Expanded uncertainty (nm): $U(h)$ = 15 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 1500 nm: identification R3 (groove number)

Equation used:

$$D = \sum c_i \cdot x_i$$

$D =$ 1383 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity o	1383	1.342	N	1	1.342	5
standard (nm **2- calibration (rel.) static**	0	1.00E-04	N	1383	1.38E-01	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	1383	1.38	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 6.41

Effective degree of freedom: v_eff (h) = 141

Expanded uncertainty (nm): $U(h)$ = 13 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 8000 nm: identification R6 (groove number)

Equation used:

$$Pt = \sum c_i \cdot x_i$$

Pt = 8369 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$/nm	degrees of freedom v_i
repeatability uniformity c	8369	5.367	N	1	5.367	5
standard (nm z-calibration (rel.) static	0	1.00E-04	N	8369	8.37E-01	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	8369	8.37	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 11.70

Effective degree of freedom: $v_{eff}(h)$ = 83

Expanded uncertainty (nm): $U(h)$ = 24 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement (60 mm scanning arm)

Depth setting standard A2 (EN 806) with a nominal depth of 8000 nm: identification R6 (groove number)

Equation used:

$$D = \sum c_i \cdot x_i$$

D = 8347 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$/nm	degrees of freedom v_i
repeatability uniformity o	8347	0.894	N	1	0.894	5
standard (nm z- calibration (rel.) static	0	1.00E-04	N	8347	8.35E-01	100
Noise (nm)	0	2	N	1	2.00E+00	100
Reference flatness (nm)	0	10	R	1	5.774	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-03	N	8347	8.35	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 10.42

Effective degree of freedom: v_{eff} (h) = 196

Expanded uncertainty (nm): $U(h)$ = 21 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Geom. Standard Rub P114A/528-RS 5
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 505 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	505	0.289	N	1	0.289	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	505	0.051	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	505	2.424	100
Transfer-Characteristic, stylus tip	0	0.008	N	505	4.04	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 4.9

Effective degree of freedom: v_eff (h) = 184

Expanded uncertainty (nm): $U(h)$ = 10 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Geom. Standard Rub P114A/528-RS 5
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 1610 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	1610	1.732	N	1	1.732	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	1610	0.161	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	1610	7.728	100
Transfer-Characteristic, stylus tip	0	0.02	N	1610	32.2	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 34.8

Effective degree of freedom: ν_eff (h) = 134

Expanded uncertainty (nm): $U(h)$ = 70 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Geom. Standard Rub P114A/528-RS 5
Measurement of RSm with a scanning arm of 60 mm

Equation used:

$$RSm = \sum c_i \cdot x_i$$

RSm = 49 465 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution $u_\mathrm{i}(\mathrm{h})/\mathrm{nm}$	degrees of freedom v_i
repeatability uniformity standard (nm	49465	82.272	N	1	82.272	12
noise (nm)	0	2	R	1	1.155	100
x-calibration (rel.) static	0	1.00E-04	N	49465	4.95E+00	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software	0	1.00E-04	N	49465	4.95E+00	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 82.6

Effective degree of freedom: v_eff (h) = 12

Expanded uncertainty (nm): $U(h)$ = 166 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Geom. Standard PTB 7070/PGN10
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 2956 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	2955	2.887	N	1	2.887	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	2955	0.296	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	2955	14.184	100
Transfer-Characteristic, stylus tip	0	0.008	N	2955	23.64	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 27.8

Effective degree of freedom: ν_{eff} (h) = 168

Expanded uncertainty (nm): $U(h)$ = 56 with a coverage factor k=2

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A4 - Uncertainty of measurement

Geom. Standard PTB 7070/PGN10
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 9625 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	9625	8.660	N	1	8.660	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	9625	0.963	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	9625	46.200	100
Transfer-Characteristic, stylus tip	0	0.02	N	9625	192.5	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 198.43

Effective degree of freedom: v_{eff} (h) = 113

Expanded uncertainty (nm): $U(h)$ = 397 with a coverage factor k=2

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A4 - Uncertainty of measurement

Geom. Standard PTB 7070/PGN10
Measurement of RSm with a scanning arm of 60 mm

Equation used:

$$RSm = \sum c_i \cdot x_i$$

RSm = 198 603 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity	198603	147.802	N	1	147.802	12
standard (nm noise (nm)	0	2	R	1	1.155	100
x-calibration (rel.) static	0	1.00E-04	N	198603	1.99E+01	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	1.00E-04	N	198603	1.99E+01	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 150.45

Effective degree of freedom: ν_{eff} (h) = 13

Expanded uncertainty (nm): $U(h)$ = 301 with a coverage factor k=2

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A4 - Uncertainty of measurement

Geom. Standard PTB 8194/PGN3
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 904 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	904	2.309	N	1	2.309	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	904	0.090	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	904	4.339	100
Transfer-Characteristic, stylus tip	0	0.008	N	904	7.232	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 8.8

Effective degree of freedom: ν_{eff} (h) = 182

Expanded uncertainty (nm): $U(h)$ = 18 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Geom. Standard PTB 8194/PGN3
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 3 103 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	3103	15.877	N	1	15.877	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	3103	0.310	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	3103	14.894	100
Transfer-Characteristic, stylus tip	0	0.02	N	3103	62.06	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 66.58

Effective degree of freedom: v_{eff} (h) = 127

Expanded uncertainty (nm): $U(h)$ = 134 with a coverage factor k=2

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A4 - Uncertainty of measurement

Geom. Standard PTB 8194/PGN3
Measurement of RSm with a scanning arm of 60 mm

Equation used:

$$RSm = \sum c_i \cdot x_i$$

RSm = 119 095 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity o standard (nm	119095	312.924	N	1	312.924	12
noise (nm)	0	2	R	1	1.155	100
x-calibration (rel.) static	0	1.00E-04	N	119095	1.19E+01	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	1.00E-04	N	119095	1.19E+01	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 313.4

Effective degree of freedom: v_eff (h) = 12

Expanded uncertainty (nm): $U(h)$ = 627 with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness Standard 629f
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 152 nm

quantity X_i	estimate x_i	uncertainty $u(x_\text{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_\text{i}(\text{h})/\text{nm}$	degrees of freedom v_i
repeatability uniformity standard (nm)	152	0.866	N	1	0.866	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	152	0.015	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	152	0.730	100
Transfer-Characteristic, stylus tip	0	0.015	N	152	2.28	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 2.8

Effective degree of freedom: v_eff (h) = 181

Expanded uncertainty (nm): $U(h)$ = 6 with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness Standard 629f
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 1269 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	1269	13.568	N	1	13.568	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	1269	0.127	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	1269	6.091	100
Transfer-Characteristic, stylus tip	0	0.03	N	1269	38.07	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 42.2

Effective degree of freedom: v_eff (h) = 132

Expanded uncertainty (nm): $U(h)$ = 85 with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness Standard 629f
Measurement of Rk with a scanning arm of 60 mm

Equation used:

$$Rk = \sum c_i \cdot x_i$$

Rk = 466 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity c standard (nm)	466	4.619	N	1	4.619	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	466	0.047	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	466	2.237	100
Transfer-Characteristic, stylus tip	0	0.015	N	466	6.99	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 8.8

Effective degree of freedom: v_{eff} (h) = 160

Expanded uncertainty (nm): $U(h)$ = 18 with a coverage factor k=2

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A4 - Uncertainty of measurement

Roughness Standard 629f
Measurement of Rpk with a scanning arm of 60 mm

Equation used:

$$Rpk = \sum c_i \cdot x_i$$

Rpk = 137 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	137	3.464	N	1	3.464	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	137	0.014	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	137	0.658	100
Transfer- Characteristic, stylus tip	0	0.03	N	137	4.11	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 5.54

Effective degree of freedom: v_{eff} (h) = 63

Expanded uncertainty (nm): $U(h)$ = 12 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 629f
Measurement of Rvk with a scanning arm of 60mm

Equation used:

$$Rvk = \sum c_i \cdot x_i$$

Rvk = 294 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity o standard (nm)	294	6.640	N	1	6.640	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	294	0.029	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	294	1.411	100
Transfer- Characteristic, stylus tip	0	0.03	N	294	8.82	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 11.19

Effective degree of freedom: v_{eff} (h) = 70

Expanded uncertainty (nm): $U(h)$ = 23 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 633g
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

$R_a =$ 1516 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution $u_\mathrm{i}(\mathrm{h})$/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	1516	0.866	N	1	0.866	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	1516	0.152	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	1516	7.277	100
Transfer-Characteristic, stylus tip	0	0.015	N	1516	22.74	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 23.9

Effective degree of freedom: v_eff (h) = 121

Expanded uncertainty (nm): $U(h)$ = 48 with a coverage factor k=2

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Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 633g
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 7581 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	7581	54.271	N	1	54.271	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	7581	0.758	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	7581	36.389	100
Transfer-Characteristic, stylus tip	0	0.03	N	7581	227.43	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 236.9

Effective degree of freedom: v_eff (h) = 114

Expanded uncertainty (nm): $U(h)$ = 474 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 633g
Measurement of Rk with a scanning arm of 60 mm

Equation used:

$$Rk = \sum c_i \cdot x_i$$

Rk = 4241 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	4241	45.899	N	1	45.899	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	4241	0.424	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	4241	20.357	100
Transfer-Characteristic, stylus tip	0	0.015	N	4241	63.615	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 81.1

Effective degree of freedom: v_{eff} (h) = 81

Expanded uncertainty (nm): $U(h)$ = 163 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 633g
Measurement of Rpk with a scanning arm of 60 mm

Equation used:

$$Rpk = \sum c_i \cdot x_i$$

Rpk = 875 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	875	41.569	N	1	41.569	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	875	0.088	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	875	4.200	100
Transfer-Characteristic, stylus tip	0	0.03	N	875	26.25	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 49.36

Effective degree of freedom: v_{eff} (h) = 23

Expanded uncertainty (nm): $U(h)$ = 99 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 633g
Measurement of Rvk with a scanning arm of 60 mm

Equation used:

$$Rvk = \sum c_i \cdot x_i$$

Rvk = 2569 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	2569	93.531	N	1	93.531	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	2569	0.257	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	2569	12.331	100
Transfer-Characteristic, stylus tip	0	0.03	N	2569	77.07	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 121.8

Effective degree of freedom: ν_{eff} (h) = 33

Expanded uncertainty (nm): $U(h)$ = 244 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 686sg
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 2358 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	2358	6.351	N	1	6.351	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	2358	0.236	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	2358	11.318	100
Transfer-Characteristic, stylus tip	0	0.015	N	2358	35.37	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 37.7

Effective degree of freedom: ν_{eff} (h) = 127

Expanded uncertainty (nm): $U(h)$ = 76 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 686sg
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

$R_z =$ 14 451 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	14451	85.737	N	1	85.737	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	14451	1.445	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	14451	69.365	100
Transfer-Characteristic, stylus tip	0	0.03	N	14451	433.53	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 447.5

Effective degree of freedom: v_{eff} (h) = 112

Expanded uncertainty (nm): $U(h)$ = 895 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 686sg
Measurement of Rk with a scanning arm of 60 mm

Equation used:

$$Rk = \sum c_i \cdot x_i$$

Rk = 8 036 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom ν_i
repeatability uniformity standard (nm)	8036	53.694	N	1	53.694	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	8036	0.804	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	8036	38.573	100
Transfer-Characteristic, stylus tip	0	0.015	N	8036	120.54	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 137.5

Effective degree of freedom: ν_{eff} (h) = 126

Expanded uncertainty (nm): $U(h)$ = 275 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 686sg
Measurement of Rpk with a scanning arm of 60 mm

Equation used:

$$Rpk = \sum c_i \cdot x_i$$

Rpk = 1 256 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	1256	15.011	N	1	15.011	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	1256	0.126	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	1256	6.029	100
Transfer- Characteristic, stylus tip	0	0.03	N	1256	37.68	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 41.02

Effective degree of freedom: v_{eff} (h) = 116

Expanded uncertainty (nm): $U(h)$ = 83 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard 686sg
Measurement of Rvk with a scanning arm of 60mm

Equation used:

$$Rvk = \sum c_i \cdot x_i$$

Rvk = 3 016 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	3016	101.614	N	1	101.614	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	3016	0.302	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	3016	14.477	100
Transfer- Characteristic, stylus tip	0	0.03	N	3016	90.48	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 136.8

Effective degree of freedom: v_{eff} (h) = 37

Expanded uncertainty (nm): $U(h)$ = 274 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard SFRN 150/1006
Measurement of Ra with a scanning arm of 60 mm

Equation used:

$$R_a = \sum c_i \cdot x_i$$

R_a = 25 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	25	0.289	N	1	0.289	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	25	0.003	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	25	0.120	100
Transfer-Characteristic, stylus tip	0	0.015	N	25	0.375	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 1.25

Effective degree of freedom: v_eff (h) = 133

Expanded uncertainty (nm): $U(h)$ = 2.5 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard SFRN 150/1006
Measurement of Rz with a scanning arm of 60 mm

Equation used:

$$R_z = \sum c_i \cdot x_i$$

R_z = 146 nm

quantity X_i	estimate x_i	uncertainty $u(x_\mathrm{i})$	probability distribution	sensitivity coefficient $\mathrm{c_i}$	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	146	1.732	N	1	1.732	12
noise (nm)	0	18	R	1	10.392	100
z-calibration (rel.) static	0	1.00E-04	N	146	0.015	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	146	0.701	100
Transfer-Characteristic, stylus tip	0	0.03	N	146	4.38	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 11.43

Effective degree of freedom: v_eff (h) = 141

Expanded uncertainty (nm): $U(h)$ = 23 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard SFRN 150/1006
Measurement of Rk with a scanning arm of 60 mm

Equation used:

$$Rk = \sum c_i \cdot x_i$$

Rk = 76 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution u_i(h)/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	76	1.732	N	1	1.732	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	76	0.008	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	76	0.365	100
Transfer-Characteristic, stylus tip	0	0.015	N	76	1.14	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 2.4

Effective degree of freedom: v_{eff} (h) = 42

Expanded uncertainty (nm): $U(h)$ = 5 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard SFRN 150/1006
Measurement of Rpk with a scanning arm of 60 mm

Equation used:

$$Rpk = \sum c_i \cdot x_i$$

$Rpk =$ 30 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	30	0.866	N	1	0.866	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	30	0.003	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	30	0.144	100
Transfer-Characteristic, stylus tip	0	0.03	N	30	0.9	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 1.71

Effective degree of freedom: v_{eff} (h) = 119

Expanded uncertainty (nm): $U(h)$ = 3.5 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

A4 - Uncertainty of measurement

Roughness Standard SFRN 150/1006
Measurement of Rvk with a scanning arm of 60 mm

Equation used:

$$Rvk = \sum c_i \cdot x_i$$

Rvk = 30 nm

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$/nm	degrees of freedom v_i
repeatability uniformity standard (nm)	30	2.021	N	1	2.021	12
noise (nm)	0	2	R	1	1.155	100
z-calibration (rel.) static	0	1.00E-04	N	30	0.003	100
Temp. Dev. (K)	0	0.5	R	1.00E-05	0	100
Software and Evaluation	0	4.80E-03	N	30	0.144	100
Transfer-Characteristic, stylus tip	0	0.03	N	30	0.9	100

For the type of probability distribution please use: N = normal; R = rectangular; T = triangular; U = U-shaped.

Combined standard uncertainty (nm): $u_c(h)$ = 2.50

Effective degree of freedom: v_{eff} (h) = 28

Expanded uncertainty (nm): $U(h)$ = 5 with a coverage factor k=2

Laboratory: Marco Bieri at METAS

Date: 03.06.2002 Signature:

Comment from METAS

To our surprise in a few cases there occurred larger deviations (which even resulted in the failure of the En-criteria) of the following parameters: Pt and D for the R1 and R3 groove of the depth setting standard EN 806 and the RSm values for the roughness standards, type C. As indicated in the measurement report A3, METAS used styli with 60 mm and 20 mm arm length for the measurements. Since the difference of the two styli was well within the given uncertainty range and the fact that the stylus with 60 mm arm length is used for most calibration services, the results given in the report were all from the 60 mm stylus. Unfortunately we found out, that measurements with this stylus contained more noise than the ones obtained with the 20 mm stylus. We underestimated the contribution of noise (which is more significant for small groove depths and maybe not the same everyday) in the uncertainty assessment. On the other hand we would like to indicate the results obtained with the 20 mm stylus would have agreed well with the reference value:
EN 806:
R1: Pt = (292 ± 19) nm; D = (288 ± 19) nm
R2: Pt = (1375 ± 40) nm; D = (1370 ± 40) nm

Our values of the RSm parameters in the report were all computed by the software package Ultra Version 6 except for the RSm value of the data file 7080.SMD where the evaluation was done using our own METAS software (LabView program).
The RSm value for the data file 7080 shows no significant deviation from the reference value (PTB). Evaluating the measured RSm parameters for the roughness standard 7070 / PGN 10 with the METAS software (instead of using UltraVersion 6) leeds to values with much smaller deviations from the reference value. It seems therefore, that Ultra Version 6 does not calculate RSm parameters correctly in some cases while it does sometimes in other cases (see also the strange grouping of values in fig. 5).

RSm values computed with METAS software:
7070 / PGN 10: RSm = (199'987 ± 70) nm
8194 PGN 3: RSm = (119'955 ± 52) nm
P114A: RSm = (50’044 ± 28) nm

Shortly after METAS had made the measurements for the comparison we began to use only values calculated with our own software for certificates.
The implementation of the RSm value seems to be a general problem, as e. g. discussed in: "Ambiguities in the definition of spacing parameters for surface-texture characterization", Richard K Leach and Peter M Harris, Meas. Sci. Technol. 13 (2002) 1924–1930.

Appendix B1

Reports of MIKES

Measurement uncertainty of surface texture	Sivu:	1/2	KMP 09
		Version:	0.3
		Date:	14.6.02
			BAH

Calculation of measurement uncertainty of surface texture of a steel specimen, using the instrument Taylor Hobson Talysurf 2 (inductive, 2µm tip radius). The calculations are done according to GUM and partly EA-4/02 and also partly according to suggestion by NPL/Leach presented in Euromet Length Workshop 2001.

The measurement model for the surface roughness parameter is:

$$R_x = \frac{1}{k}\sum_{1}^{k} F_{Rx}(Z_{m,i})$$

where profile Z_m is:

$$Z_{m,i} = C\,Z_p + Z_{ref} + Z_{pl} + Z_{tip}$$

where:

Z_m	profile;
Z_p	indicated profile;
C	calibration of vertical displacement;
Z_{ref}	slideway profile;
Z_{pl}	plastic deformation error;
Z_{tip}	effect of tip geometry;

The calculation is done for three cases:

- Case A: Rt is 0.2µm, Ra 0.1µm and measurement length 2 mm
- Case B: Rt is 2µm, Ra 1µm and measurement length 5 mm
- Case C: Rt is 10µm, Ra 5µm and measurement length 12.5 mm

C	When measuring a 500 µm step made by two gauge blocks the result is in average about 42 nm to large. For a 0.2 µm (case A) step the same relative error makes about 0.17 nm. For cases B and C we get respectively the standard uncertainties 1.7 nm and 8.5 nm This uncertainty is combined with a standard deviation result $\frac{10nm}{\sqrt{3}} = 6nm$ (representing repeatability of the instrument) from measurements of a A2 type depth setting standard with grooves, and the result is roughly 6 nm for cases A and B and 11 nm for case C.
Z_{ref}	When measuring an optical flat the peak to peak result is typically about 30 nm when the length is 2mm. A triangular distribution is assumed and the standard uncertainty for straightness of the profile slideway is 30/12 = 9 nm. For cases B and C we get respectively the standard uncertainties 12 nm and 14 nm

Z_{pl} According to NPL/Leach suggestion a 0,75mN measuring force and 2µm tip radius the deformation is 20 nm on metal. A similar result is also given by Hertz formula steel-steel contact MIKES report J12). The standard uncertainty for fluctuations in the deformation is approximated to ±10% of average deformation.

Z_{tip} It is assumed that the characteristic wavelength is much larger than the 2 µm tip radius. Therefore the effect of tip geometry is minor.

SEOM Standard deviation of mean for 12 measurements, the following calculations are done for the value 8 nm

Table 1. Measurement uncertainty for the profile case A.

quantity	Estimate		standard uncertainty		Distribution	Sensitivity		Uncertainty contrib	Degree of freedom
Z_p		nm							
Z_m		nm		nm	Normal	1			
C	1	nm	6	nm	Normal	1		6,00	4
Z_{ref}	0	nm	9	nm	Triangular	1		9,00	6
SEOM	0	nm	8	nm	Normal	1		8,00	11
Z_{pl}	20	nm	2	nm	Normal	1		2,00	4
								13,60	20
							Expanded uncertainty (k=2.0)	27,20	nm

Table 2. Measurement uncertainty for the profile case B.

quantity	Estimate		standard uncertainty		Distribution	Sensitivity		Uncertainty contrib	Degree of freedom
Z_p		nm							
Z_m		nm		nm	Normal	1			
C	1	nm	6	nm	Normal	1		6,00	4
Z_{ref}	0	nm	12	nm	Triangular	1		12,00	6
SEOM	0	nm	8	nm	Normal	1		8,00	11
Z_{pl}	20	nm	2	nm	Normal	1		2,00	4
								15,75	15
							Expanded uncertainty (k=2.0)	31,50	nm

Table 3. Measurement uncertainty for the profile case C.

quantity	Estimate		standard uncertainty		Distribution	Sensitivity		Uncertainty contrib	Degree of freedom
Z_p		nm							
Z_m		nm		nm	Normal	1			
C	1	nm	11	nm	Normal	1		11,00	4
Z_{ref}	0	nm	14	nm	Triangular	1		14,00	6
SEOM	0	nm	8	nm	Normal	1		8,00	11
Z_{pl}	20	nm	2	nm	Normal	1		2,00	4
								19,62	15
							Expanded uncertainty (k=2.0)	39,24	nm

Appendix B1

Reports of NMi-VSL

Euromet project 600
Final report NMi VSL

Date: 25-04-2003

Richard Koops

Description of the measuring instrument

Type of instrument

All measurements were performed with a Form Talysurf-120L (FTS) that has been updated in January 2003 to operate with the acquisition and analysis software package Ultra version 4.3.14. The instrument operates with a moving stylus. The stylus movements in the Z (=vertical) direction are measured by a laser interferometer, the stylus movements in the X (=horizontal) direction are measured using a line scale. The resolution is 1 nm in the Z direction and 0,25 µm in the X direction. The measurement uncertainty in both directions is determined as described below.

Environment characterization

All measurements were performed in a laboratory with temperature and humidity control yielding a temperature of (20 +/- 0,5) ^{o}C and a relative humidity of (50 +/- 5) %RH. No special precautions for dust control have been taken since the normal environmental operating conditions result a sufficiently clean conditions. The construction of the instrument and the mechanical support provide sufficient noise protection for normal operation of the instrument. The residuals due to the electronics and environmental noise were determined as described below and incorporated in the measurement uncertainty. Measurements that were influenced by excessive noise (i.e. slamming doors) were excluded and redone.

Calibration of the instrument

- Stylus radius
The stylus tip radius was checked by scanning the edge of a razor blade. By manually fitting a circle to the data the tip radius was determined to be (1,2 +/- 0,5) µm.

- Probing force
The probing force was calibrated using a calibrated force balance. The force was determined to be (0,55 +/- 0,03) mN.

- Z-axis
The calibration of the Z axis of the system was performed using a two step process. In step one a calibrated radius standard was used to determine the corrections of the arcuate movement of the probe. These corrections are stored as polynomial coefficients within the acquisition and analysis software. Secondly, a set of calibrated step height and depth setting standards was used to check the linearity and to calibrate the Z direction. The datasets obtained with the FTS of these calibrated standards had to be analyzed off-line using a specially developed analysis tool. Based on these results we decided to use a calibration factor of 1 and add the deviations from 1 to the measurement uncertainty for all parameters that depend on the Z coordinate

- X-axis
The calibration of the X axis was performed using a calibrated line scale. Also here we add the deviation of the X-axis position from the true value to the measurement uncertainty for all parameters that depend on the X coordinate.

- Scanning speed
The scanning speed was calibrated by determining the time to scan a 100 mm line scale. The scanning speed was (0,495 +/- 0,004) mm/s.

- Sample alignment
The angular misalignment in the X direction of the samples with respect to the probe direction was determined by estimating the maximum change in position of the probe with respect to the sample edges, yielding 0,5 mm misalignment over 10 mm sample length. Assuming a rectangular distribution this results in a length dependent uncertainty contribution for the X coordinates of 1-cos[0,5/(10*2*sqrt(3))] = 1e-4.l.

The angular misalignment in the Z direction of the samples with respect to the probe direction depends on the parallelism of the specimen surface with respect to the support. Since we do not check the parallelism the maximum angular misalignment was estimated by the maximum angular misalignment of the support. The value was 0,2 mm on a support base of 30 mm yielding a length dependent uncertainty contribution for the Z coordinates of 1-cos[0,2/(30*2*sqrt(3))] = 2e-6.l.

Characterizing the guiding mechanism

The influence of the guiding mechanism of the FTS was evaluated by scanning an optical flat on different positions using the same part of the guiding mechanism. By averaging 24 different data sets the characteristics of the guiding mechanism were extracted. This dataset was then used to evaluate the values of all relevant parameters for the comparison and these values were used as uncertainty contributions due to the guiding mechanism.

Characterizing noise

Measurement noise (i.e. electronic and environmental) was evaluated by repeated scanning of an optical flat on the same position using the same part of the guiding mechanism of the FTS. The difference between the data sets excludes the influence of the guiding mechanism and the optical flat leaving only the instrumental noise. This dataset was then used to evaluated the values of all relevant parameters for the comparison and these values were used as uncertainty contributions due to instrumental noise.

Data analysis

Most analysis could be performed by Ultra software. For the analysis of the depth setting standard data and the softgauges additional tools were developed in order to extract the desired parameters. Also some tools had to be developed to subtract and average profile data sets and to process the stylus radius data.

Notes on the analysis of the measurement results of the depth setting standard of type A2.

Since our Form Talysurf Ultra software can not analyze the measurement results on the depth setting standard according to ISO 5436-1:1998 to obtain d, the measured data sets were analyzed off-line with a specially developed software tool. The interpretation of the measurement data sets was based on the description provided by Taylor Hobson of the structure of the exported ASCII file generated by the Form Talysurf software. The appropriate scaling factors from the ASCII file header were used to calculate the X and Z values in units of length. Our analysis tool allows the determination of the width W of the groove either automatically or by hand. In practice the determination by hand was considered more suitable especially in the case of the most shallow groove R1 where measurement noise was significant. After the determination of the width W of each groove the appropriate intervals W/3 at the bottom of the groove and on the upper level are set. The region at the bottom of the groove is used to fit a least squares circle and the regions on the upper level are used to fit a least squares mean line. Finally the distance d is determined as the largest distance between the circle circumference and the line. The uncertainty in d is calculated from the residuals of the fit and the degrees of freedom.

Notes on the analysis of the softgauges

Since our Form Talysurf software was not able to read the file format of the softgauges provided in this comparison a semi-automated conversion tool was developed. The major difference between the softgauge files and the Form Talysurf files is the presence of both X and Z data in the original softgauge files while the Form Talysurf files only contain the Z data and the value for the X spacing in the raw data files. Additionally there were many small differences between the header structures, as illustrated below, that required conversion before the softgauges could be analyzed. The conversion was based on the information provided in the datasheet D5 of the technical report and the description of the Form Talysurf ASCII format file structure provided by the operator manual from Taylor Hobson.

First the header of the softgauge files was analyzed providing the header length, the number of points, the units and scaling factors. Our tool then stripped the X coordinates from the original files leaving only the Z values. A dummy header with the correct structure for the Form Talysurf analysis software, the remaining Z values and appropriate file termination characters were then written to a new profile file. Finally, the number of points, the units and scaling factors and the X spacing were manually changed to the correct values taken from the header of the original softgauge files. The X spacing was calculated from the difference between the second and first X coordinate in the original files for each softgauge. As a result the X coordinates used in our analysis differ slightly form the values provided by the original softgauges in the files “1001.smd” and “7080.smd”; for these two files we use multiples of 1.500086e-004 mm for the X coordinate. Since the differences between our X values and the X values of the original softgauges remain in the sub nm range we consider the effect of the conversion on the analysis results negligible.

```
ISO 5436 - 2000 1001
PRF  0 PTB_2d_k
CX A 11666 mm  1.0e0 D
CZ A 11666 nm  1.0e0 D
_
DATE 05/17/01
TIME 14:22:10
LAST_CALIBRATION 05/17/01 14:46:18
PROBING_SYSTEM nanostep contacting 2.000000e+000 um
9.000000e+001
SPEED 5.000000e-002
PROFILE_FILTER none    Ls 8.000000e-007 Lc 8.000000e-007
_
0.000000e+000
6.354600e+001
1.500086e-004
6.292300e+001
3.000171e-004
6.416900e+001
...
...
```

Original softgauge file “1001.smd”

```
1 2
ref_tr 0.000000e+000 PRF
CX M 1.166600e+004 MM 1.000000e+000 D
CZ M 1.166600e+004 MM 1.000000e-006 D
EOR
STYLUS_RADIUS 0.000000e+000 MM
SPACING CX 1.500086e-004
MAP 1.000000e+000 CZ CZ 1.000000e+000 1.000000e+000
MAP 2.000000e+000 CZ CX 1.000000e+000 0.000000e+000
EOR
6.354600e+001
6.292300e+001
6.416900e+001
...
...
```

Converted to Form Talysurf ASCII format

Notes on the analysis of the files “1001.smd” and “505.smd”

The roughness and Rk analysis was performed on 5 cutoff lengths with filter settings Ls = 0,0025 mm and Lc = 0,25 mm for “1001.smd” and with filter settings Ls = 0,0025 mm and Lc = 0,8 mm for “505.smd”. Since the data tracks were 6 points short for the determination of the Rk parameters we added 3 points to the beginning and end of each track by repeating the begin and end values of the tracks. Since these values are not used in the final analysis but are only used to be able to filter the tracks the addition of these points has no influence on the parameter values.

Notes on the analysis of the file “7080.smd”

The analysis was performed on 1 cutoff length of 0,8 mm according to the ISO tables for Ra and Rz with filter settings Ls = 0,0025 mm and Lc = 0,8 mm. There was insuficient track length for the 5 cutoff analysis and the determination of the Rk parameters.

Uncertainty of the measurements

The uncertainty analysis was based on experimental data and on data taken from literature. The only parameter we could not measure was the effect of the plastic deformation of the specimen surfaces as a result of the probing tip. The uncertainty due to plastic deformation was therefore taken from [1].

The general equation for the determination of a parameters P was:

P = C(Pm + Pref + Pnoise + Ppl)

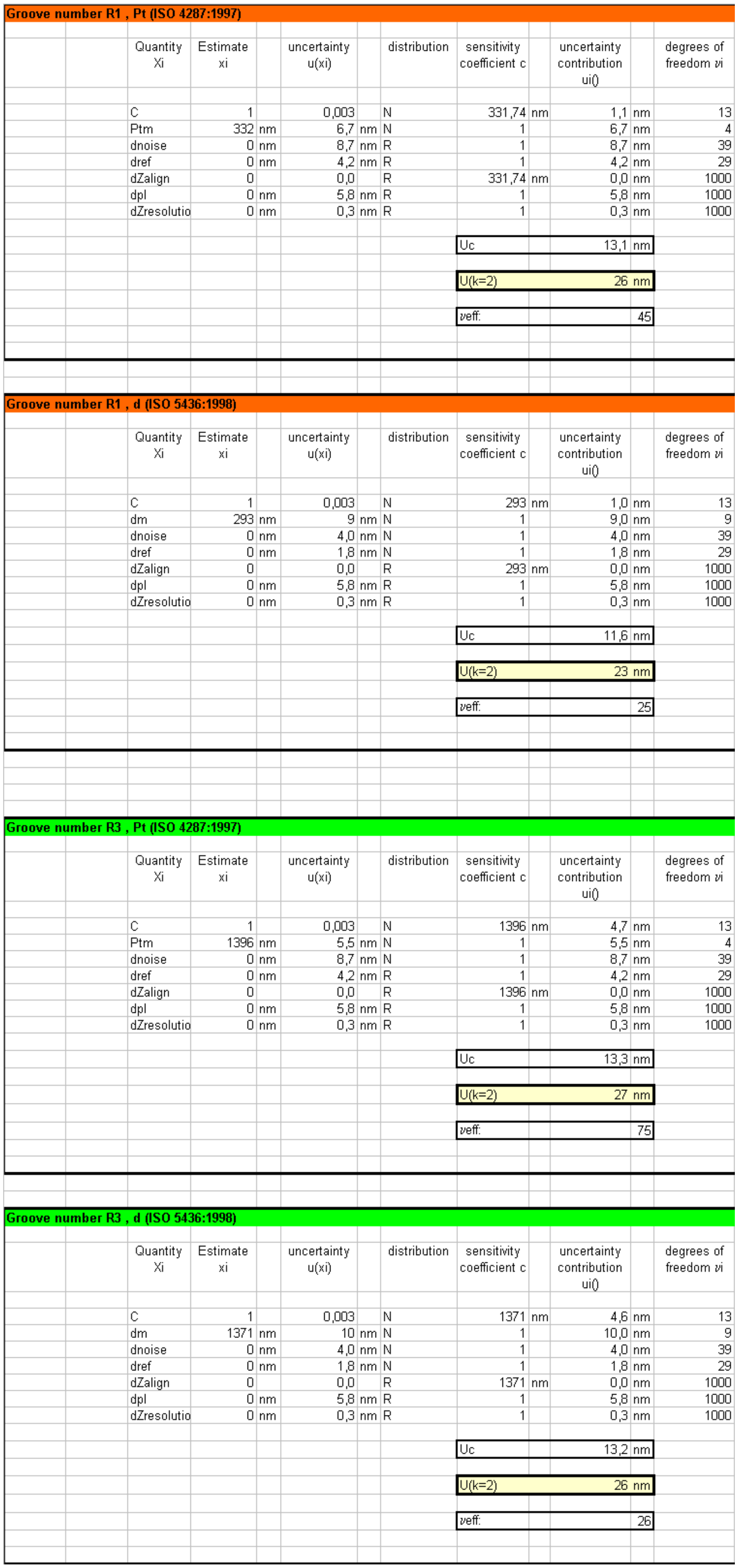
with

P	: the parameter to be determined
C	: the calibration factor for the Z and X direction. We have set these factors to 1 and added the deviation from 1 to the uncertainty.
Pm	: the value of the parameter as generated by the instrument. The standard deviation was used as uncertainty in this value.
Pref	: the influence of the guiding mechanism of the instrument. We do not correct for the influence of the guiding mechanism but add the influence to the measurement uncertainty. We do this by calculating the parameter value from a profile that represents the guiding mechanism.
Pnoise	: the influence of noise (both instrumental and environmental). As with Pref, the influence of noise is added to the measurement uncertainty by calculating the parameter value from a profile that represents the noise only.
Ppl	: the plastic deformation of the specimen surface as a result of the probing tip. This value was taken from [1].

Depending on the specific parameter, uncertainty contributions due to instrumental resolution and specimen alignment were taken into account where necessary. Specifically we estimated the uncertainty in R_{Sm} by incorporating the calibration uncertainty for the X-axis and X-alignment for both the start value and end value of the X-region that was used to calculate R_{Sm}. The uncertainty in the M_R parameters was calculated using two uncertainty contributions. First the standard deviation of the values generated by the instrument and secondly the uncertainty in R_k using the following reasoning. We assume that the ordinate axis of the Abbott-Firestone curve can be normalized to 100% using Rmax. We then have percentages on both axis. We further assume a slope of 1 of the curve at the region defined by R_k. Finally we estimate the uncertainty in M_{R1} and M_{R2} due to R_k by half the normalized uncertainty in R_k. Since the uncertainty in R_k includes all other uncertainty sources they are also incorporated in the uncertainty of M_{R1} and M_{R2} this way.

The following pages contain the detailed uncertainty statements for all parameters that were determined in this comparison. Concerning the degrees of freedom we inserted a, more or less arbitrary, value of 1000 in cases where the degree was infinite.

[1] Richard Leach ,"Uncertainties when using a stylus instrument: a simplified approach", Euromet Length uncertainty workshop, 2001



Groove number R1 , Pt (ISO 4287:1997)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	331,74	nm	1,1	nm	13
Ptm	332	nm	6,7	nm	N	1		6,7	nm	4
dnoise	0	nm	8,7	nm	R	1		8,7	nm	39
dref	0	nm	4,2	nm	R	1		4,2	nm	29
dZalign	0		0,0		R	331,74	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc 13,1 nm

U(k=2) 26 nm

νeff: 45

Groove number R1 , d (ISO 5436:1998)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	293	nm	1,0	nm	13
dm	293	nm	9	nm	N	1		9,0	nm	9
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,8	nm	N	1		1,8	nm	29
dZalign	0		0,0		R	293	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc 11,6 nm

U(k=2) 23 nm

νeff: 25

Groove number R3 , Pt (ISO 4287:1997)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1396	nm	4,7	nm	13
Ptm	1396	nm	5,5	nm	N	1		5,5	nm	4
dnoise	0	nm	8,7	nm	N	1		8,7	nm	39
dref	0	nm	4,2	nm	R	1		4,2	nm	29
dZalign	0		0,0		R	1396	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc 13,3 nm

U(k=2) 27 nm

νeff: 75

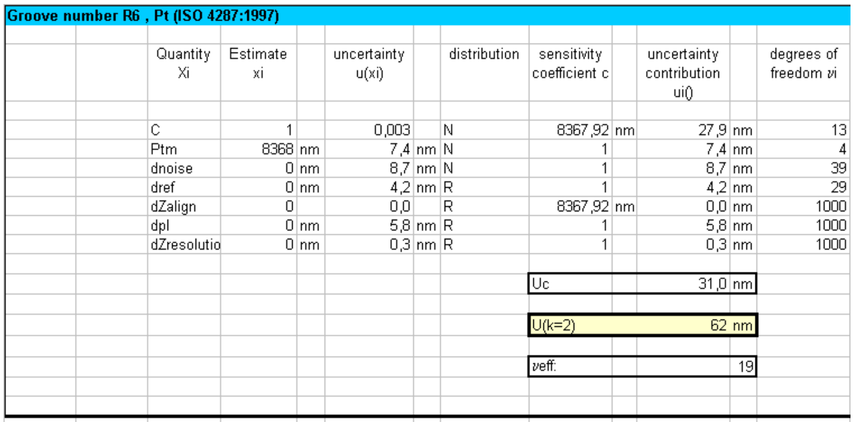
Groove number R3 , d (ISO 5436:1998)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1371	nm	4,6	nm	13
dm	1371	nm	10	nm	N	1		10,0	nm	9
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,8	nm	N	1		1,8	nm	29
dZalign	0		0,0		R	1371	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc 13,2 nm

U(k=2) 26 nm

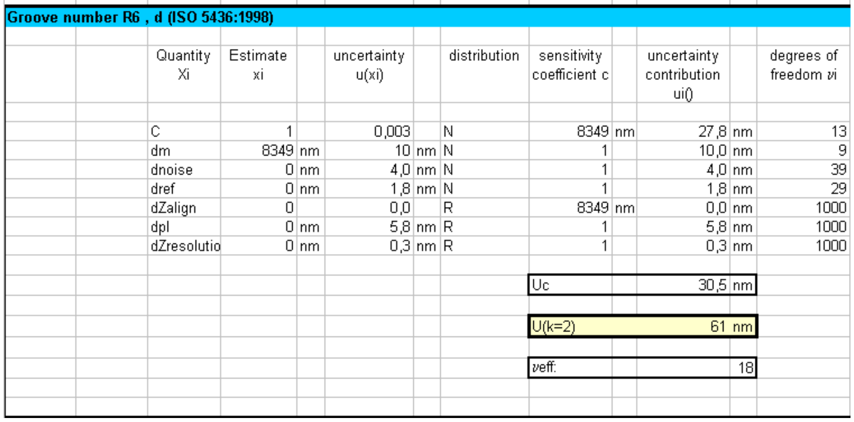
νeff: 26



Groove number R6 , Pt (ISO 4287:1997)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	8367,92	nm	27,9	nm	13
Ptm	8368	nm	7,4	nm	N	1		7,4	nm	4
dnoise	0	nm	8,7	nm	N	1		8,7	nm	39
dref	0	nm	4,2	nm	R	1		4,2	nm	29
dZalign	0		0,0		R	8367,92	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

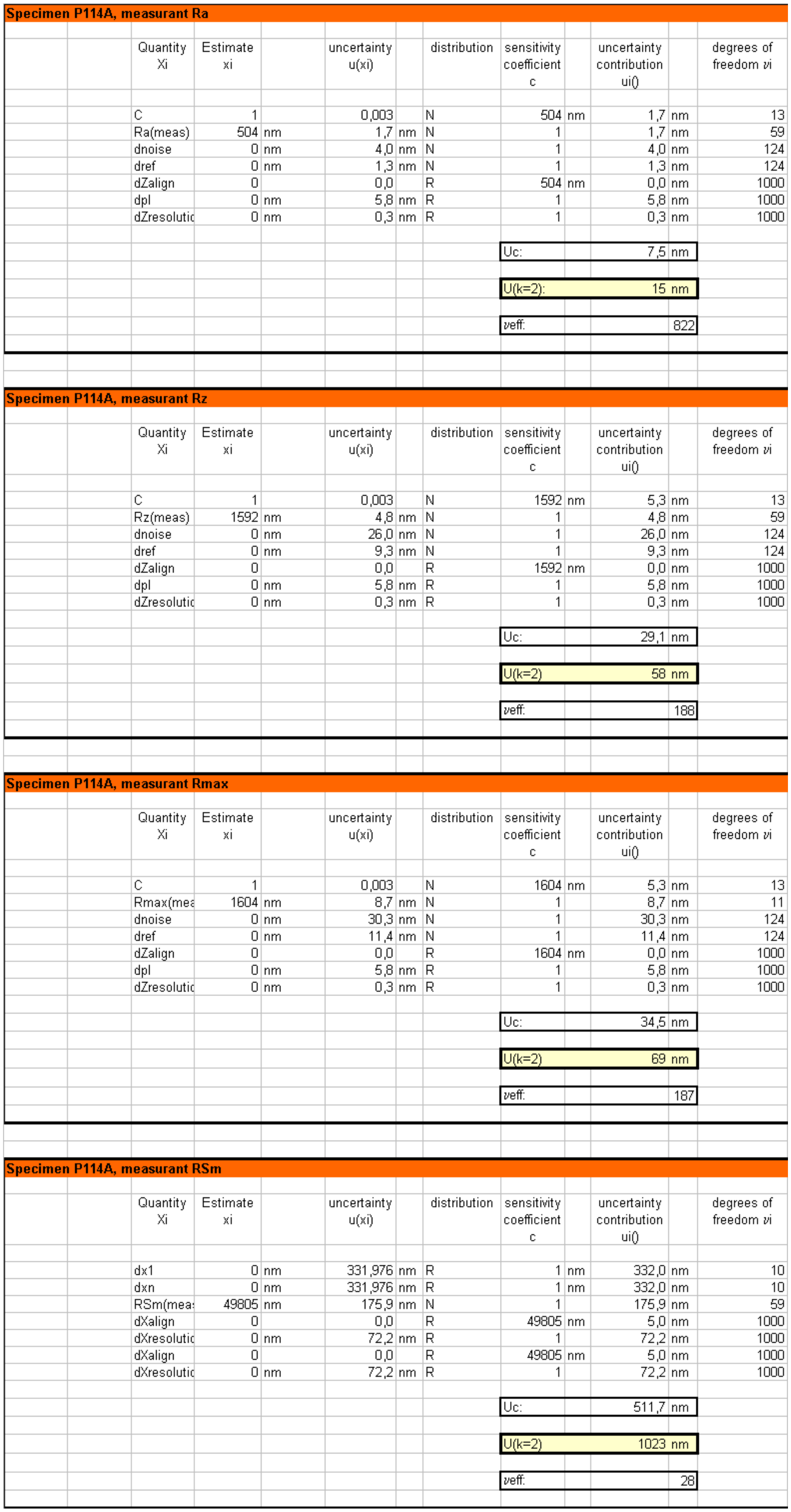
Uc	31,0	nm
U(k=2)	62	nm
νeff:	19	



Groove number R6 , d (ISO 5436:1998)

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	8349	nm	27,8	nm	13
dm	8349	nm	10	nm	N	1		10,0	nm	9
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,8	nm	N	1		1,8	nm	29
dZalign	0		0,0		R	8349	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc	30,5	nm
U(k=2)	61	nm
νeff:	18	



Specimen P114A, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	504	nm	1,7	nm	13
Ra(meas)	504	nm	1,7	nm	N	1		1,7	nm	59
dnoise	0	nm	4,0	nm	N	1		4,0	nm	124
dref	0	nm	1,3	nm	N	1		1,3	nm	124
dZalign	0		0,0		R	504	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		7,5	nm	
						U(k=2):		15	nm	
						νeff:			822	

Specimen P114A, measurant Rz

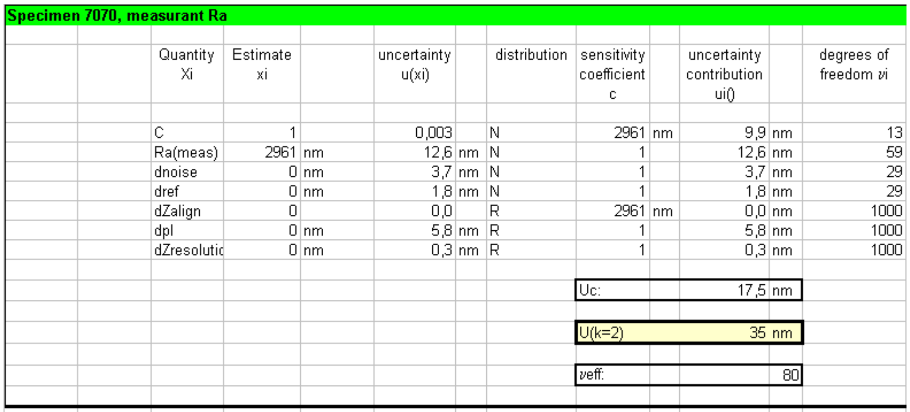
Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1592	nm	5,3	nm	13
Rz(meas)	1592	nm	4,8	nm	N	1		4,8	nm	59
dnoise	0	nm	26,0	nm	N	1		26,0	nm	124
dref	0	nm	9,3	nm	N	1		9,3	nm	124
dZalign	0		0,0		R	1592	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		29,1	nm	
						U(k=2)		58	nm	
						νeff:			188	

Specimen P114A, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1604	nm	5,3	nm	13
Rmax(mea	1604	nm	8,7	nm	N	1		8,7	nm	11
dnoise	0	nm	30,3	nm	N	1		30,3	nm	124
dref	0	nm	11,4	nm	N	1		11,4	nm	124
dZalign	0		0,0		R	1604	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		34,5	nm	
						U(k=2)		69	nm	
						νeff:			187	

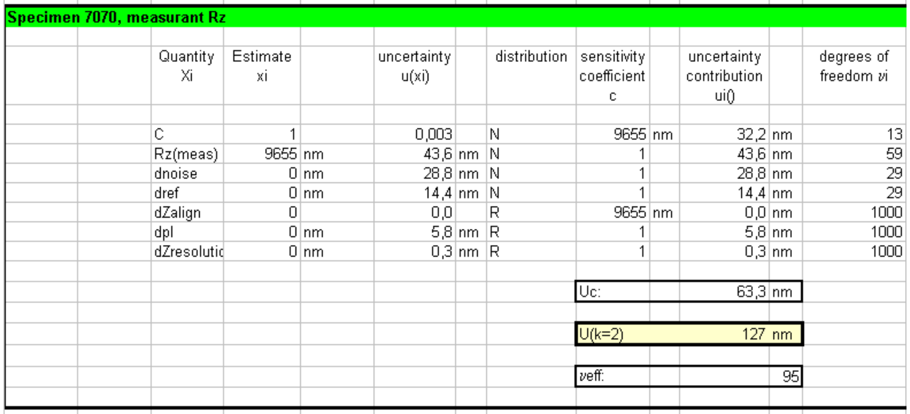
Specimen P114A, measurant RSm

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
dx1	0	nm	331,976	nm	R	1	nm	332,0	nm	10
dxn	0	nm	331,976	nm	R	1	nm	332,0	nm	10
RSm(mea	49805	nm	175,9	nm	N	1		175,9	nm	59
dXalign	0		0,0		R	49805	nm	5,0	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
dXalign	0		0,0		R	49805	nm	5,0	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
						Uc:		511,7	nm	
						U(k=2)		1023	nm	
						νeff:			28	



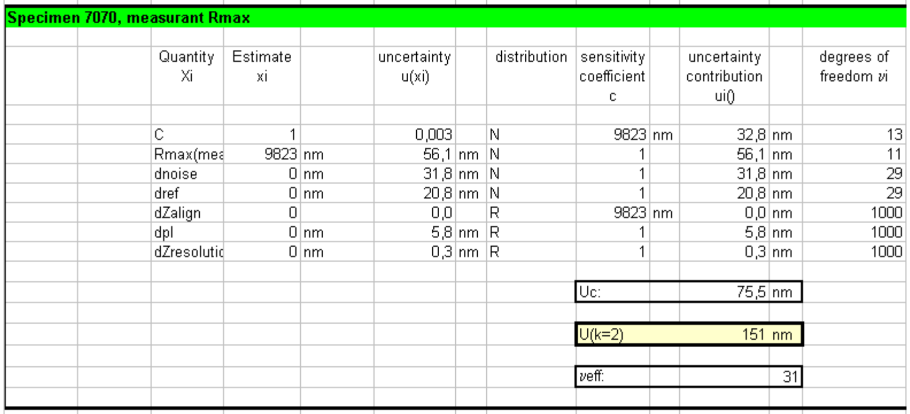
Specimen 7070, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	2961	nm	9,9	nm	13
Ra(meas)	2961	nm	12,6	nm	N	1		12,6	nm	59
dnoise	0	nm	3,7	nm	N	1		3,7	nm	29
dref	0	nm	1,8	nm	N	1		1,8	nm	29
dZalign	0		0,0		R	2961	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		17,5	nm	
						U(k=2)		35	nm	
						νeff:		80		



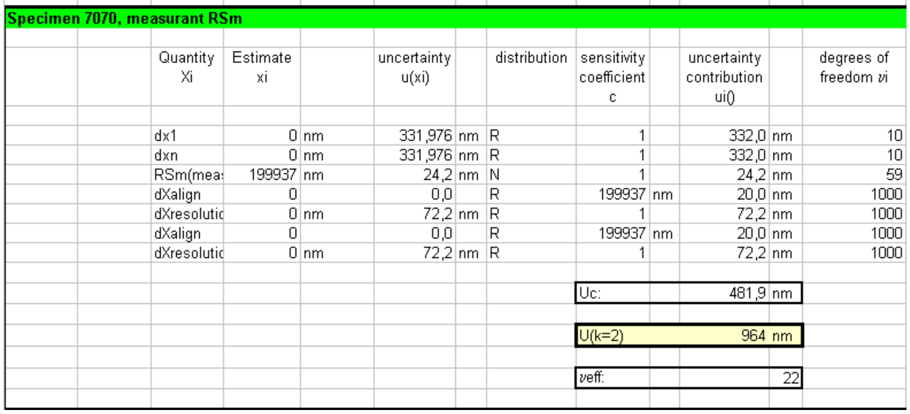
Specimen 7070, measurant Rz

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	9655	nm	32,2	nm	13
Rz(meas)	9655	nm	43,6	nm	N	1		43,6	nm	59
dnoise	0	nm	28,8	nm	N	1		28,8	nm	29
dref	0	nm	14,4	nm	N	1		14,4	nm	29
dZalign	0		0,0		R	9655	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		63,3	nm	
						U(k=2)		127	nm	
						νeff:		95		



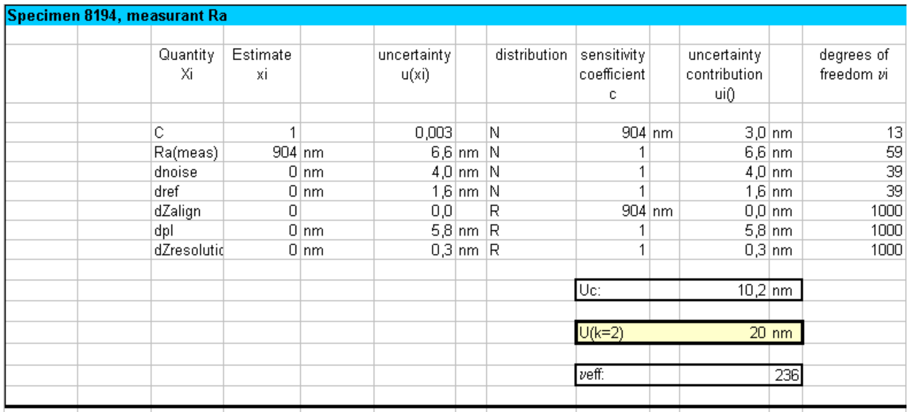
Specimen 7070, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	9823	nm	32,8	nm	13
Rmax(mea	9823	nm	56,1	nm	N	1		56,1	nm	11
dnoise	0	nm	31,8	nm	N	1		31,8	nm	29
dref	0	nm	20,8	nm	N	1		20,8	nm	29
dZalign	0		0,0		R	9823	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		75,5	nm	
						U(k=2)		151	nm	
						νeff:		31		



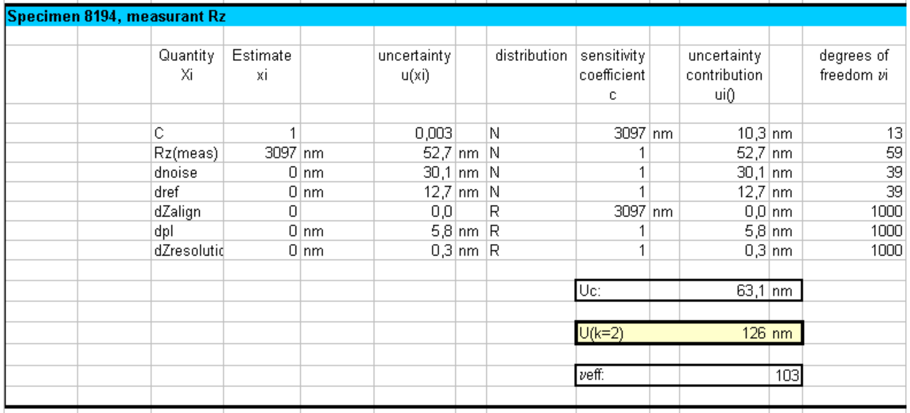
Specimen 7070, measurant RSm

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
dx1	0	nm	331,976	nm	R	1		332,0	nm	10
dxn	0	nm	331,976	nm	R	1		332,0	nm	10
RSm(mea:	199937	nm	24,2	nm	N	1		24,2	nm	59
dXalign	0		0,0		R	199937	nm	20,0	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
dXalign	0		0,0		R	199937	nm	20,0	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
						Uc:		481,9	nm	
						U(k=2)		964	nm	
						νeff:		22		



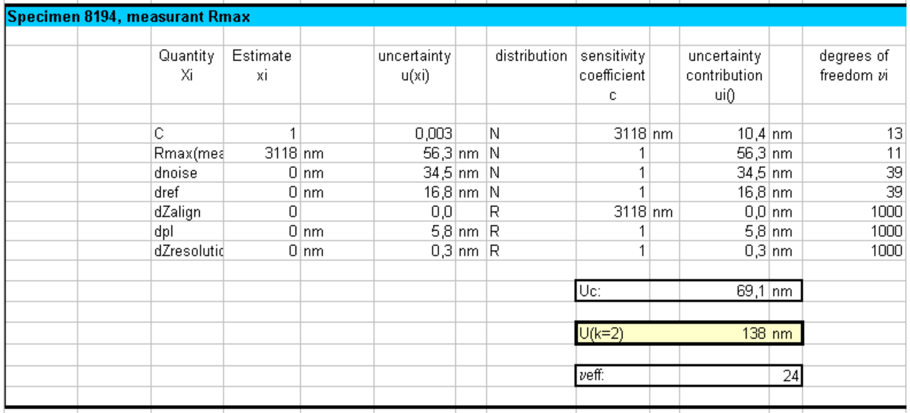
Specimen 8194, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	904	nm	3,0	nm	13
Ra(meas)	904	nm	6,6	nm	N	1		6,6	nm	59
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,6	nm	N	1		1,6	nm	39
dZalign	0		0,0		R	904	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		10,2	nm	
						U(k=2)		20	nm	
						νeff:		236		



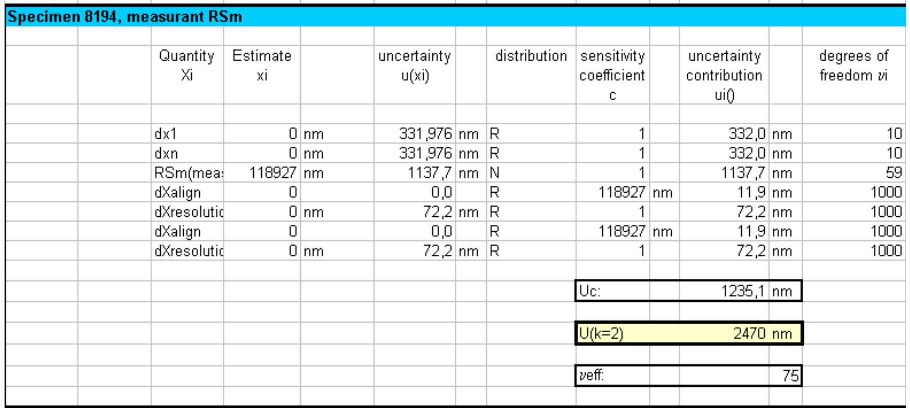
Specimen 8194, measurant Rz

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	3097	nm	10,3	nm	13
Rz(meas)	3097	nm	52,7	nm	N	1		52,7	nm	59
dnoise	0	nm	30,1	nm	N	1		30,1	nm	39
dref	0	nm	12,7	nm	N	1		12,7	nm	39
dZalign	0		0,0		R	3097	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		63,1	nm	
						U(k=2)		126	nm	
						νeff:		103		



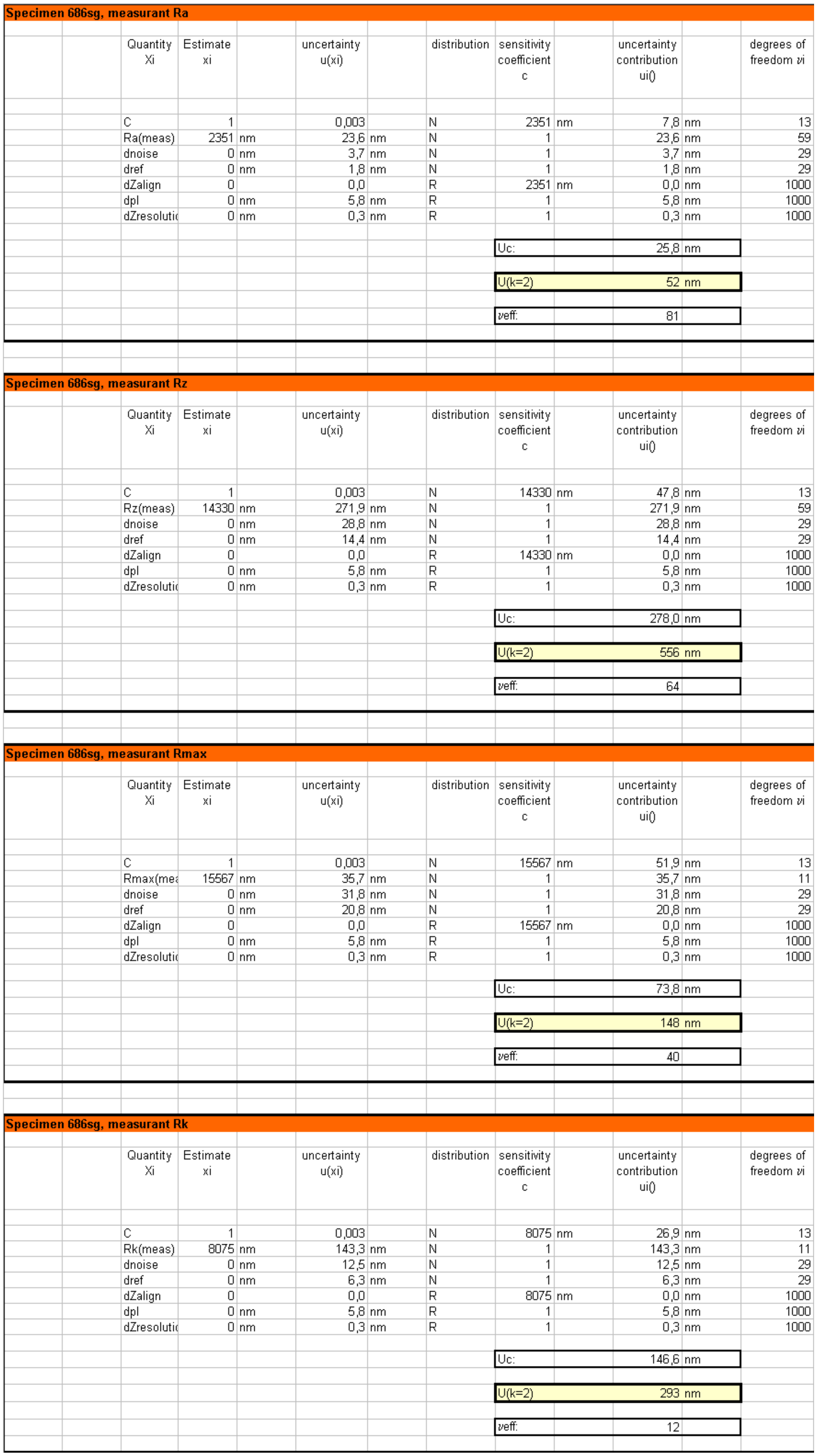
Specimen 8194, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	3118	nm	10,4	nm	13
Rmax(mea	3118	nm	56,3	nm	N	1		56,3	nm	11
dnoise	0	nm	34,5	nm	N	1		34,5	nm	39
dref	0	nm	16,8	nm	N	1		16,8	nm	39
dZalign	0		0,0		R	3118	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		69,1	nm	
						U(k=2)		138	nm	
						νeff:		24		



Specimen 8194, measurant RSm

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
dx1	0	nm	331,976	nm	R	1		332,0	nm	10
dxn	0	nm	331,976	nm	R	1		332,0	nm	10
RSm(mea:	118927	nm	1137,7	nm	N	1		1137,7	nm	59
dXalign	0		0,0		R	118927	nm	11,9	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
dXalign	0		0,0		R	118927	nm	11,9	nm	1000
dXresolutic	0	nm	72,2	nm	R	1		72,2	nm	1000
						Uc:		1235,1	nm	
						U(k=2)		2470	nm	
						νeff:		75		



Specimen 686sg, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	2351	nm	7,8	nm	13
Ra(meas)	2351	nm	23,6	nm	N	1		23,6	nm	59
dnoise	0	nm	3,7	nm	N	1		3,7	nm	29
dref	0	nm	1,8	nm	N	1		1,8	nm	29
dZalign	0		0,0		R	2351	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		25,8	nm	
						U(k=2)		52	nm	
						νeff:		81		

Specimen 686sg, measurant Rz

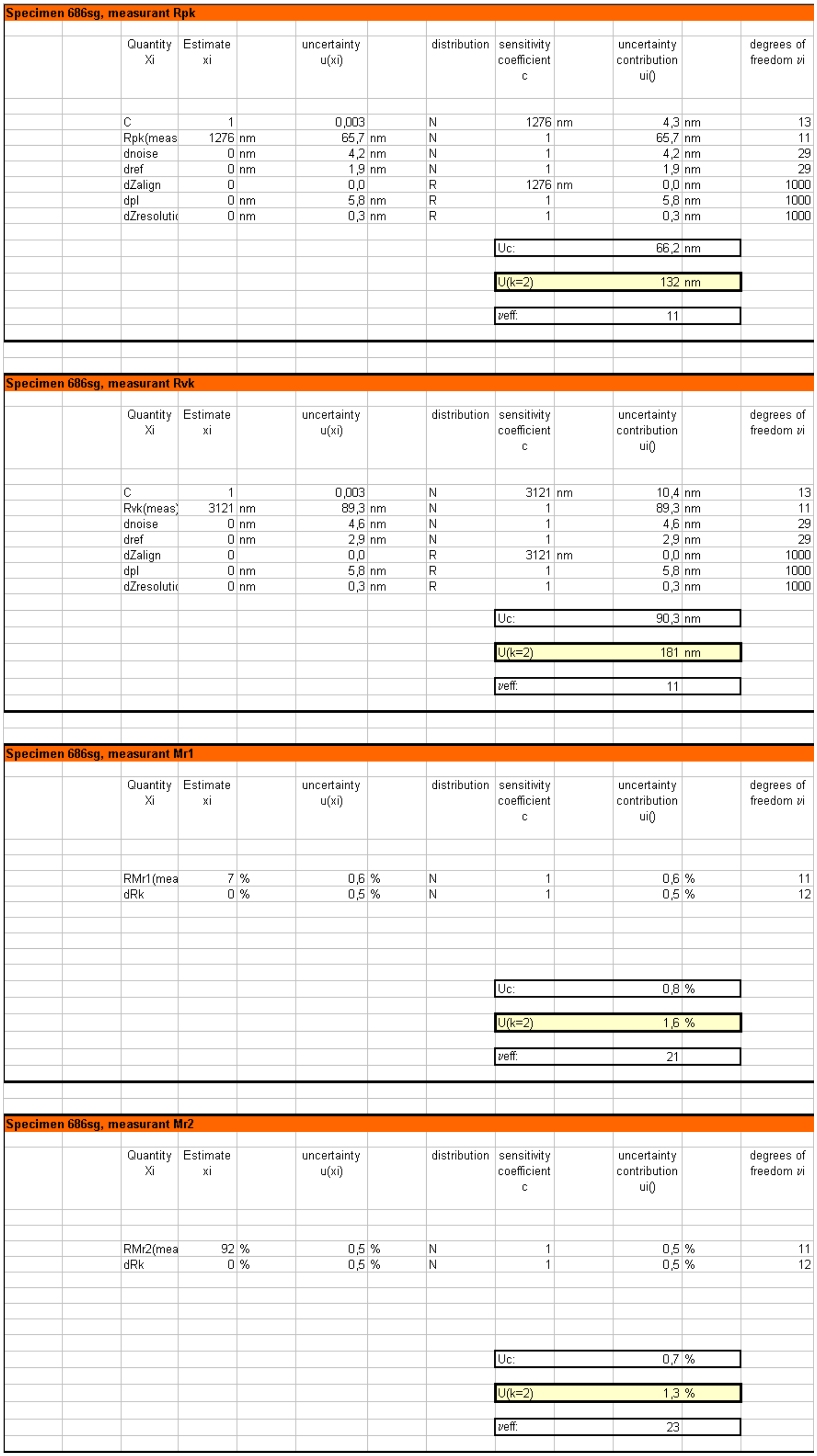
Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	14330	nm	47,8	nm	13
Rz(meas)	14330	nm	271,9	nm	N	1		271,9	nm	59
dnoise	0	nm	28,8	nm	N	1		28,8	nm	29
dref	0	nm	14,4	nm	N	1		14,4	nm	29
dZalign	0		0,0		R	14330	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		278,0	nm	
						U(k=2)		556	nm	
						νeff:		64		

Specimen 686sg, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	15567	nm	51,9	nm	13
Rmax(mea	15567	nm	35,7	nm	N	1		35,7	nm	11
dnoise	0	nm	31,8	nm	N	1		31,8	nm	29
dref	0	nm	20,8	nm	N	1		20,8	nm	29
dZalign	0		0,0		R	15567	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		73,8	nm	
						U(k=2)		148	nm	
						νeff:		40		

Specimen 686sg, measurant Rk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	8075	nm	26,9	nm	13
Rk(meas)	8075	nm	143,3	nm	N	1		143,3	nm	11
dnoise	0	nm	12,5	nm	N	1		12,5	nm	29
dref	0	nm	6,3	nm	N	1		6,3	nm	29
dZalign	0		0,0		R	8075	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		146,6	nm	
						U(k=2)		293	nm	
						νeff:		12		



Specimen 686sg, measurant Rpk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1276	nm	4,3	nm	13
Rpk(meas	1276	nm	65,7	nm	N	1		65,7	nm	11
dnoise	0	nm	4,2	nm	N	1		4,2	nm	29
dref	0	nm	1,9	nm	N	1		1,9	nm	29
dZalign	0		0,0		R	1276	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		66,2	nm	
						U(k=2)		132	nm	
						νeff:		11		

Specimen 686sg, measurant Rvk

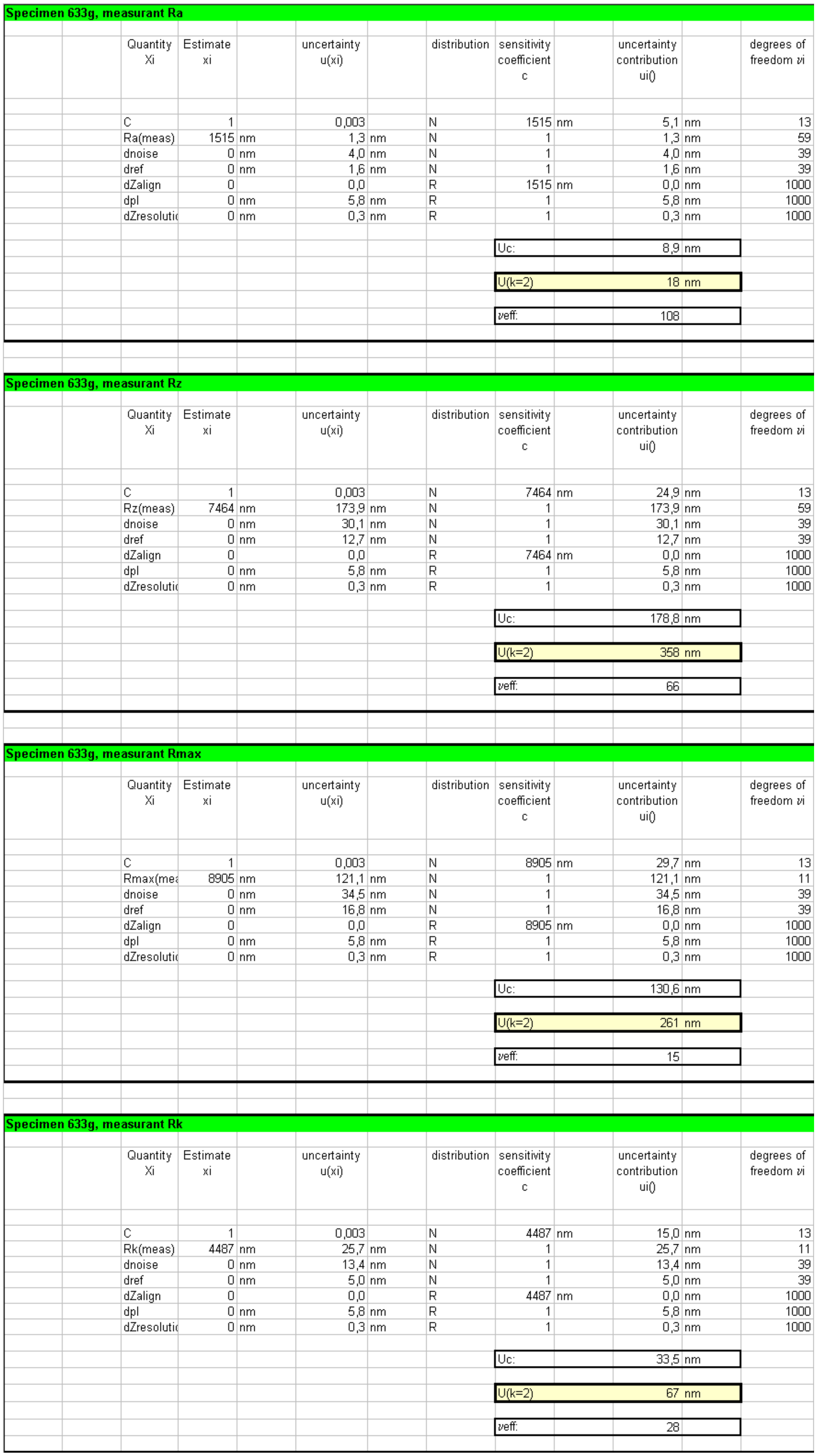
Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	3121	nm	10,4	nm	13
Rvk(meas)	3121	nm	89,3	nm	N	1		89,3	nm	11
dnoise	0	nm	4,6	nm	N	1		4,6	nm	29
dref	0	nm	2,9	nm	N	1		2,9	nm	29
dZalign	0		0,0		R	3121	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		90,3	nm	
						U(k=2)		181	nm	
						νeff:		11		

Specimen 686sg, measurant Mr1

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr1(mea	7	%	0,6	%	N	1		0,6	%	11
dRk	0	%	0,5	%	N	1		0,5	%	12
						Uc:		0,8	%	
						U(k=2)		1,6	%	
						νeff:		21		

Specimen 686sg, measurant Mr2

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr2(mea	92	%	0,5	%	N	1		0,5	%	11
dRk	0	%	0,5	%	N	1		0,5	%	12
						Uc:		0,7	%	
						U(k=2)		1,3	%	
						νeff:		23		



Specimen 633g, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1515	nm	5,1	nm	13
Ra(meas)	1515	nm	1,3	nm	N	1		1,3	nm	59
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,6	nm	N	1		1,6	nm	39
dZalign	0		0,0		R	1515	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		8,9	nm	
						U(k=2)		18	nm	
						νeff:		108		

Specimen 633g, measurant Rz

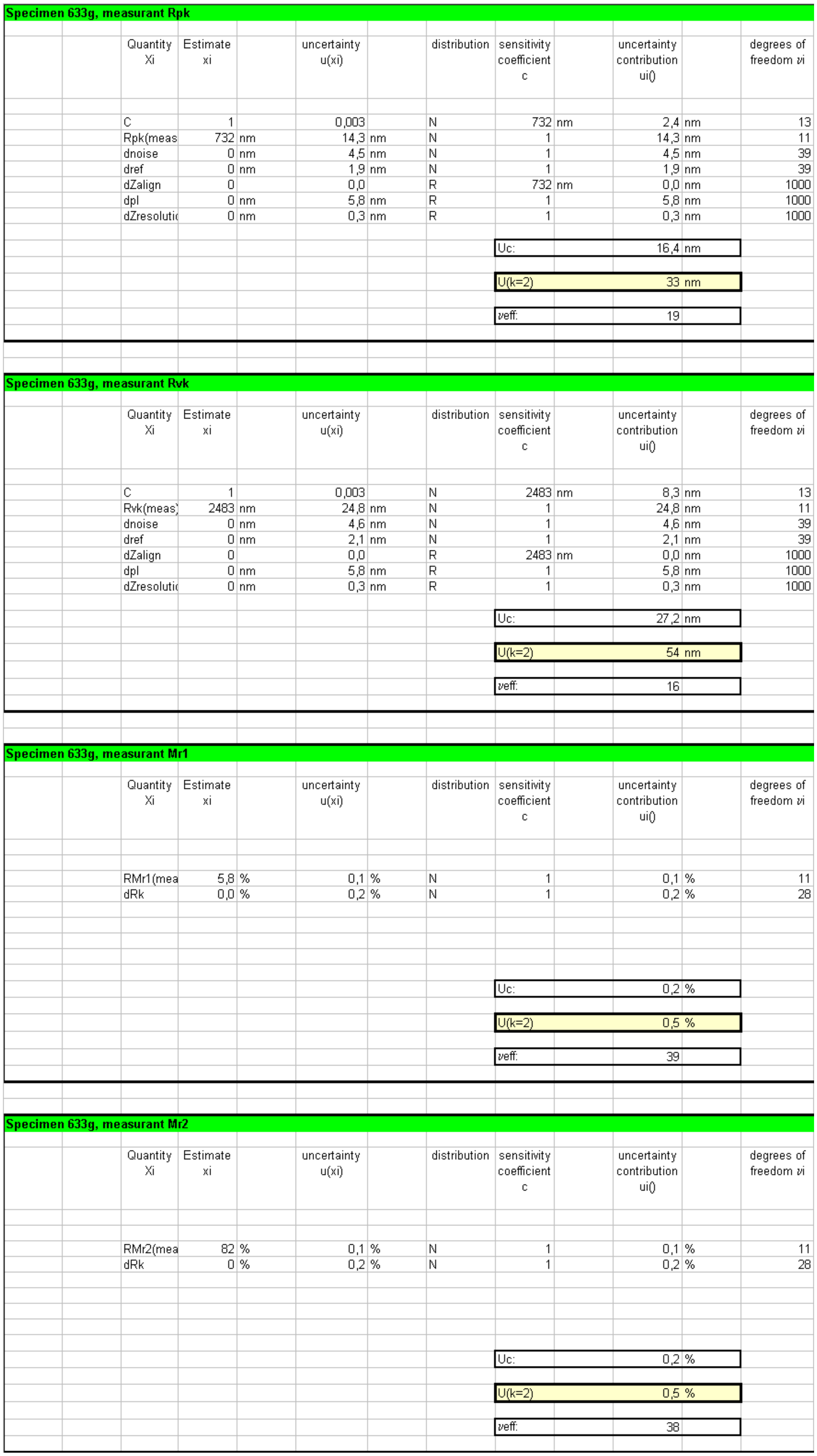
Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	7464	nm	24,9	nm	13
Rz(meas)	7464	nm	173,9	nm	N	1		173,9	nm	59
dnoise	0	nm	30,1	nm	N	1		30,1	nm	39
dref	0	nm	12,7	nm	N	1		12,7	nm	39
dZalign	0		0,0		R	7464	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		178,8	nm	
						U(k=2)		358	nm	
						νeff:		66		

Specimen 633g, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	8905	nm	29,7	nm	13
Rmax(mea	8905	nm	121,1	nm	N	1		121,1	nm	11
dnoise	0	nm	34,5	nm	N	1		34,5	nm	39
dref	0	nm	16,8	nm	N	1		16,8	nm	39
dZalign	0		0,0		R	8905	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		130,6	nm	
						U(k=2)		261	nm	
						νeff:		15		

Specimen 633g, measurant Rk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	4487	nm	15,0	nm	13
Rk(meas)	4487	nm	25,7	nm	N	1		25,7	nm	11
dnoise	0	nm	13,4	nm	N	1		13,4	nm	39
dref	0	nm	5,0	nm	N	1		5,0	nm	39
dZalign	0		0,0		R	4487	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		33,5	nm	
						U(k=2)		67	nm	
						νeff:		28		



Specimen 633g, measurant Rpk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	732	nm	2,4	nm	13
Rpk(meas	732	nm	14,3	nm	N	1		14,3	nm	11
dnoise	0	nm	4,5	nm	N	1		4,5	nm	39
dref	0	nm	1,9	nm	N	1		1,9	nm	39
dZalign	0		0,0		R	732	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		16,4	nm	
						U(k=2)		33	nm	
						νeff:		19		

Specimen 633g, measurant Rvk

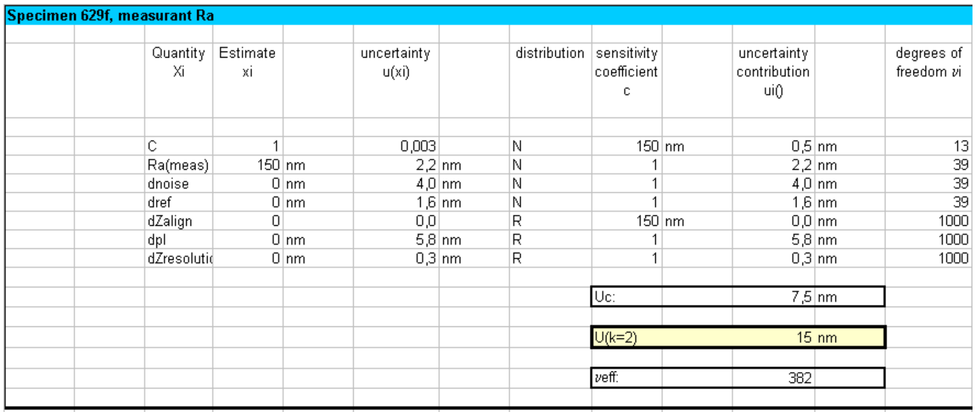
Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	2483	nm	8,3	nm	13
Rvk(meas)	2483	nm	24,8	nm	N	1		24,8	nm	11
dnoise	0	nm	4,6	nm	N	1		4,6	nm	39
dref	0	nm	2,1	nm	N	1		2,1	nm	39
dZalign	0		0,0		R	2483	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		27,2	nm	
						U(k=2)		54	nm	
						νeff:		16		

Specimen 633g, measurant Mr1

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr1(mea	5,8	%	0,1	%	N	1		0,1	%	11
dRk	0,0	%	0,2	%	N	1		0,2	%	28
						Uc:		0,2	%	
						U(k=2)		0,5	%	
						νeff:		39		

Specimen 633g, measurant Mr2

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr2(mea	82	%	0,1	%	N	1		0,1	%	11
dRk	0	%	0,2	%	N	1		0,2	%	28
						Uc:		0,2	%	
						U(k=2)		0,5	%	
						νeff:		38		



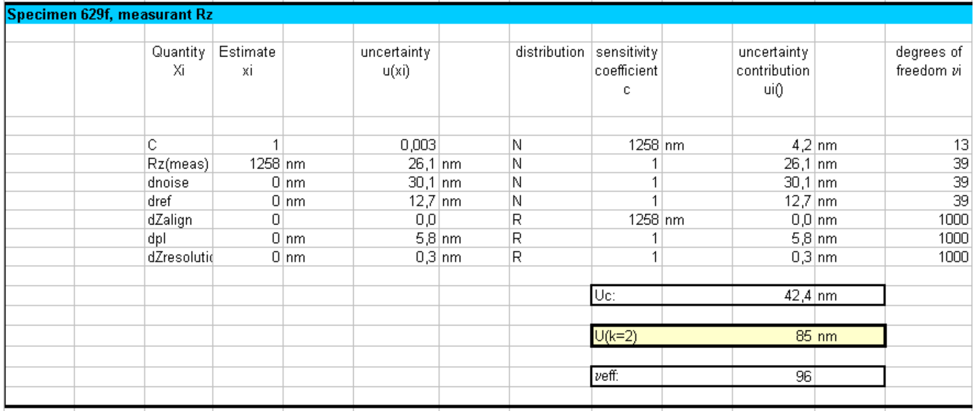
Specimen 629f, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	150	nm	0,5	nm	13
Ra(meas)	150	nm	2,2	nm	N	1		2,2	nm	39
dnoise	0	nm	4,0	nm	N	1		4,0	nm	39
dref	0	nm	1,6	nm	N	1		1,6	nm	39
dZalign	0		0,0		R	150	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 7,5 nm

U(k=2) 15 nm

νeff: 382



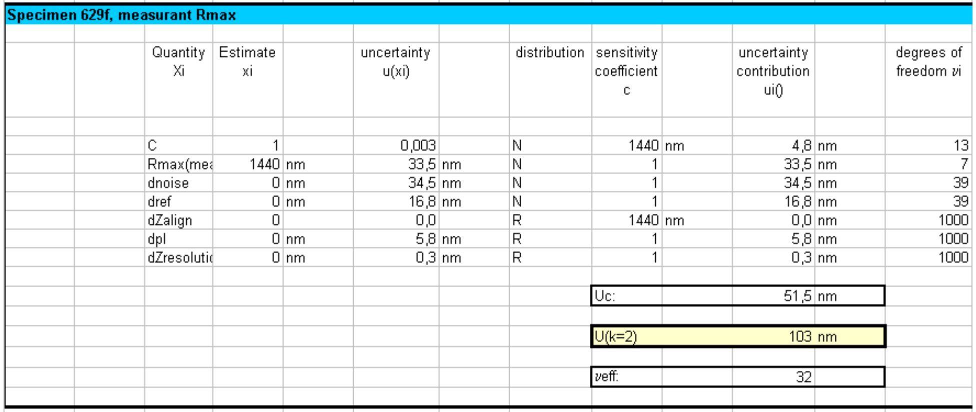
Specimen 629f, measurant Rz

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1258	nm	4,2	nm	13
Rz(meas)	1258	nm	26,1	nm	N	1		26,1	nm	39
dnoise	0	nm	30,1	nm	N	1		30,1	nm	39
dref	0	nm	12,7	nm	N	1		12,7	nm	39
dZalign	0		0,0		R	1258	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 42,4 nm

U(k=2) 85 nm

νeff: 96



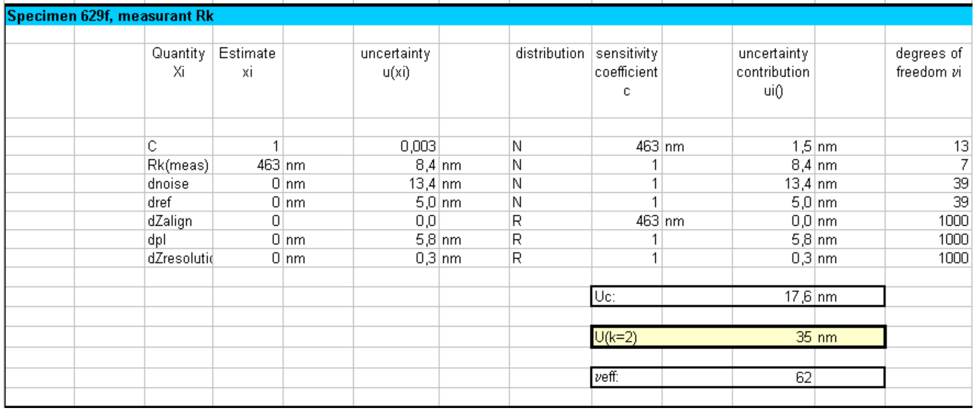
Specimen 629f, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	1440	nm	4,8	nm	13
Rmax(mea	1440	nm	33,5	nm	N	1		33,5	nm	7
dnoise	0	nm	34,5	nm	N	1		34,5	nm	39
dref	0	nm	16,8	nm	N	1		16,8	nm	39
dZalign	0		0,0		R	1440	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 51,5 nm

U(k=2) 103 nm

νeff: 32



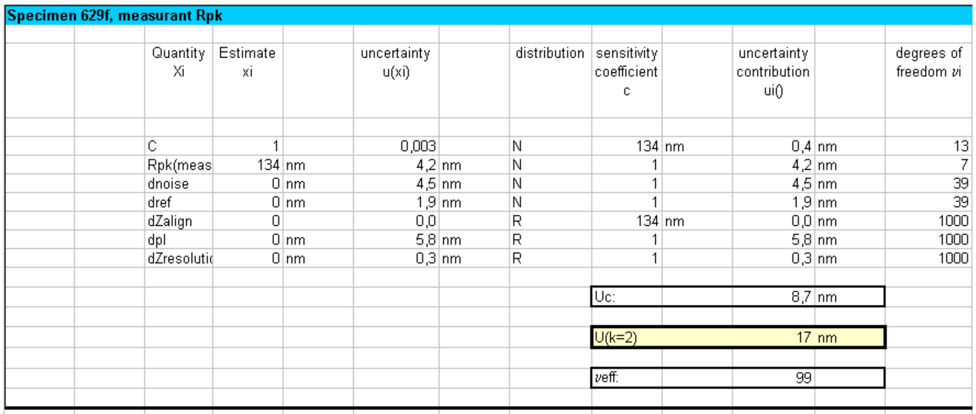
Specimen 629f, measurant Rk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	463	nm	1,5	nm	13
Rk(meas)	463	nm	8,4	nm	N	1		8,4	nm	7
dnoise	0	nm	13,4	nm	N	1		13,4	nm	39
dref	0	nm	5,0	nm	N	1		5,0	nm	39
dZalign	0		0,0		R	463	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresoluti	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 17,6 nm

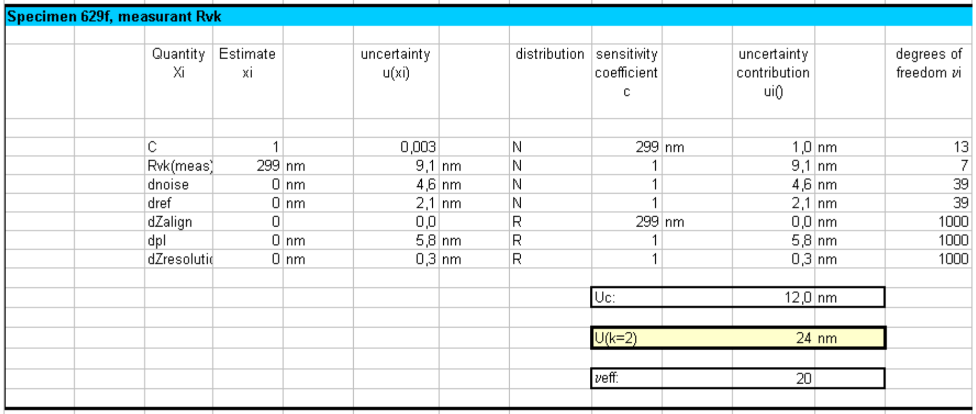
U(k=2) 35 nm

νeff: 62



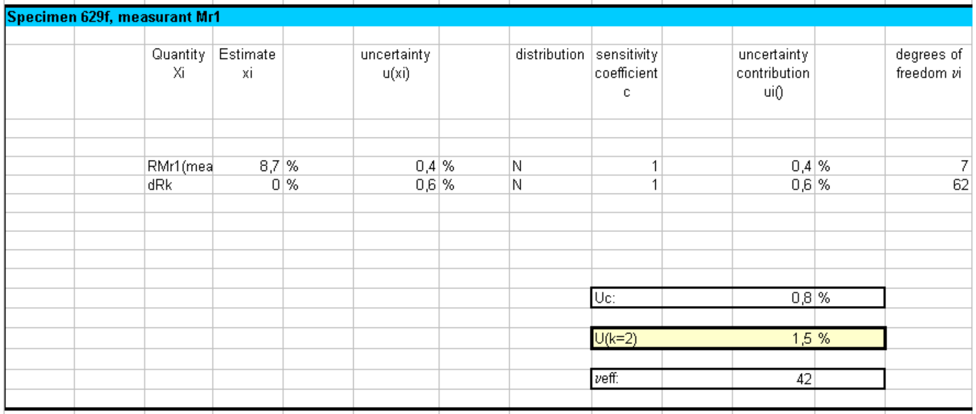
Specimen 629f, measurant Rpk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	134	nm	0,4	nm	13
Rpk(meas	134	nm	4,2	nm	N	1		4,2	nm	7
dnoise	0	nm	4,5	nm	N	1		4,5	nm	39
dref	0	nm	1,9	nm	N	1		1,9	nm	39
dZalign	0		0,0		R	134	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		8,7	nm	
						U(k=2)		17	nm	
						νeff:		99		



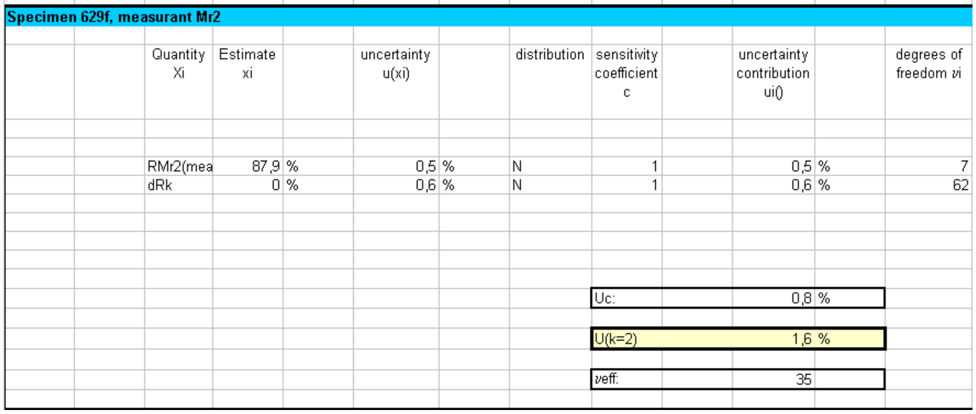
Specimen 629f, measurant Rvk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	299	nm	1,0	nm	13
Rvk(meas)	299	nm	9,1	nm	N	1		9,1	nm	7
dnoise	0	nm	4,6	nm	N	1		4,6	nm	39
dref	0	nm	2,1	nm	N	1		2,1	nm	39
dZalign	0		0,0		R	299	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutio	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		12,0	nm	
						U(k=2)		24	nm	
						νeff:		20		



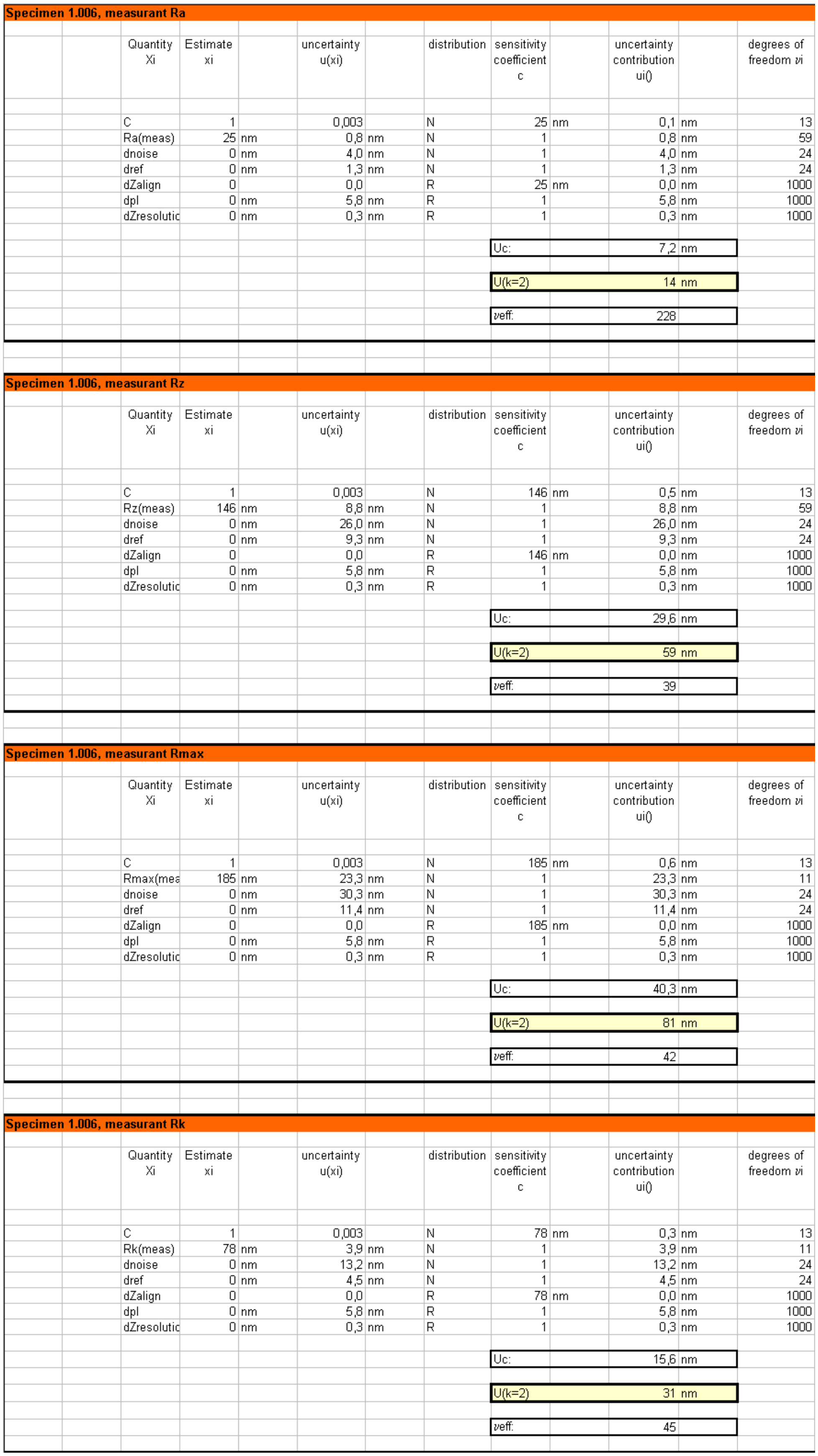
Specimen 629f, measurant Mr1

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr1(mea	8,7	%	0,4	%	N	1		0,4	%	7
dRk	0	%	0,6	%	N	1		0,6	%	62
						Uc:		0,8	%	
						U(k=2)		1,5	%	
						νeff:		42		



Specimen 629f, measurant Mr2

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr2(mea	87,9	%	0,5	%	N	1		0,5	%	7
dRk	0	%	0,6	%	N	1		0,6	%	62
						Uc:		0,8	%	
						U(k=2)		1,6	%	
						νeff:		35		



Specimen 1.006, measurant Ra

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	25	nm	0,1	nm	13
Ra(meas)	25	nm	0,8	nm	N	1		0,8	nm	59
dnoise	0	nm	4,0	nm	N	1		4,0	nm	24
dref	0	nm	1,3	nm	N	1		1,3	nm	24
dZalign	0		0,0		R	25	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 7,2 nm

U(k=2) 14 nm

νeff: 228

Specimen 1.006, measurant Rz

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	146	nm	0,5	nm	13
Rz(meas)	146	nm	8,8	nm	N	1		8,8	nm	59
dnoise	0	nm	26,0	nm	N	1		26,0	nm	24
dref	0	nm	9,3	nm	N	1		9,3	nm	24
dZalign	0		0,0		R	146	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 29,6 nm

U(k=2) 59 nm

νeff: 39

Specimen 1.006, measurant Rmax

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	185	nm	0,6	nm	13
Rmax(mea	185	nm	23,3	nm	N	1		23,3	nm	11
dnoise	0	nm	30,3	nm	N	1		30,3	nm	24
dref	0	nm	11,4	nm	N	1		11,4	nm	24
dZalign	0		0,0		R	185	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 40,3 nm

U(k=2) 81 nm

νeff: 42

Specimen 1.006, measurant Rk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	78	nm	0,3	nm	13
Rk(meas)	78	nm	3,9	nm	N	1		3,9	nm	11
dnoise	0	nm	13,2	nm	N	1		13,2	nm	24
dref	0	nm	4,5	nm	N	1		4,5	nm	24
dZalign	0		0,0		R	78	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000

Uc: 15,6 nm

U(k=2) 31 nm

νeff: 45

Specimen 1.006, measurant Rpk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	28	nm	0,1	nm	13
Rpk(meas)	28	nm	1,7	nm	N	1		1,7	nm	11
dnoise	0	nm	4,3	nm	N	1		4,3	nm	24
dref	0	nm	1,5	nm	N	1		1,5	nm	24
dZalign	0		0,0		R	28	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		7,5	nm	
						U(k=2)		15	nm	
						νeff:		200		

Specimen 1.006, measurant Rvk

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
C	1		0,003		N	33	nm	0,1	nm	13
Rvk(meas)	33	nm	2,4	nm	N	1		2,4	nm	11
dnoise	0	nm	4,7	nm	N	1		4,7	nm	24
dref	0	nm	1,7	nm	N	1		1,7	nm	24
dZalign	0		0,0		R	33	nm	0,0	nm	1000
dpl	0	nm	5,8	nm	R	1		5,8	nm	1000
dZresolutic	0	nm	0,3	nm	R	1		0,3	nm	1000
						Uc:		8,0	nm	
						U(k=2)		16	nm	
						νeff:		168		

Specimen 1.006, measurant Mr1

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr1(mea	12,3	%	0,9	%	N	1		0,9	%	11
dRk	0	%	4,2	%	N	1		4,2	%	45
						Uc:		4,3	%	
						U(k=2)		8,6	%	
						νeff:		49		

Specimen 1.006, measurant Mr2

Quantity Xi	Estimate xi		uncertainty u(xi)		distribution	sensitivity coefficient c		uncertainty contribution ui()		degrees of freedom νi
RMr2(mea	86,8	%	1,1	%	N	1		1,1	%	11
dRk	0	%	4,2	%	N	1		4,2	%	45
						Uc:		4,3	%	
						U(k=2)		8,7	%	
						νeff:		50		

Results and measurement conditions

Below we have summarized our measurement results and measurement conditions according to the table from the technical report.

Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
	EN 806										mm	µm	mm/s	mN	µm
R1	0,2 µm	value/µm	0,332	0,293									0,5	0,55	0,25
		std. dev./nm	7	9											
		U/nm (k=2)	26	23											
R3	1,5 µm	value/µm	1,396	1,371									0,5	0,55	0,25
		std. dev./nm	6	10											
		U/nm (k=2)	27	26											
R6	8 µm	value/µm	8,368	8,349									0,5	0,55	0,25
		std. dev./nm	7	10											
		U/nm (k=2)	62	61											
Geom. Standard			Ra	Rz	Rmax	RSm									
Rub	P114A/528-RS 5	value/µm	0,504	1,592	1,604	49,805					0,25	2,5	0,5	0,55	0,25
		std. dev./nm	2	5	9	176									
		U/nm (k=2)	15	58	69	1023									
PTB	7070/PGN10	value/µm	2,961	9,655	9,823	199,937					2,5	8	0,5	0,55	0,25
		std. dev./nm	13	44	56	24									
		U/nm (k=2)	35	127	151	964									
PTB	8194/PGN3	value/µm	0,904	3,097	3,118	118,927					0,8	2,5	0,5	0,55	0,25
		std. dev./nm	7	53	56	1138									
		U/nm (k=2)	20	126	138	2470									
Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
											mm	µm	mm/s	mN	µm
very coarse	686sg	value/µm	2,351	14,330	15,567	8,075	1,276	3,121	7,4	92,5	2,5	8	0,5	0,55	0,25
		std. dev./nm	24	272	36	143	66	89	0,6	0,5					
		U/nm (k=2)	52	556	148	293	132	181	1,6	1,3					
coarse	633g	value/µm	1,515	7,464	8,905	4,487	0,732	2,483	5,8	81,8	0,8	2,5	0,5	0,55	0,25
		std. dev./nm	1	174	121	26	14	25	0,1	0,1					
		U/nm (k=2)	18	358	261	67	33	54	0,5	0,5					
fine	629f	value/µm	0,150	1,258	1,440	0,463	0,134	0,299	8,7	87,9	0,8	2,5	0,5	0,55	0,25
		std. dev./nm	2	26	33	8	4	9	0,4	0,5					
		U/nm (k=2)	15	85	103	35	17	24	1,5	1,6					
SFRN 150	1.006	value/µm	0,025	0,146	0,185	0,078	0,028	0,033	12,3	86,8	0,25	2,5	0,5	0,55	0,25
		std. dev./nm	1	9	23	4	2	2	0,9	1,1					
		U/nm (k=2)	14	59	81	31	15	16	8,6	8,7					
Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%
			ISO 4287							DIN 4768	ISO 13565-2				
file 1	1001	value/µm	0,087	0,108	0,230	0,239	0,610	-0,014	0,470	0,610	0,066	0,264	0,096	10,4	89,5
file 2	505	value/µm	0,186	0,230	0,509	0,724	1,452	-0,258	1,233	1,419	0,130	0,640	0,244	7,4	90,3
file 3	7080	value/µm	0,430	0,491	0,762	0,730	1,492	0,016	1,492	1,492	-	-	-	-	-
*) ISO 13565-1															

Comment from NMi-VSL

What we have done so far is to check all relevant measurement data and the uncertainty contributions derived for this comparison. In our case two values were, based on the En criterion, excluded for the calculation of the reference values: Pt for the EN806 depth standard and Rmax for the 686sg roughness standard. After examining the measurement data and the uncertainty calculation for these parameters and we were not able to find any irregularities. However, since Pt is strongly influenced by noise one might argue that we have estimated the uncertainty contribution due to noise a bit on the low side. For Rmax we have measured an exceptionally low standard deviation on the 686sg standard and therefore a low overall measurement uncertainty. This seems to have been measured also by other contributers. So far we can not explain this effect other than that it might be the standard itself.

When looking at the results of the software standards it is surprising to see the variance in the results and in other cases the good agreement without matching the PTB reference value. This might be a starting point for a discussion with the software suppliers in order to reach agreement on the correct implementation on the calculation of the various parameters.

Appendix B1

Reports of NPL

A3 – MEASUREMENT REPORT

Description of the measurement methods and instruments

NanoSurf IV

NanoSurf IV is an NPL-developed instrument that measures surface texture with an uncertainty given by the equation below. The surface is traversed by a dry-bearing prismatic slideway and a diamond-tipped stylus measures the height variations across the surface. The displacement of the probe and slideway are measured using optical interferometry. A full description of NanoSurf IV can be found elsewhere*.

A4 - Uncertainty of measurement

Uncertainties

The standard uncertainty of the NanoSurf IV instrument is $u(x,z)=\sqrt{0.66^2+(0.039L)^2}$ with 45 degrees of freedom where L is the measured displacement in millimetres. The expanded uncertainty at a confidence level of 95% is found by multiplying the standard uncertainty by a coverage factor of 2. The calculation of this uncertainty can be found in Leach 2002** and is for displacement measurements in both the x and z axes, referred to as the *instrument uncertainty*. When measuring a surface, the uncertainty due to the variation over the surface (referred to as the *surface uncertainty*) has to be taken into account. Where parameters that have units of length are reported the standard uncertainty equation is applied to the mean parameter value to find the *instrument uncertainty* (*i.e.* the value of the parameter is used as the L term in the above equation) and this is added in quadrature to the standard error of the mean over the surface (the *surface uncertainty*), giving the combined standard uncertainty. This process is not mathematically rigorous as the uncertainties should be propagated through the equation for the parameter, but this is not possible using standard *GUM* rules for some parameters (for example *Ra*) so other methods must be applied (for example Monte-Carlo simulation). For this comparison the simpler method has been applied and preliminary tests have shown that the values for the uncertainties obtained are very close to those obtained using Monte-Carlo simulation. The effective degrees of freedom are calculated using the Welch-Satterthwaite equation. For the measurements of the type A2 samples the *instrument uncertainty* is found by propagating the equations for the least-squares lines and adding this in quadrature to the standard uncertainty found by substituting the mean height for L in the above equation. This is then added in quadrature to the *surface uncertainty* which is found in the normal manner.

*Leach R K 2000 Traceable measurement of surface texture at the National Physical Laboratory using NanoSurf IV *Meas. Sci. Technol.* **11** 1162-1172

Leach R K 2002 Traceability, calibration and uncertainty issues in surface metrology Version 2 *NPL Report* **CLM7 1-57

Laboratory: NPL

Date: 22 August 2002 Signature:..
NPL

Comment from NPL

Please find attached the amended Euromet 600 results.

The following changes were required:
Type A - we found that to calculate Pt we need to level the profiles in a different manner to when we calculate d. We had not come across this, as we never have been asked to quote Pt.

Type C and D - our filter was not operating correctly as NanoSurf IV does not have a uniform sampling rate. This problem is now fixed but it meant that we had to re-analyse the data.

Type F1 - NanoSurf IV requires a *(-1) multiplier. The softgauges do not, so we have had to re-analyse the data.

(Table see below)

Depth standard			Pt	D							lambda-c	lambda-s	Speed
	EN 806										mm	µm	mm/s
R1	0,2 µm	value/µm	0,295	0,283									0,009
		std. dev./nm	3,0	2,8									
		U/nm (k=2)	3,3	7,0									
		D of F	8,9	47,8									
R3	1,5 µm	value/µm	1,375	1,365									0,009
		std. dev./nm	5,4	3,3									
		U/nm (k=2)	5,2	6,2									
		D of F	5,3	38,2									
R6	8 µm	value/µm	8,365	8,351									0,02
		std. dev./nm	15,9	6,3									
		U/nm (k=2)	14,4	11,6									
		D of F	4,1	37,5									
Geom. Standard			Ra	Rz	Rmax	RSm							
Rub	P114A/528-RS 5	value/µm	0,504	1,583	1,591	50,067					0,25	2,5	0,04
		std. dev./nm	1,6	4,5	13,0	19,9							
		U/nm (k=2)	1,7	3,0	7,6	11,6							
		D of F	49,8	17,0	11,7	11,3							
PTB	7070/PGN10	value/µm	2,951	9,625	9,780	200,049					2,5	8	0,09
		std. dev./nm	12,3	38,3	67,5	52,2							
		U/nm (k=2)	7,3	22,2	40,0	30,2							
		D of F	11,8	11,1	11,0	11,0							
PTB	8194/PGN3	value/µm	0,900	3,080	3,097	120,030					0,8	2,5	0,09
		std. dev./nm	8,4	51,3	55,8	43,4							
		U/nm (k=2)	5,1	29,7	32,3	25,1							
		D of F	12,7	11,0	11,0	11,1							

Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed
											mm	µm	mm/s
very coarse	686sg	value/µm	2,345	14,293	15,525	8,078	1,25	3,22	7,55	92,62	2,5	8	0,09
		std. dev./nm	20,7	301,4	46,8	202,3	52,4	303,8	0,81	0,75			
		U/nm (k=2)	12,1	174,1	27,1	116,9	30,3	202,6	1,40	1,39			
		D of F	11,3	11,0	11,1	11,0	11,0	8,0	53,6	52,7			
coarse	633g	value/µm	1,515	7,418	8,868	4,579	0,680	2,263	5,17	82,85	0,8	2,5	0,09
		std. dev./nm	2,1	153,3	126,4	72,4	34,6	54,2	0,29	0,89			
		U/nm (k=2)	1,8	88,6	73,0	41,9	20,1	31,3	1,33	1,42			
		D of F	38,8	11,0	11,0	11,0	11,1	11,0	46,4	54,5			
fine	629f	value/µm	0,148	1,234	1,410	0,451	0,136	0,297	9,87	87,66	0,8	2,5	0,09
		std. dev./nm	3,6	50,8	60,3	14,2	6,4	16,4	0,69	0,52			
		U/nm (k=2)	2,5	29,4	34,9	8,3	4,0	9,6	1,38	1,35			
		D of F	20,8	11,0	11,0	11,6	13,9	11,4	51,9	49,2			
SFRN 150	1.006	value/nm **	25,06	140,91	185,70	79,48	26,21	30,50	11,20	86,22	0,25	2,5	0,04
		std. dev./nm	0,63	4,52	14,97	6,14	3,36	4,13	1,78	1,44			
		U/nm (k=2)	1,37	3,02	8,74	3,79	2,35	2,72	1,67	1,56			
		D of F	51,3	16,6	11,5	14,2	22,3	18,4	46,5	53,4			

Data files			Ra	Rq	Rp	Rv	Rt	Rsk#	Rz	Rku#	Rsm	Rmax	Rpk
			ISO 4287									DIN 4768	ISO 13565-2
file 1	xz7080	value/µm	0,424	0,484	0,754	0,721	1,484	0,010	1,475	1,680	99,825		
file 2	xz1001	value/µm	0,087	0,107	0,232	0,238	0,628	-0,160	0,470	2,710	66,135		
file 3	xz505	value/µm	0,187	0,230	0,498	0,748	1,425	-0,220	1,246	2,680	98,808		

*) ISO 13565-1

#) These parameters do not have units

**) Values for this artefact quoted in nm

Calibration, traceability and uncertainty issues in surface texture metrology
Version 2

NMS Programme for Length 1997 - 1999
Milestone 2.6.6

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Abstract

Achieving consistent surface texture measurements is of vital importance to the performance of many components in well-established fields such as mechanical engineering and manufacturing, and is becoming increasingly important in the emerging field of nanotechnology. The route to traceability in surface texture measurements is still ill-defined and it is very uncommon to find a measured surface texture parameter presented with its associated uncertainty. This report summarises the methods used to calibrate surface texture measuring instruments and discusses the various ISO standards in the field. An uncertainty analysis of a fully traceable two-dimensional surface texture measuring instrument: NanoSurf IV, is undertaken and the uncertainties in measured surface texture parameters are analysed.

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Approved on behalf of the Managing Director
by Dr David Robinson, Head of Centre for Basic, Thermal and Length Metrology

CONTENTS

FIGURE LEGENDS

TABLES

NOMENCLATURE

Note: Surface texture parameters, for example *Ra*, are defined in table 5.14.

Section 1

$g(s)$	general function of fringe dispersion
δ	a small error in $g(s)$
h	a step height measurement
s	fringe dispersion
σ_s	variance in the measurement of s
n	integer fringe number
λ	the wavelength of light

Section 5

$u_c(x)$	combined standard uncertainty in a measurement of x
$u(x)$	standard uncertainty in a measurement of x
L	length measurement made using an interferometer
c_i, c_{ij}, c_{ijj}	partial derivatives of the model equation
i, j	subscripts
ν	degrees of freedom
n	number of measurements
u_{eff}	effective number of degrees of freedom
U	expanded uncertainty
k	coverage factor
L_ϕ	displacement measured by a two-beam interferometer
λ	wavelength of light
$\Delta\phi$	difference in phase from the reference and measurement arms
L_Ω	correction for diffraction
L_n	correction due to the change in air refractive index
L_t	correction for thermal effects on the metrology frame
L_m	correction for mechanical effects on the metrology frame
L_A	correction for imperfect optics and stray beams
L_d	correction for the dead path length
L_T	correction for air turbulence

L_j	correction for the measurement set-up
λ_0	fringe displacement
k	wavenumber
w_0	waist of a laser beam
u	aperture radius
w_f	defined by equation (5.13)
b	defined by equation (5.14)
D	absolute distance of the lens from the waist of the beam
f	focal length
s''	image to lens distance
s	object to lens distance
z_R	Rayleigh length
m	magnification
α	misalignment angle
z	distance between waist and detector
l	distance between waist and retro-reflector
θ	defined in the text
v	defined in the text
σ	defined in the text

λ_{vac}	wavelength of light in a vacuum
n	refractive index of air
σ	wavenumber
x	carbon dioxide content
t	air temperature
p	air pressure
f	water vapour partial pressure
t_{dp}	dewpoint temperature

$a(x, y)$	complex amplitude at point (x, y)
$\phi(x, y)$	phase of light at point (x, y)
$a_s(x, y)$	complex amplitude of stray light at point (x, y)
$\phi_s(x, y)$	phase of stray light at point (x, y)
p	path difference between stray light and test beams
I	intensity

D	dead path length
N	half the number of fringes counted during a displacement
n_2	refractive index at the end of a measurement
Δn	change in refractive index
d	displacement
z	vertical axis
x	axis of scan
a	intercept on z axis
b	gradient
χ	least-squares minimisation parameter
a^*	least-squares intercept on z axis
b^*	least-squares gradient
$S, S_x, S_z, S_{xx}, S_{zz}, S_{zx}$	summations defined by equations (5.46)
d	constant of proportionality
r	population correlation coefficient
f	defined in equation (5.55)
N	number of data points
μ_2	second moment

1. INTRODUCTION

Only in recent years have sound metrological principles been applied to the measurement of surface texture. Demonstration of true traceability of surface texture measurements is still rare and often only achieved by the time-consuming task of measuring the characteristics of the separate elements that make up the instrument. There are many different artefacts that can be used to characterise an instrument and a huge number of parameters that can be calculated from the measured data. There is a vast library of specification standards on the subject. The report will only consider those published by the International Standards Organisation (ISO). It is also rare to see an uncertainty figure quoted with a measured surface texture parameter - a taboo in dimensional metrology not seeming to cover surface texture. The aims of this report are to summarise the work to date on calibration of surface texture instruments and their associated uncertainties, to outline and discuss the relevant ISO standards and to carry out an uncertainty analysis for a fully traceable instrument developed at NPL. The results of this uncertainty analysis will then be extended to cover the surface texture parameters that would be calculated from the measured height and length data from the instrument. No attempt has been made in this analysis to examine the effects of the surface-probe interaction or the dynamic effects of scanning - it is assumed that the probe has perfect fidelity with the surface. For this reason NanoSurf IV is always operated as close to these conditions as possible, dynamic and static filtering due to the measurement process are assumed to limit the bandwidth of the instrument, not its measurement uncertainty.

2. CALIBRATION OF SURFACE TEXTURE MEASURING INSTRUMENTS (A HISTORY)

The metrological issues described in this section have been explored since the 1930s when the first surface texture instruments were being used. The traditional method of calibrating a surface texture measuring instrument is to traverse a lined calibration artefact. The period and amplitude of the lines would be chosen to, ideally, encompass the whole operating bandwidth of the instrument or its transmission characteristics. One of the early standards took the form of acid-etched lines in a substrate and was developed by Timms of NPL (1946). Underwood (also of NPL) introduced his Caliblocks in 1953 which were formed with a diamond tool mounted in a dividing engine and used to rule electro-deposited gold. Schobinger (1956) made specimens by vacuum coating glass surfaces with silica through a wire mask. These early artefacts had limited topography and could not match the lower spatial bandwidth limits of the instruments they were designed to calibrate.

Sharman of the National Engineering Laboratory (NEL) (1967) was, perhaps, the first to introduce essentially sinusoidal gratings as artefacts. These were formed by vacuum depositing aluminium and chromium on a lapped steel substrate and for a given peak-to-peak height a single specimen could be used to generate any pitch from 0.25 μm to 13 μm. The pitch variation was achieved by mounting the specimen on a small rotary table and rotating the specimen relative to the direction of traverse of the pick-up head. Much of the literature suggests the use of step-height standards, such as wrung gauge blocks for low magnification and lever arm devices or evaporated or etched films for high magnifications (Reason 1967).

Van Hasselt & Bruin (1963) and Bendeli, Duruz, *et. al.* (1974) introduced the idea of using a vibrating platform to simulate the spatial frequencies present in a surface. Calibration of a stylus instrument requires low frequency or static calibration to determine scale and linearity of the low frequency recording equipment. Also, dynamic calibration is necessary for transmission characteristics of averaging instruments with meter readouts. They suggest that the problems with using standard artefacts are the difficulty in obtaining satisfactory accuracies for static calibrations at very high magnifications (50 000x and above) without having to rely on the trueness of the attenuators and the effect of the finite shape of the stylus. Their method is, of course, limited to stylus instruments.

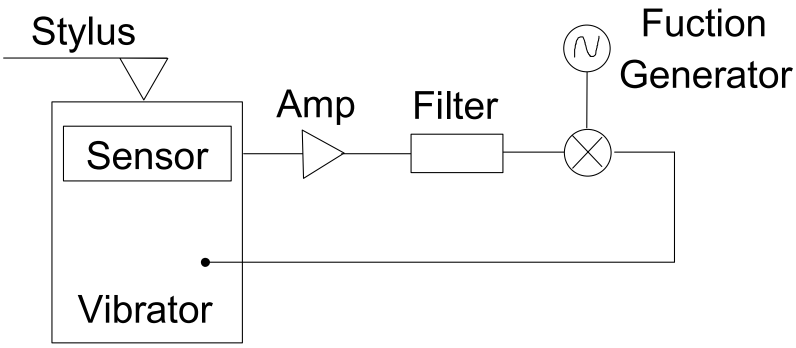

Figure 2.1 Vibrating stylus calibration rig, from Bendeli, Duruz, *et. al.* (1974)

Bendeli's instrumentation is shown in figure 2.1 and its operation is fairly self evident. The method has the following features:

- it provides a measurement of scale factor and linearity of low frequency recorders;
- it provides a measurement of transmission characteristics by applying a random signal to the vibration platform;
- it calibrates parameter meters by applying signals that generate desired profile shapes and characteristics;
- its displacement range is equal to ± 2 μm with -3 dB cut-off point at 800 Hz;
- calibration is via a spherical-ended capacitance probe with an AC resistance bridge, resolution 2 nm;
- its sensitivity is equal to 0.543 V μm^{-1} ± 0.5% per month;
- its non-linearity is less than 25 nm at extremities, but 10 nm over ± 1.5 μm.

Teague (1978) used interferometrically determined step-heights to calibrate other surface texture measuring instruments. The main sources of error using this technique are due to the geometry of the step (microscopic surface texture of the sides, non-flat surfaces and non-parallel planes) and errors in the interferometry. Teague derived a formula for the normalised uncertainty in a step height measurement, *h*, which is simply re-stated here

$$\frac{\delta h}{h} = \frac{\sigma_s}{h(n,s)}\left[1+\left(\frac{\mathrm{d}\delta}{\mathrm{d}s}\right)^2\right]^{\frac{1}{2}} \tag{2.1}$$

where *h* is given by

$$h = (n + g(s))\frac{\lambda}{2} \tag{2.2}$$

and n is the integer fringe number, $g(s)$ is a general function of the fringe dispersion, s (the lateral fringe displacement over the fringe spacing), λ is the wavelength of light, σ_s is the variance in the measurement of s and δ is a small error in $g(s)$. Teague then used least-squares methods to calculate the step-height from the measurement data and proved that the uncertainty in assigning a height value to a stylus step-profile is approximately equal to the *Ra* or *Rq* of the step's surface texture.

Tsukada & Kanada (1986) describe how it is difficult to specify, for an entire surface, any averaging parameter due to the enormous amount of data required. They also discussed the difficulties with relating the surface texture tolerances stated on real engineering drawings to the statistical surface texture parameters. By carrying out repeated measurements at different points on the same surface they reached the following conclusions:

- two-dimensional parameters, such as *Ra*, *Rq* and *Rz* when measured locally at different points on a surface, fluctuate according to a Gaussian distribution;
- each sample standard deviation, *S*, has a strong correlation with the population mean *F* and it can be expressed by $S = hF$ (h being a constant);
- three-dimensional surface texture parameters are larger than their two-dimensional brethren.

Whitehouse (1988) discussed the various sources of uncertainty when measuring surface texture with a stylus instrument. He suggested using ruled or etched standards or crystal lattice spacings as calibration artefacts and discussed the need for a knowledge of the inherent elasticity in the instrument being used. He also advocated using x-ray interferometry to calibrate stylus instruments and described a system developed at Warwick University (Chetwynd, Siddons, *et. al.* 1983). The most critical area, with x-ray techniques, was the mechanical interface between the silicon monolith and the transducer.

Song (1988) discussed the use of D-type random profile specimens for calibration of surface texture instruments (see §3 on standards for a fuller description of a D-type specimen). The disadvantages of the D-type specimens were:

- *Ra* range limited from 1.5 to 0.2 μm;

- no smooth datum plane at both sides of the measuring area - this makes comparisons awkward;
- large measurement error resulting from the phase error between the skid and stylus.

Song produced many more random profile specimens to overcome these problems.

Griffith & Grigg (1993) suggested using carbon-60 and other fullerene-like structures as calibration artefacts for surface texture measuring instruments requiring nanometre spacings. Franks (1993) used Amplitude-Wavelength space (Stedman 1987) to investigate the performance of various instruments and suggested ways of correlating different probing types by assessing the strength of their surface-probe interaction. Jörgensen, Garnoes, *et. al.* (1997) used waffle-plates to measure lateral non-linearity of scanning probe instruments and Fourier techniques to analyse the measurement data.

Haitjema (1997) reported on a EUROMET project (number 301) that compared methods of measuring depth-setting standards (step-heights). The project involved measuring five standards with groove widths of 0.01 mm and 0.1 mm and nominal depths of 32 nm, 64 nm, 160 nm, 1 μm and 3.2 μm. The samples were silicon substrates with a chromium overcoat and the definition of the groove was taken from ISO 5436. Instruments used were the Form Talysurf, Talystep, Nanostep and interference microscopes. If possible, participants were asked to carry out tests on the homogeneity of the specimens and the sensitivity of the depths to their definitions. Results showed that the depths are not sensitive to the definition to within a nanometre. The depth results were in good agreement for the small depths but the 3.2 μm standard gave a sample standard deviation of around 40 nm. Haitjema suggests that this situation must improve and that agreement should be within 1% (*i.e.* 30 nm in 3 μm).

NPL has been producing a number of sinusoidal specimens with varying period and amplitude to be used for calibrating surface texture measuring instruments (NMS Programme for Length 1996-1999). Replicas of these samples, and even replicas of the replicas can be produced (Daly, Ferguson, *et. al.* 1997). These samples are measured with a stylus instrument and mathematical techniques (similar to reversal methods) can be applied to extract the shape of the stylus. It is planned by NPL that the range of sinusoidal samples will be increased to include samples with multiple harmonics and varying phases. A number of comparisons of different instruments will then be carried out to assess the samples suitability as calibration artefacts. Watts, Sambles, *et. al.*

(1997) have developed a method using surface plasmons to optically measure the shape of a stylus.

Scheer & Stover (1998) have developed square-wave gratings with depths in the range 1 to 10 nm. These samples are measured using AFM and angle resolved scatter (ARS) and power spectral analysis is used to correlate instruments with differing bandwidths. The production techniques stem from the silicon wafer technologies. Their route to traceability is via the laser source of the ARS instrument.

Haitjema (1998) has recently reported on a thorough investigation of the Form Talysurf stylus instrument. He suggests that deviations in comparisons are caused by short wavelength cut-offs due to stylus geometry and probe resonance oscillations. His method of calibration involves splitting the instrument into a number of sub-systems and using various metrological tools to calibrate the system as a whole. These separate measurements are described below:

x axis calibration

x axis calibration is required for the definition of the cut-off spatial wavelength, the sampling length and to calculate spacing and hybrid parameters (for example Δq). He uses a graduated rule and time-based analysis (this requires a constant traversing speed) to calibrate the x axis internal scales.

z axis calibration

Haijema has three methods for calibrating the z axis. Firstly, the stylus traces a standard sphere with known radius and the instrument calculates a polynomial correction for arcuate movement of the probe. Secondly, the length of a 0.5 mm gauge block wrung to a flat surface is measured and a length difference of around 10 μm is achieved by comparing two gauge blocks. The third method uses the set-up shown in figure 2.2. A piezoelectric actuator with capacitive feedback control (DPT) is connected to a function generator and used to move a small gauge block. The gauge block acts as a mirror for a differential plane mirror interferometer and as the contact point for the stylus. This is a very similar system to that of Bendeli, Duruz, *et. al.* (1974) except the traceability path is via the wavelength of the laser source as opposed to capacitance sensors. The same calibration procedures apply in both instruments.

Straightness datum

An optical flat ($Ra \approx 10$ nm) is traced and the known profile minus the measured profile gives the noise. For more confidence in the measurements, the same part of the datum is used in a measurement of different parts of the flat.

Filter definition and dynamic probe behaviour

The frequency and amplitude of the vibrating gauge are varied and the dynamics of the system are investigated. The filtered and unfiltered data are compared plus the Rq measured with the Talysurf to the standard deviation measured with the interferometer system. From these data probe resonances can be identified as well as the effect of stylus flight.

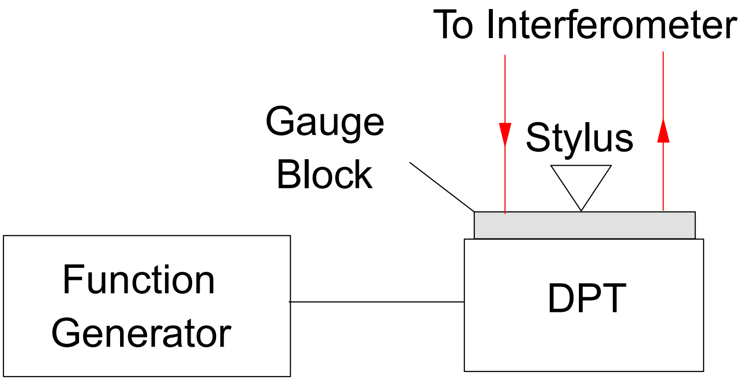

Figure 2.2 Vibrating stylus calibration rig, from Haitjema (1998)

Stylus geometry

The tip of an uncoated razor blade (< 0.1 µm tip radius) is measured and the stylus geometry calculated. Whitehouse (1994) also discusses using a razor blade to measure the stylus geometry plus an etched artefact with decreasing line-widths to measure geometry and wear.

Measuring force

For the static measuring force a mass balance is probed. Assuming that no stylus flight was apparent from the observations of the dynamic probe behaviour, the dynamic force will be less than the static force and is not measured. This assumption is not necessarily true (Liu, Chetwynd, *et. al.* 1993). The force is also checked as the direction of probing is reversed.

The above examples illustrate that traceability and calibration in surface texture measurement involves a multitude of artefacts and measurement strategies. The next section will examine the ISO standards that apply in the field.

3. STANDARDS

In 1994 Whitehouse listed over one hundred standards for surface texture measurement, but as more countries adopt the International Standards, this number has dropped to around fifty. There are, however, many more standards that relate to surface texture in some way. The following is a list of surface texture standards compiled using the 1998 Standards Infobase.

AGMA 118.01 (1995)	Information sheet - gear tooth surface texture for aerospace gearing (surface roughness, waviness, form and lay)
AS 2382 (1981)	Surface roughness comparison specimens
ASME B46.1 (1978)	Surface texture, (surface roughness, waviness and lay)
ASTM F 1048- (1992)	Test method for measuring the effective surface roughness of optical components by total integrated scatter
ASTM F 1438- (1997)	Test method for determining surface roughness by scanning tunneling microscopy for gas distribution system components
ASTM F 1811- (1997)	Practice for estimating the power spectral density function and related finish parameters from surface profile data
BS 1134: PT1 (1988)	Assessment of surface texture - methods and instrumentation
BS 1134: PT2 (1990)	Assessment of surface texture - guidance and general information
BS 2634: PT1 (1987)	Specification for roughness comparison specimens - specification for turned, ground, bored, milled, shaped and planed specimens
BS 2634: PT2 (1987)	Specification for roughness comparison specimens - specification for spark-eroded, shot blasted, grit-blasted and polished specimens
BS 6393 (1987)	As ISO 5436-
BS 6741: PT1 (1987)	Glossary of surface roughness terms - surface and its parameters
BS 6741: PT2 (1987)	Glossary of surface roughness terms - measurement of surface roughness parameters
BS 7900 (1998)	Specification for examination of surface texture of precision steel castings
BS ISO 3274 (1998)	As ISO 3274-
DD ENV 623 PT4 (1994)	Advanced technical ceramics - monolithic ceramics - general and textural properties - determination of surface roughness
DIN 31670 PT8 (1986)	Plain bearings: quality assurance of plain bearings: checking the geometrical tolerances and surface roughness of shafts, collars and thrust collars

DIN 31699 (1986)	Plain bearings: shafts, collars, thrust collars; geometrical tolerances and surface roughness
DIN 3969 PT1 (1991)	Surface roughness of tooth flanks; roughness parameters, surface grades
DIN 40686 SUPP2 (1983)	Surfaces of dense ceramic components for electrical engineering; determination of surface roughness
DIN 4762 (1981)	Surface roughness; terminology; surface & its parameters
DIN 4762 PT1 (1981)	Progressive ratio number values of surface roughness parameters
DIN 4766 PT1 (1981)	Surface roughness associated with types of manufacturing methods; attainable arithmetical mean value of peak-to-valley height Rz
DIN 4766 PT2 (1981)	Surface roughness associated with types of manufacturing methods; attainable arithmetical mean value Ra
DIN 4768 (1974)	Determination of values of surface roughness parameters Ra, Rz, Rmax using electrical contact (stylus) instruments; concepts and measuring conditions
DIN 4768 PT1 (1978)	Determination of surface roughness Ra, Rz, Rmax with electric stylus instruments; basic data
DIN 4772 (1979)	Electrical contact (stylus) instruments for measurement of surface roughness by profile method
DIN 4775 (1982)	Measuring of the surface roughness of workpieces; visual and tactile comparison, methods by means of contact stylus instruments
DIN 4776 (1990)	Determination of surface roughness parameters Rk, Rpk, Rvk, Mr1, Mr2 serving to decrease the material component of roughness profile
DIN 4776 SUPP1 (1990)	Measurement of surface roughness; parameters Rk, Rpk, Rvk, Mr1, Mr2 for description of material portion (profile bearing length ratio) in roughness profile; measuring conditions and evaluation procedures
DIN 54530 PT10 (1993)	Testing of paper and board cores; surface quality; determination of surface roughness and waviness
DIN V ENV 623 PT4	As DD ENV 623 PT4
ISO 1879-	Classification of instruments and devices for measurement and evaluation of the geometrical parameters of surface finish
ISO 1879- (1981)	Instruments for the measurement of surface roughness by the profile method - vocabulary
ISO 1880- (1979)	Instruments for the measurement of surface roughness by the profile method - contact (stylus) instruments of progressive profile transformation - profile recording instruments
ISO 3274- (1975)	Geometrical product specifications (GPS) - surface texture: profile method - nominal characteristics of contact (stylus) instruments

ISO 4287/1-(1984)	Surface roughness - terminology - surface and its parameters
ISO 4287/2- (1984)	Surface roughness - terminology - measurement of surface roughness parameters
ISO 4288- (1983)	Geometrical product specifications (GPS) - surface texture: profile method - rules and procedures for the assessment of surface texture
ISO 468- (1972)	Surface roughness - parameters, their values and general rules for specifying requirements
ISO 5436- (1985)	Calibration specimens - stylus instruments - types, calibration and use of specimens
JIS-B0601 (1982)	Surface roughness - definitions and designation
JIS-B0652 (1973)	Instruments for the measurement of surface roughness by the interferometric method
JIS-K7104 (1976)	Methods for comparison of surface roughness of plastics
MIL-I-45177 (1996)	Instrument, tracer, surface roughness
NAS 30 (1956)	Surface roughness designation
NAS 31 (1958)	Conversion table, surface roughness designations
SIS 81 20 05 (1973)	Concrete surfaces. Determination of surface roughness
SS 674 (1989)	Surface roughness - guidance for the choice of surface roughness
SS 675 (1989)	Surface roughness - measurement of surface roughness by means of electrical profile recording instruments
SS ENV 623-4	As DD ENV 623 PT4
SS ISO 4287-1	As ISO 4287/1-
SS ISO 4287-2	As ISO 4287/2-
SS ISO 4288 (1988)	Rules and procedures for the measurement of surface roughness using stylus instruments
SS ISO 468	As ISO 468-
UNI ISO 1879	As ISO 1879-
UNI ISO 1880	As ISO 1880-
UNI ISO 4287/1	As ISO 4287/1-
UNI ISO 4287/2	As ISO 4287/2-
UNI ISO 4288	As SS ISO 4288
UNI ISO 468	As ISO 468-
VD/VDE 2615 (1988)	Surface roughness measurement of cylindrical gears and bevel gears by means of electrical stylus-type instruments

The most important standard as far as this report is concerned is ISO 5436 (1985*): Calibration specimens - stylus instruments - types, calibration and use of specimens*. This standard advocates the use of calibration specimens or artefacts to calibrate the operating characteristics of contact stylus instruments. Four different types of specimen are described:

Type A - These are used to measure the vertical magnification of an instrument. They come in two sub-groups: *Type A1* - a wide calibrated groove with a flat valley the size of which is dictated by the dimensions of the stylus tip, *Type A2* - same as A1 but with a rounded valley.

Type B - These are used to investigate the geometry of the stylus tip. They also come with two sub-groups: *Type B1* - narrow grooves proportioned to be sensitive to the dimensions of the stylus; *Type B2* - two grids of equal *Ra*, one sensitive to the tip dimensions the other insensitive.

Type C - These are used to check parameter meters. They consist of a grid of repetitive grooves of similar shape (for example sinusoidal, triangular and arcuate waveforms) with low harmonic amplitudes. Type C specimens have well documented surface texture parameters and can be used to check the horizontal magnification.

Type D - These are used for an overall check of the meter calibration. They have irregular profiles in the direction of traverse, but they have the convenience of an approximately constant cross-section along their lengths.

All the specimens are made of suitably hard materials but glass or quartz is favoured. At the time of writing the type B1 specimens are still under development.

Calibration of the specimens is carried out using interferometry and the route to traceability is via the calibrated vacuum wavelength of the source. The use of interferometry usually requires the surface to be metalised and only shallow grooves can be measured without having to resort to specialised fringe analysis techniques. Problems arise due to the differences between the interaction of a contact stylus instrument and the surface and an optical beam and the surface. Examples quoted in the standard are the effects of the optical properties of the specimen material and the effects of oblique incidence. The magnitude of these effects is assumed negligible by the standard - a assumption that is not considered wise by the author.

ISO 5436 goes on to consider the calibration aspects of instruments with a datum skid, the effects of stylus wear, practical use of the standard specimen and error statements. Very little, if any, real consideration is given to the statement of uncertainty that would either accompany a calibrated instrument or the artefacts used to calibrate an instrument. This is thought to be an aspect of the standards that is not sufficiently covered.

4. A FULLY TRACEABLE INSTRUMENT: NANOSURF IV

NanoSurf IV is a surface texture measuring instrument that measures displacements in two nominally orthogonal axes with an uncertainty of better than 1 nm. Many instruments can resolve sub-nanometre features but the user has no way of knowing whether the readout of the co-ordinates from the instrument is correct. They are fiducial indicators - not measuring instruments in the true sense of the word. NanoSurf IV is simply a stylus instrument but with traceable metrology inherent in its design. Figure 4.1 shows the subsystems of NanoSurf IV and illustrates how they are related. In addition to the core subsystems there is also instrumentation to input the signals from the interferometers and control the moving parts in the instrument, a computing system that automates a measurement and carries out any data analysis, plus systems to control the environment in which the instrument is housed. Each is described in detail elsewhere (Leach 2000). Figure 4.2 is a photograph of NanoSurf IV with only the electronic and computer subsystems not shown.

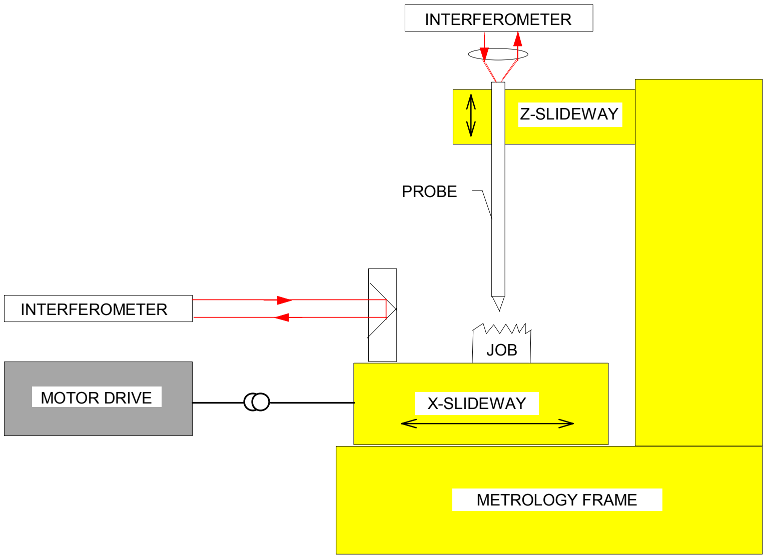

Figure 4.1 Schema of NanoSurf IV

Briefly, with reference to figure 4.1, the object to be measured is placed on a specimen table that in turn sits on the x slideway. The z slideway is used to bring the stylus into contact with the surface to be measured. The drive mechanism pushes or pulls the x slideway via a coupling rod and hence moves the surface being measured whilst the stylus follows the surface. The displacements in the x and z axes are measured using two non-polarising Michelson interferometers.

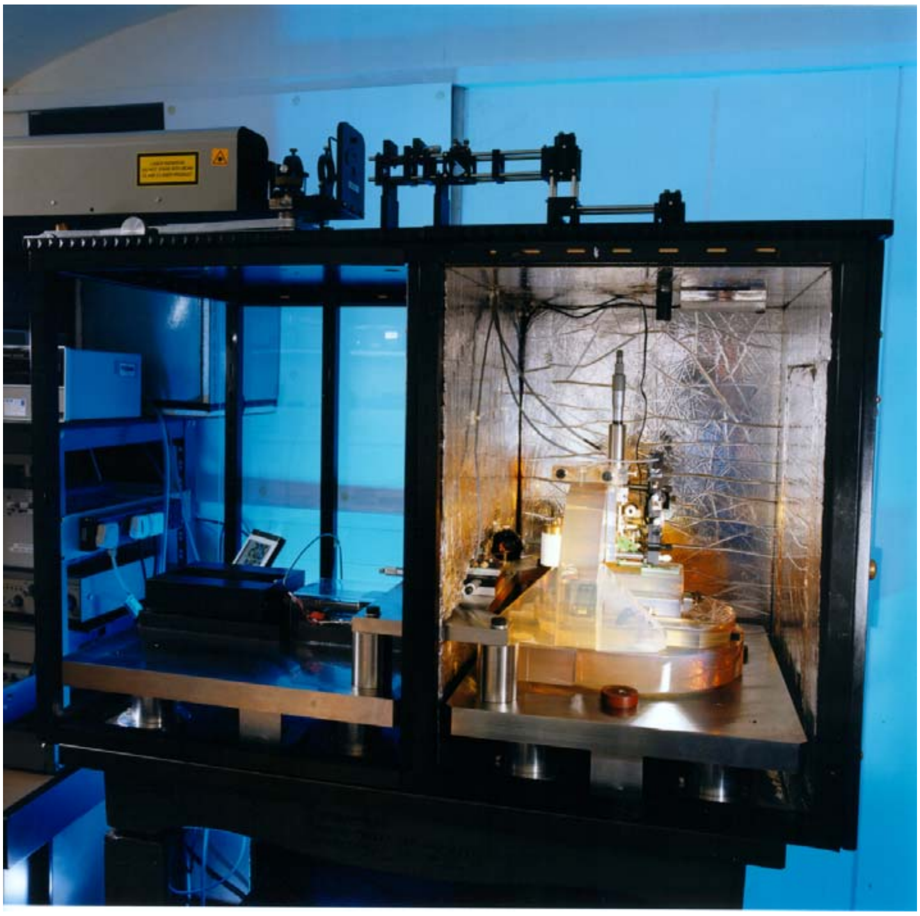

Figure 4.2 The sub-systems of NanoSurf IV

5. UNCERTAINTY ANALYSIS OF NANOSURF IV

The uncertainty analysis of NanoSurf IV has been split into two sections. Firstly, the uncertainty of a length measurement made using the interferometers and secondly the uncertainty in a measurement of a surface roughness parameter. At all times the uncertainty calculation follows internationally accepted guidelines for the evaluation and expression of uncertainties as laid out in the *Guide to the Expression of Uncertainty in Measurement* (1993), herein simply referred to as the *GUM.*

5.1 COMBINED STANDARD UNCERTAINTY

The combined standard uncertainty, $u_c(L)$ is an estimate of the standard deviation of the distribution of possible values (or probability distribution) of a length measurement made using an interferometer, *L*. The combined standard uncertainty, as its name implies, is a quadrature sum of the uncertainties $u(x_i)$ of all the influence factors x_i, weighted by a sensitivity coefficient [§5.1.2 *GUM*]

$$u_c^{\,2}(L) = \sum_{i=1}^{N} c_i^{\,2} u^2(x_i) + \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\frac{1}{2} c_{ij}^{\,2} + c_i c_{ijj} \right] u^2(x_i) u^2(x_j) \tag{5.1}$$

where $u(x_i)$ are the standard uncertainties attributed to the influence quantities x_i, and where the sensitivity coefficients

$$c_i = \frac{\partial L}{\partial x_i},\ c_{ij} = \frac{\partial^2 L}{\partial x_i \partial x_j},\ c_{ijj} = \frac{\partial^3 L}{\partial x_i \partial^2 x_j} \tag{5.2}$$

are the partial derivatives of the model equation. Note that equation (5.1) assumes the input quantities are uncorrelated and is only an approximation of the uncertainty.

It is convenient to think of equation (5.1) as consisting of two parts: terms containing $u^2(x_i)$, and cross terms containing $u^2(x_i)u^2(x_j)$ that take into account the degree of non-linearity in the model. The cross terms may be referred to as second order terms by some authors in the literature, including the *GUM.*

5.2 TYPE A AND TYPE B UNCERTAINTIES COMPONENTS

In the *GUM* there is considerable concern about distinguishing between Type A and Type B uncertainty components. The distinction between Type A and Type B uncertainties relates to the manner in which they are established and not how they are subsequently treated when they are combined. Type A uncertainties are those for which repeated measurements are made and the standard deviation is evaluated from the data, and used as the standard uncertainty. Type B uncertainties are those for which repeated measurements cannot simply isolate the influence, and the uncertainty must be referred to by some other means [§4.2, §4.3 *GUM*].

The rectangular distribution occurs in Type B uncertainty evaluation and is used frequently in this section. As explained in §4.4.5 of the *GUM*, if data to estimate the uncertainty distribution of an influence parameter are limited, often an adequate and useful approximation is to assume an upper $+a$ and a lower $-a$ bound for a range of equally probable values. The standard uncertainty (§4.3.7 *GUM*) is then given by $a/\sqrt{3}$. Similarly, a reading from a meter read-out of resolution b has a standard uncertainty of $b/\sqrt{12}$ [§F.2.2.1 *GUM*]; the reading is considered to be a rectangular distribution bounded by $\pm a = +b/2$ and $-b/2$.

5.3 DEGREES OF FREEDOM

The degrees of freedom, ν_{x_i} are estimated for each of the $u(x_i)$. For Type A uncertainty evaluation, the degrees of freedom $\nu = n - 1$, where n is the number of observations taken to determine the arithmetic mean [§G.3.3 *GUM*]. In many cases, the uncertainty evaluation is Type B, and the degrees of freedom are estimated according to the relative uncertainty in the uncertainty $\Delta u/u$, or to put it another way - the judgement of reliability or confidence in the estimation of the uncertainty is given by [§G.4.2 *G UM*]

$$\nu_i \approx \frac{1}{2}\left[\frac{\Delta u(x_i)}{u(x_i)}\right]^{-2}. \tag{5.3}$$

Degrees of freedom for influence parameter uncertainties are combined in one step for the overall uncertainty budget effective degrees of freedom, by applying the Welch-Satterthwaite formula [§G.4.1 *GUM*]

$$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{N} \frac{u_i^4(y)}{\nu_i}}. \tag{5.4}$$

Degrees of freedom are always truncated to the next integer [§G.4.1 *GUM*].

5.4 EXPANDED UNCERTAINTY

It is desirable to express uncertainties so that for most of the measurements the measured value is within the uncertainty range of the 'true value'. The expanded uncertainty [§6.2 *GUM*]

$$U = ku_c(L) \tag{5.5}$$

is defined as the combined uncertainty multiplied by a coverage factor *k*. The value of the coverage factor is chosen depending on the level of confidence that would facilitate the interpretation of the uncertainty and the number of degrees of freedom. Most measurements are expressed with a value of *k* between two and three. $k = 2$ corresponds to a confidence level of approximately 95% assuming a high number of degrees of freedom [§6.2.2 *GUM*].

The steps involved in this uncertainty analysis are based upon those presented by Decker, Ulrich, *el. al.* (1998):

Step 1: Analyse the measurement process and identify the influence quantities.
Step 2: List any simplifying assumptions and their impact on the measurement.
Step 3: Form a mathematical model of the measurement in terms of the influence quantities (expressed in an optimal form).
Step 4: Evaluate the sensitivity coefficients of the influence quantities.
Step 5: Evaluate the standard uncertainties and degrees of freedom of the influence quantities.
Step 6: Determine correlated components.

Step 7: Calculate the combined and expanded uncertainties and degrees of freedom for the overall process.

5.5 MEASUREMENT PROCESS

At this stage only the displacement of either the cat's-eye in the z axis or the corner-cube in the x axis is analysed. The following influence quantities are considered:

Laser source:

- short and long-term calibration;
- frequency stability;
- intensity stability;
- beam characteristics;
- polarisation.

Interferometer characteristics:

- collimation/obliquity effects;
- quality of the optical components;
- air refractive index ;
- stray beams;
- diffraction effects;
- dead path error;
- air turbulence effects.

Metrology frame:

- thermal expansion;
- mechanical expansion and rigidity;
- Abbe offset;
- cosine error;
- co-ordinate orthogonality.

Detection system:

- linearity of photo-detectors;

- detector geometry;
- electronic noise;
- frequency response;
- resolution.

Computing/software:

- quality of mathematical fits and models.

By identifying the specific characteristics of the measurement procedure and considering the conditions of the laboratory, some of these influence quantities can be combined or be deemed negligible. When an influence quantity is deemed negligible it is because sound physical laws have been applied to model its magnitude and effect, or because it has been measured to be negligible. It is important to appreciate that the final uncertainty in length measurement is for a strict range of conditions and techniques.

5.6 ASSUMPTIONS

Evaluation of measurement uncertainty must be for a specific measurement scenario. The specifics of the measurement and the influence factors should be well defined before trying to consider their uncertainties. At this stage their are no simplifying assumptions apparent to the NanoSurf IV measurement technique. Of course, the assumption is made that operators of NanoSurf IV are applying best laboratory practice that is free of blunders. The ISO 9001 Quality Management System in operation at NPL should ensure this.

5.7 MATHEMATICAL MODEL OF THE MEASUREMENT

The primary influence factors recognised above can be expressed algebraically and combined to yield a mathematical model representing the measurement. Starting from first principles the measured displacement of one of the retro-reflectors in an ideal Michelson interferometer is given by

$$L_\phi = \frac{\lambda}{2\pi}\Delta\phi \tag{5.6}$$

where λ is the wavelength of the laser source and $\Delta\phi$ is the difference in the phase from the reference and measurement arms of the interferometer. A non-ideal interferometer will measure a length given by

$$L = L_{\phi} + L_{\Omega} + L_n + L_t + L_m + L_A + L_d + L_T + L_j \tag{5.7}$$

where L_Ω is a correction to the measured length for the effects of diffraction, L_n is a correction due to the change in the refractive index of the air in which the laser operates, L_t is that for thermal effects on the metrology frame, L_m is that for mechanical effects on the metrology frame, L_A is that for the imperfect optics and stray beams, L_d is that for the dead path length, L_T is that for the effects of air turbulence and L_j is that for the measurement set-up, *i.e.* Abbe and cosine errors. Once again, it assumed that the input quantities are uncorrelated.

5.8 EVALUATION OF THE SENSITIVITY COEFFICIENTS

The equation for the combined standard uncertainty is applied to the mathematical model describing the measurement. Simply making the substitution of the influence variables in place of the x_i in equation (5.1), the combined standard uncertainty can be written as

$$\begin{aligned} u_c^2(L) = {} & c_{L_\phi}^2 u^2(L_\phi) + c_{L_\Omega}^2 u^2(L_\Omega) + c_{L_n}^2 u^2(L_n) + c_{L_t}^2 u^2(L_t) + c_{L_m}^2 u^2(L_m) + c_{L_A}^2 u^2(L_A) \\ & + c_{L_d}^2 u^2(L_d) + c_{L_T}^2 u^2(L_T) + c_{L_j}^2 u^2(L_j) + \text{higher order terms} \end{aligned} \tag{5.8}$$

where the sensitivity coefficients, c_i, for the first order terms are

$$\begin{aligned} & c_{L_\phi} = \frac{\partial L}{\partial L_\phi},\ c_{L_\Omega} = \frac{\partial L}{\partial L_\Omega},\ c_{L_n} = \frac{\partial L}{\partial L_n},\ c_{L_t} = \frac{\partial L}{\partial L_t},\ c_{L_m} = \frac{\partial L}{\partial L_m},\ c_{L_A} = \frac{\partial L}{\partial L_A},\ c_{L_d} = \frac{\partial L}{\partial L_d}, \\ & c_{L_T} = \frac{\partial L}{\partial L_T},\ c_{L_j} = \frac{\partial L}{\partial L_j}. \end{aligned} \tag{5.9}$$

Calculating the partial derivatives c_i, c_{ij} and c_{ijj} in equation (5.8) determines the sensitivity coefficients for the uncertainty in displacement measurement. In the case of equation (5.8) all of the first order terms are equal to unity and the higher order terms are equal to zero. Each term in equation (5.8) is now examined in detail.

5.9 STANDARD UNCERTAINTIES OF INFLUENCE QUANTITIES

5.9.1 Optical path difference

The combined uncertainty in the measurement of the optical path difference is given by

$$u_c^2(L_\phi) = c_{\Delta\phi}^2 u^2(\Delta\phi) + c_\lambda^2 u^2(\lambda) + \text{higher order terms.} \tag{5.10}$$

The first order sensitivity coefficients are given by $(\lambda/2\pi)$ and $(\Delta\phi/2\pi)$ respectively. For convenience, c_λ is expressed as L/λ. The second-order nature of the all higher order coefficients means they are negligible.

5.9.2 Measured parameters influencing the measurement of the optical path difference

Vacuum wavelength

The laser wavelength is calibrated by beat frequency measurement against one of the standard NPL iodine-stabilised lasers. The wavelength stability is quoted as ± 1 x 10^{-9} over 24 hours with a drift of ± 1 x 10^{-8} between calibrations (every 2500 hours). Table 5.1 shows the uncertainty contributions.

Source	Size	k	Standard uncertainty	Sensitivity coefficient	Contribution
Primary laser accuracy	$2.5 \times 10^{-11}\ \lambda$	1	$2.5 \times 10^{-11}\ \lambda$	L/λ	$2.5 \times 10^{-11}\ L$
Stability of laser	$1 \times 10^{-9}\ \lambda$	1	$1 \times 10^{-9}\ \lambda$	L/λ	$1 \times 10^{-9}\ L$
Yearly drift range	$1 \times 10^{-8}\ \lambda$	1	$1 \times 10^{-8}\ \lambda$	L/λ	$1 \times 10^{-8}\ L$
					$1 \times 10^{-8}\ L$

Table 5.1 Summation of uncertainties due to the laser source

Phase difference

The uncertainty in the phase difference measurement cannot easily be differentiated from other sources of uncertainty. Its effect is measured in §5.9.4 and summarised in table 5.2. Notice that the effect of this uncertainty is considered twice in the uncertainty analysis - once in combination with the calibration parameters of the laser wavelength and again in §5.12 as a purely random and experimentally determined parameter.

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
Random phase fluctuation	0.1 nm	1	0.1 nm	1	0.1 nm
					0.1 nm

Table 5.2 Summation of uncertainties due to fluctuations in the phase measurement

5.9.3 Overall uncertainty due to the measured optical path difference

Combining the values for the sensitivity coefficient and the measured parameters gives a total uncertainty in the measurement of the optical path difference of

$$u_c(L_\phi) = \sqrt{(1\times 10^{-2}L)^2 + 0.01}\ \text{nm} \qquad (5.11)$$

where L is in millimetres.

5.10 DIFFRACTION EFFECTS AND MISALIGNMENT

As the interferometers are illuminated by a laser source, the shift of the phase and changes in the curvature of the wavefronts lead to systematic errors, to which there must be added the error caused by misalignments. Consider an ideal interferometer illuminated by a monochromatic Gaussian beam that produces two interfering beams. No diffraction is assumed to occur in the optical system. The error in the fringe spacing when the interference pattern is focussed onto the detector is given by (Mana 1989)

$$\frac{2\Delta\lambda_0}{\lambda} = \left(\frac{1}{k^2 w_0^{\,2}}\right)\left(\frac{\left[1 + 2u^2 \;/\; w_f^{\,2}\right]e^{-2u^u/w_f^{\,2}} \;-1}{e^{-2u^u/w_f^{\,2}} \;-1}\right) + \left(\frac{2}{k^2 w_0^{\,2}}\right)\left(\frac{b}{2D}\right)^2 \qquad (5.12)$$

where λ is the wavelength of the laser source, λ_0 is the fringe displacement, k is the wavenumber, w_0 is the waist of the laser, u is the aperture radius, D is the absolute distance of the lens from the waist of the beam, f is the focal length of the lens and w_f and b are given by

$$w_f = 2\left(\frac{f}{b}\right)w_0 \qquad (5.13)$$

and

$$b = kw_0^{\,2}\,. \qquad (5.14)$$

Before calculating the error term given by equation (5.12) it is necessary to calculate the effective beam waist due to the collimating telescope. To do this a new waist is found for each of the optical elements by using the following (Self 1983)

$$\frac{1}{f} = \frac{1}{s''} + \frac{1}{s + z_R^{\,2}/(s-f)} \qquad (5.15)$$

and

$$z_R{}'' = m^2 z_R \qquad (5.16)$$

where s is the object to lens distance, s'' is the image to lens distance, m is the magnification and z_R is the Rayleigh length or the distance over which the beam radius spreads by a factor of √2. The Rayleigh length is related to the beam waist by

$$z_R = \frac{\pi w_0^{\,2}}{\lambda}\,. \qquad (5.17)$$

From the numerical values of the interferometer systems, $\Delta\lambda$ turns out to be less than 30 fm and is considered negligible.

Assuming the size of the detector is a lot larger than the spot size and that

$$\frac{\alpha}{\theta} \leq \frac{z}{|z-l|} \tag{5.18}$$

where α is the misalignment angle, l is the distance between the waist and the retro-reflector, z is the distance between the waist and the detector, $\theta = \lambda/(\pi w_0)$, the normalised error can be reduced to

$$\frac{4}{\theta^2}\frac{2\Delta\lambda_0}{\lambda} = 1 - \left(\frac{v^2-2}{8v^2}\right)\sigma^2. \tag{5.19}$$

In equation (5.19) $v = w/w_o$, $\sigma = 2\alpha/(v\theta)$ and

$$w^2 = w_0^2\left[1+4(z/b)^2\right]. \tag{5.20}$$

Inserting values for the parameters in equation (5.19), even if the interferometer were misaligned by as much as α = 5 °, $\Delta\lambda$ would only be equal to 0.1 pm. This source of uncertainty is, therefore, taken to be negligible.

According to the above the correction for the effects of diffraction and misalignment of the interferometer, $L_\Omega = 0$, as are its associated uncertainties.

5.11 AIR REFRACTIVE INDEX

When performing optical interferometry in air, it is important to correct the laser wavelength for the refractivity of the air through which it passes. The correction factor, the refractive index, is applied to the vacuum wavelength of the light emitted by the laser

$$\lambda = \frac{\lambda_{vac}}{n} \tag{5.21}$$

where λ_{vac} is the wavelength in vacuum and n is the refractive index of air, for ambient conditions.

5.11.1 Equations for the refractivity of air

In 1965 Edlén reviewed the most recent work, collated findings and issued new formulae for the dispersion of air. The formulae derived in that paper have since been widely used to correct for the refractivity of air, with a minor correction to the humidity term suggested by Birch & Downs (1988) and a further correction suggested by Bönsch and Potulski (1998) for the latest standard conditions. The calculation starts with the dispersion of dry air for the new standard conditions, temperature t = 20 °C (ITS-90), pressure p = 100 000 Pa and 0.04% carbon dioxide content, describing the refractivity of standard air dependent on the wavenumber $\sigma = 1/\lambda$.

$$(n-1)_N .10^8 = 8091.37 + \frac{233\,3983}{130-\sigma^2} + \frac{15\,518}{38.9-\sigma^2}\,. \tag{5.22}$$

A CO_2 content x, differing from 0.04%, changes the refractivity to

$$(n-1)_x = (n-1)_N\left[1+0.5327(x-0.0004)\right]. \tag{5.23}$$

The deviation of temperature and pressure from the reference conditions is taken into account by

$$(n-1)_{tp} = \frac{(n-1)_x\, p}{93214.6}\,\frac{1+10^{-8}(0.5953-0.009876t)p}{1+0.003661t}\,. \tag{5.24}$$

The influence of water vapour with partial pressure f is calculated, which results in the refractive index for moist air

$$n_{tpf} - n_{tp} = -f\left(3.802-0.0384\sigma^2\right).10^{-10}\,. \tag{5.25}$$

The uncertainty attributed to the empirical determination of the numerical coefficients in this equation ± 1 × 10^{-8} at the one standard deviation level of confidence (Birch & Downs 1994).

The length correction that accounts for the refractive index of air is given by

$$L_n = -nL \tag{5.26}$$

and its combined standard uncertainty

$$\begin{aligned} u_c^2(L_n) = &\left(\frac{\partial L_n}{\partial p}\right)^2 u_c^2(p) + \left(\frac{\partial L_n}{\partial x}\right)^2 u_c^2(x) + \left(\frac{\partial L_n}{\partial t}\right)^2 u_c^2(t) + \left(\frac{\partial L_n}{\partial f}\right)^2 u_c^2(f) \\ &+ \left(\frac{\partial L_n}{\partial \lambda}\right)^2 u_c^2(\lambda) + \text{higher order terms} \end{aligned} \quad . \tag{5.27}$$

Calculating the partial derivatives and putting in the values of the reference conditions the sensitivity coefficients are given by (see §5.11.2 for the reference values of humidity)

$$\begin{aligned} \left(\frac{\partial L_n}{\partial p}\right) &= 2.68 \times 10^{-9}\, L\,/\,\text{Pa} \\ \left(\frac{\partial L_n}{\partial x}\right) &= 1.4 \times 10^{-10}\, L\,/\,\text{ppm} \\ \left(\frac{\partial L_n}{\partial t}\right) &= -9.30 \times 10^{-7}\, L/{}^\circ\text{C}\,. \\ \left(\frac{\partial L_n}{\partial f}\right) &= -3.8 \times 10^{-10}\, L\,/\,\text{Pa} \\ \left(\frac{\partial L_n}{\partial \lambda}\right) &= 1.22 \times 10^{-5}\, L\,/\,\mu\text{m} \end{aligned} \tag{5.28}$$

The largest cross term is given by

$$\frac{1}{2} c_{tt}^{\;2} + c_t c_{ttt} = 8 \times 10^{-9}\, L^2\,/\,{}^\circ\text{C}^2, \tag{5.29}$$

but this would multiply $u^2(x_t)$ and it is therefore considered that all cross terms are negligible.

5.11.2 Conversion of humidity units

The humidity is measured using a dewpoint hygrometer, which displays results in the form of °C dewpoint temperature. Magnus' relation (BS 1339: 1965) is used to convert °C dewpoint into partial pressure of water vapour for use by the Edlén equations and is given by

$$f = 10^{\left(0.7857 + \frac{7.5 t_{dp}}{237.3 + t_{dp}}\right)} \tag{5.30}$$

where t_{dp} is the dewpoint temperature in °C. Partially differentiating gives

$$\left(\frac{\partial f}{\partial t_{dp}}\right) = \ln(10) \times \left[\frac{-7.5t_{dp}}{\left(237.3+t_{dp}\right)^2} + \frac{7.5}{237.3+t_{dp}}\right] \times 10^{\left(0.7857+\frac{7.5t_{dp}}{237.3+t_{dp}}\right)}. \tag{5.31}$$

In most dimensional metrology laboratories the humidity is controlled at around 10 °C dewpoint. Substituting t_{dp} = 10 °C gives

$$\left(\frac{\partial f}{\partial t_{dp}}\right) = 82.2\,\mathrm{Pa}\ {}^{\circ}\mathrm{C}^{-1}. \tag{5.32}$$

Hence a variation in humidity of 1 °C dewpoint alters the partial pressure by 82.2 Pa and hence the refractive index by 3.12 x 10^{-8}.

5.11.3 Measured parameters influencing the refractive index of air

Air temperature

The air temperature is measured by platinum resistance thermometers (PRTs) inside the anechoic chamber and close to the object being measured. The calibration certificate of the PRTs states a calibration uncertainty of ± 0.005 °C at a 95% confidence level. The self-heating of the PRT (Downs, Ferris, *et. al.* 1990) was assessed by observing a typical PRT resistance reading as the current was increased by a factor of √2 from its initial value of 1 mA. Table 5.3 summarises the contributions due to the air temperature measurement.

Air pressure

The pressure transducer is located inside the equipment rack and is connected to the anechoic chamber via PVC tubing. The calibration certificate quotes an uncertainty of ± 5 Pa at a confidence level of 95% for the primary standard, and shows a variation of ± 20 Pa in calibrated results. Table 5.4 summarises the contributions due to the measurement of air pressure.

Source	Size	k	Standard uncertainty	Sensitivity coefficient	Contribution
Resistance bridge accuracy	3 mK	$\sqrt{3}$	1.7 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$1.6 \times 10^{-9}\,L$
PRT calibration	5 mK	1.96	2.6 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$2.4 \times 10^{-9}\,L$
ITS90 equations	0.13 mK	1	0.13 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$1.2 \times 10^{-10}\,L$
PRT inter-calibration drift	2 mK	1	2 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$1.9 \times 10^{-9}\,L$
PRT - air lag	10 mK	$\sqrt{3}$	5.8 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$5.4 \times 10^{-9}\,L$
Self heating of PRT	12 mK	$\sqrt{3}$	6.9 mK	$9.30 \times 10^{-7}\,L/\mathrm{K}$	$6.4 \times 10^{-9}\,L$
					$9.1 \times 10^{-9}\,L$

Table 5.3 Summation of uncertainties due to air temperature measurement

Source	Size	k	Standard uncertainty	Sensitivity coefficient	Contribution
Primary standard uncertainty	5 Pa	1.96	2.6 Pa	$2.68 \times 10^{-9}\,L/\mathrm{Pa}$	$7.0 \times 10^{-9}\,L$
Sensor variability	20 Pa	$\sqrt{3}$	11.6 Pa	$2.68 \times 10^{-9}\,L/\mathrm{Pa}$	$3.1 \times 10^{-8}\,L$
Sensor resolution	1 Pa	$\sqrt{12}$	0.3 Pa	$2.68 \times 10^{-9}\,L/\mathrm{Pa}$	$8.0 \times 10^{-10}\,L$
					$3.2 \times 10^{-8}\,L$

Table 5.4 Summation of uncertainties due to air pressure measurement

Humidity

The humidity transducer is located inside the equipment rack and is connected to the anechoic chamber via PVC tubing. The calibration certificate quotes an uncertainty of ± 0.2 °C at a confidence level of 95%. Table 5.5 summarises the contributions due to the measurement of humidity.

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
Dewpoint meter calibration	0.2 °C DP	1.96	0.10 °C DP	3.0 x 10^{-8} L/°C DP	3.0 x 10^{-9} L
Magnus' equation	0.2 °C DP	√3	0.12 °C DP	3.0x10^{-8} L/°C DP	3.6 x 10^{-9} L
Interface resolution	0.5 °C DP	√12	0.14 °C DP	3.0 x 10^{-8} L/°C DP	4.2 x 10^{-9} L
					6.3 x 10^{-9} L

Table 5.5 Summation of uncertainties due to air humidity measurement where DP = Dewpoint temperature

Carbon dioxide content

Typical changes in the carbon dioxide content in a laboratory, due to such things as human respiration, can be up to 100 ppm (Downs 1998). Table 5.6 shows the effect of this departure on the uncertainty due to the refractive index.

Source	Size	k	Standard uncertainty	Sensitivity coefficient	Contribution
Departure from standard conditions (*i.e.* 400 ppm)	100 ppm	1	100 ppm	1.47 x 10^{-10} L/ppm	1.47 x 10^{-8} L
					1.47 x 10^{-8} L

Table 5.6 Summation of uncertainties due to air carbon dioxide content

Vacuum wavelength

The combined uncertainty attributed to the vacuum wavelength through its contribution to the refractive index of air is very small. Using values from table 5.1 and equation (5.28) gives

$$u_c(\lambda) = 8 \times 10^{-14} L \tag{5.33}$$

which is considered negligible.

Uncertainty of the Edlén equations

Table 5.7 presents the contribution due to the uncertainty in the Edlén equations.

Source	Size	k	Standard uncertainty	Sensitivity coefficient	Contribution
Accuracy of Edlén equations	3×10^{-8}	3	1×10^{-8}	L	$1.0 \times 10^{-8} L$
					$1.0 \times 10^{-8} L$

Table 5.7 Summation of uncertainties due to the Edlén equations

5.11.4 Overall uncertainty due to the refractive index of air measurement

Combining the values for the sensitivity coefficients and the measured parameters gives a total uncertainty in the refractive index measurement of

$$u_c(L_n) = 3.8 \times 10^{-8} L \tag{5.34}$$

where L is the measured length.

5.12 EFFECTS ON THE METROLOGY FRAME AND DETECTOR ELECTRONICS

It is very difficult to separate the effects of thermal and mechanical changes on the metrology frame plus the effects of the detector electronics and data processing. It is also very difficult to rigorously model these effects. For these reasons, the stability of the metrology frame, detection system and mathematical algorithms has been experimentally measured with no regard as to the source of any fluctuations, *i.e.* a correction for the stability of the metrology frame and detection system is equal to (L_t + L_m + L_T + L_ϕ). It must also be remembered that other random uncertainty contributions, such as refractive index fluctuations, will also be present in these measurements. The measured uncertainty term is, therefore, expected to be a pessimistic value.

To measure the stability of the metrology frame and detection system, the output of the interferometers was monitored over a one minute period with the retro-reflectors stationary. The results are given in table 5.8. During the experiments the humidity and barometric pressure were monitored for stability - any noticeable drift or large fluctuations voided the experiment.

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
x axis dimensional change	0.1 nm	1	0.1 nm	1	0.1 nm
					0.1 nm

Table 5.8 Summation of uncertainties due to dimensional fluctuations of the metrology frame

5.13 EFFECTS OF IMPERFECT OPTICS AND STRAY BEAMS

Due to the very high spatial and temporal coherence of the laser source, stray light can interfere with beams reflected from the surfaces present in reference and measurement arms of the interferometers. The dominant effects are usually due to unwanted reflections and isolated strong point scatterers, both leading to random and non-random spatial variations in the scattered phase and amplitude (Hariharan 1997). This analysis does not attempt to isolate sources of stray reflection.

Assuming the stray light affects one beam only, its amplitude, a_s, adds vectorily to the amplitude of the main beam, a as in figure 5.1.

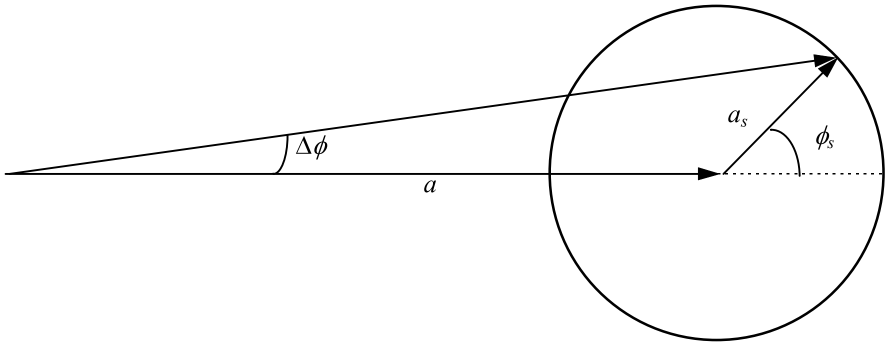

Figure 5.1 Phase shift of a beam produced by coherent stray light that has travelled an additional path

In the case of a Michelson interferometer, the complex amplitude at any point in the interference pattern is obtained by summing the complex amplitude of the stray light and the complex amplitudes of the beams reflected from the reference and test surfaces. If we assume that the beams reflected from the reference and test surfaces have unity intensity, the resultant complex amplitude is given by the relation

$$a(x,y) = \left|1 + e^{[-i\phi(x,y)]} + a_s(x,y)e^{[-i\phi_s(x,y)]}\right| \tag{5.35}$$

where $\phi_s = (2\pi/\lambda)p$, and p is the difference in the lengths of the optical paths traversed by the stray light and by the test beams relative to the beam reflected from the reference surface. The intensity in the interference pattern is then

$$I(x,y) = a^2(x,y) = 2 + |a_s|^2 + 2a_s\cos\phi_s + 2\left[1 + a_s\cos\phi_s\right]\cos\phi + 2a_s\sin\phi_s\sin\phi\,. \tag{5.36}$$

Assuming $a_s \approx 1$, $\Delta\phi$ can be found by equating the following

$$\left[1 + a_s\cos\phi_s\right]\cos\phi + a_s\sin\phi_s\sin\phi \equiv A\cos(\phi - \Delta\phi)\,. \qquad (5.37$$

After some simple trigonometry and assuming $\Delta\phi$ is a small angle the magnitude of the phase error is given by

$$\Delta\phi \approx a_s\sin\phi_s\,. \tag{5.38}$$

To minimise the effects of stray reflections all the optical components are thoroughly cleaned, the retro-reflectors are mounted at a non-orthogonal angle to the beam propagation direction (to avoid reflections off the front surfaces) and all the non-critical optical surfaces are anti-reflection (AR) coated. It is extremely difficult, if not impossible, to measure the amplitude of the stray light, simply because it propagates in the same direction as the main beams. The value of a_s is taken to be equal to the value of the reflection coefficient of the AR coat, $a_s = 0.004$. This gives a value for $\Delta\phi$ of ± 0.4 nm. Table 5.9 summarises this uncertainty contribution.

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
Uncertainty due to stray light	0.4	√3	0.23	1	0.23 nm
					0.23 nm

Table 5.9 Summation of uncertainties due to stray light

5.14 DEAD PATH LENGTH UNCERTAINTY

Dead path length, *d*, is defined as the difference in distance in air between the reference and measurement retroreflectors and the beamsplitter when the interferometer measurement is initiated (Zanoni 1988). Dead path error occurs when there is a non-zero dead path and environmental conditions change during a measurement. The equation below yields the displacement, *D*, for a single pass interferometer such as those used on NanoSurf IV

$$D = \frac{N\lambda_{vac}}{n_2} - \frac{\Delta n d}{n_2} \tag{5.39}$$

where N is half the number of fringes counted during the displacement, n_2 is the refractive index at the end of the measurement, Δn is the change in refractive index over the measurement time: that is $n_2 = n_1 + \Delta n$, and n_1 is the refractive index at the start of the measurement. The second term on the right hand side of equation (5.39) is the dead path error, L_{dp}.

Dead path error is corrected for in the software but there is still an uncertainty in the correction given by

$$u_c^2(L_{dp}) = \left(\frac{\partial L_{dp}}{\partial n_1}\right)^2 u_c^2(n_1) + \left(\frac{\partial L_{dp}}{\partial n_2}\right)^2 u_c^2(n_2) + \left(\frac{\partial L_{dp}}{\partial d}\right)^2 u_c^2(d) + \text{higher order terms} \tag{5.40}$$

The dead path imposes several critical measurement conditions on NanoSurf IV. Firstly, a sample must always be mounted such that the initial position is at the position of zero dead path. This can only be achieved to within 1 mm and $u_c^2(d)$ is ± 1 mm using a steel rule (plus the optical elements will be affected by thermal expansion and refractive index variations). Also, the environmental conditions have to be monitored. Any drifts in temperature of greater than ± 0.1 °C and pressure greater than ± 10 Pa void a measurement. Note that higher order terms in equation (5.40) are all negligible. Table 5.10 summarise the uncertainty in the measurement and correction for the dead path length.

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
Uncertainty due dead path	0.20	√3	0.12	1	0.12 nm
					0.12 nm

Table 5.10 Summation of uncertainties due to dead path

5.15 UNCERTAINTIES DUE THE MEASUREMENT SET-UP

5.15.1 Cosine error

There will always be some misalignment of the measurement axis to the axis of motion of the stage. The measurement axis is the central line parallel to the in and out beams to and from the measurement retroreflector. The misalignment manifests itself as an error in the measured length that is directly proportional to the cosine of the angle between the measurement axis and the axis of motion of the stage. The cosine error always causes the interferometer to measure shorter than the actual distance travelled by the stage.

The cosine error in the x axis can be measured (and minimised) by removing the beamsplitter, attaching a mirror to the front of the measurement retroreflector and auto-reflecting the laser beam onto the output aperture of the laser. The alignment can then be checked as the stage is moved through its full range. The worst case measured was a displacement from the aperture of less than 1 mm for a path length of around 1 m. This corresponds to a cosine error of 1.5×10^{-10} L and is negligible.

Provided the z interferometer block can be set up so as to get interference, the small length over which it operates ensures a negligible cosine error in this axis.

5.15.2 Abbe error

The causes and effects of the Abbe error are described elsewhere (Leach 2000). The Abbe offset has been made negligible in the *z* axis by virtue of the interferometer and probe design, *i.e.* the displacement measuring axis is co-axial with the displacement to be measured. In the *x* axis there can be an Abbe offset of up to 5 mm.

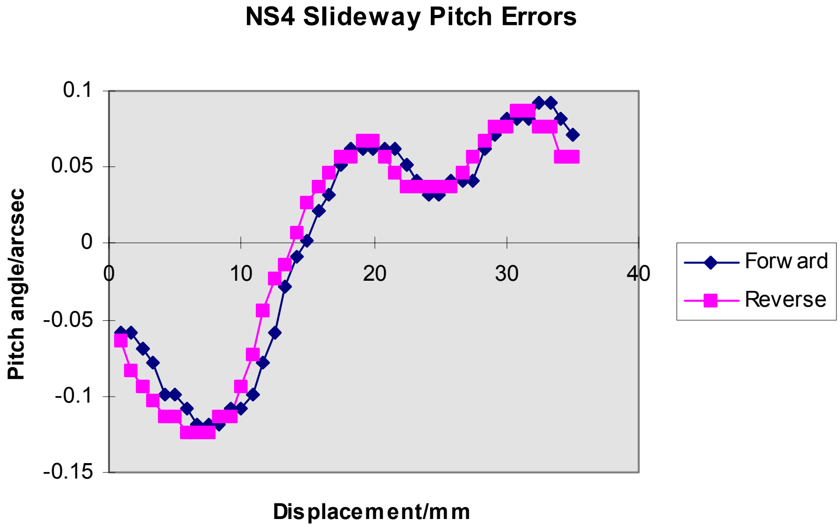

Figure 5.2 *x* axis slideway pitch errors

To determine the Abbe error in the *x* axis, the straightness of the slideway must be determined. This was carried out by setting up an autocollimator with a small aluminised microscope cover-slip epoxied to the front of the specimen mounting plate. To ensure that the slideway and autocollimator had the same mechanical earth (the stainless steel vibration isolation plate) a small, lightweight autocollimator was constructed from a compact disc reading head (Sony Model D50 Mk II, Armstrong & Fitzgerald 1992). The autocollimator has a resolution of 0.01 second of arc and was calibrated using an NPL indexing table (Moore 1440). Figures 5.2 and 5.3 show the straightness results for the *x* axis slideway. Note that there is no Abbe sensitivity to roll. From both the graphs it is apparent that the repeatability of these measurements is excellent when the direction of travel is reversed.

Over the full 35 mm travel range the pitch and yaw errors correspond to Abbe errors of 3.2 nm and 3.6 nm respectively. However, a typical measurement of surface texture would take place over less than 10 mm and over this displacement the Abbe error for both pitch and yaw is 0.84 nm. Table 5.11 shows the contribution of the Abbe error to the uncertainty.

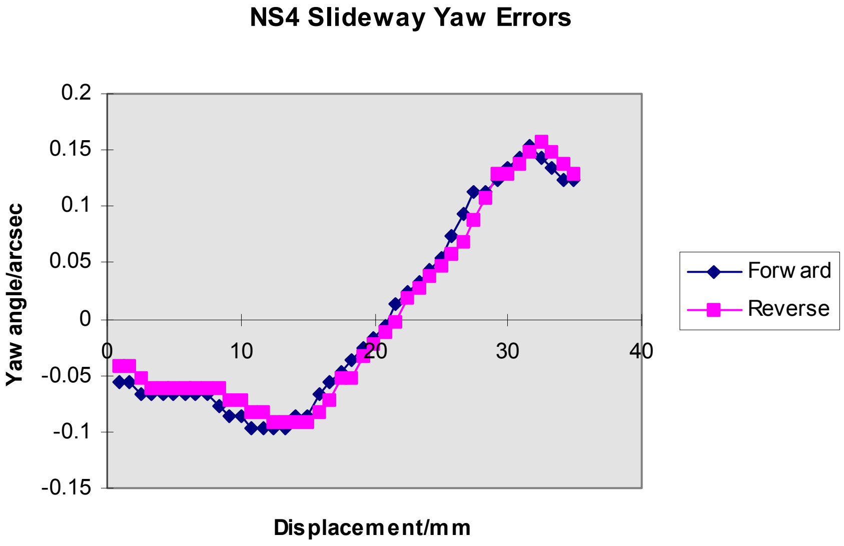

Figure 5.3 *x* axis slideway yaw errors

Source	Size	*k*	Standard uncertainty	Sensitivity coefficient	Contribution
Uncertainty due *x* straightness	0.02 arc sec	√3	0.49	1	0.49 nm
Resolution of autocollimator	0.01 arc sec	√12	0.07	1	0.07 nm
					0.59 nm

Table 5.11 Summation of uncertainties due to Abbe error

5.16 DEGREES OF FREEDOM OF THE INFLUENCE QUANTITIES

Table 5.12 lists the degrees of freedom associated with each source of measurement uncertainty plus the magnitude of the uncertainty.

Applying equation (5.4) gives an effective number of degrees of freedom of 45 .

5.17 EXPANDED UNCERTAINTY FOR A LENGTH MEASUREMENT

Adding the uncertainty contributions in table 5.12 in quadrature and multiplying by a coverage factor of k = 2 (justified with 45 degrees of freedom), gives the following combined standard uncertainty

$$u_c^2(L_x) = 2 \times \sqrt{0.66^2 + 1.5 \times 10^{-3} L^2} \tag{5.41}$$

Source of uncertainty	Uncertainty / nm	Degrees of freedom
Optical path difference	$\sqrt{(1\times 10^{-2} L)^2 + 0.01}$	19
Air refractive index	$3.8 \times 10^{-2} L$	∞
Metrology frame & detection system	0.10	19
Imperfect optics & stray beams	0.23	∞
Deadpath length	0.12	∞
Abbe error	0.59	9

Table 5.12 Sources of uncertainty and their associated degrees of freedom. L is in millimetres.

As an example, if L_z were equal to 1 mm, then $u_c^2(L_z)$ = 1.322 nm and if L_z = 1 nm, $u_c^2(L_z)$ = 1.320 nm. It is clear that in most cases the length dependent uncertainty contribution is negligible. The uncertainty in NanoSurf IV is quoted as 1.320 nm at k = 2 with 45 degrees of freedom.

5.18 UNCERTAINTIES IN MEASURING SURFACE TEXTURE PARAMETERS

In order to put a meaningful number to measured surface texture data and aid in understanding the functionality of a surface, various parameters, such as the average or peak-to-valley height, can be calculated. It is extremely rare to see rigorous uncertainty analysis applied to the calculation of uncertainty in a parameter. This section applies the guidelines laid down in the *GUM* to calculate the uncertainty in a given surface texture parameter. Only the parameters advocated by the ISO standards are considered. Note that the effects of any mechanical, electrical or computational filtering of the measured data are not considered here (with the exception of the calculation of the average reference line).

5.19 REFERENCE DATA

To obtain a reference data set, a 0.2 mm trace of an optical flat (NPL specimen D19) was taken at a speed of 0.1 mm per minute. The *x* and *z* displacements were measured at 2048 sampling points. A first-order polynomial least-squares fit was removed from the data - this filtering is necessary due to the lack of levelling of the specimen. The dominant frequency component that is clearly evident in the trace is the resonant frequency of the probing system. As this is only a reference set of data, no post measurement filtering or de-trending has been carried out (Rothe, Duparré, *et. al.* 1994). All calculations were carried out using MATLAB (MathWorks Inc.) to ensure the reliability of any mathematical algorithms. Figure 5.4 presents the first 150 data points.

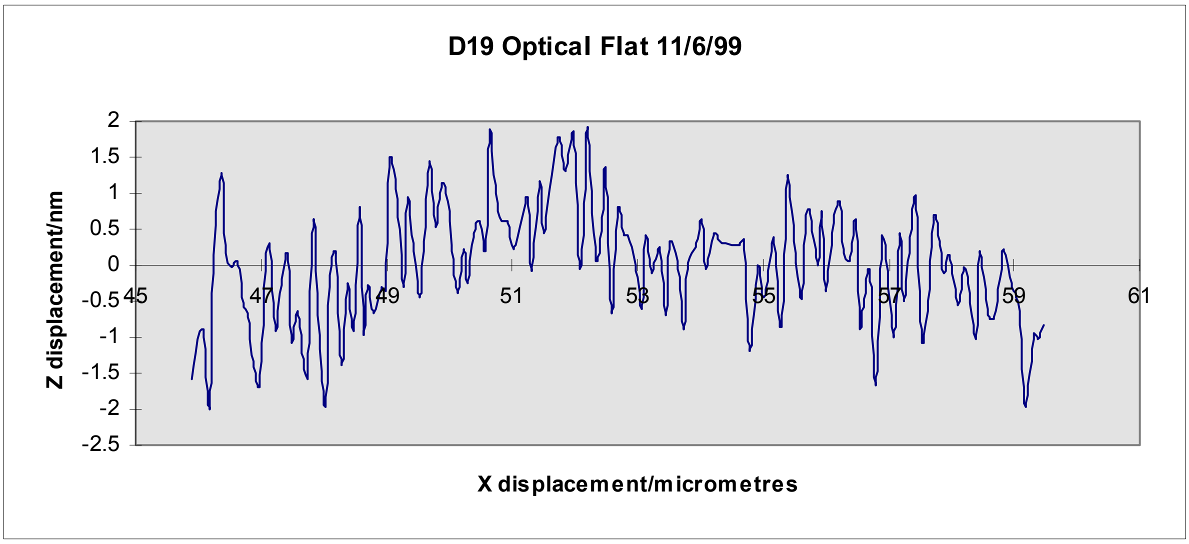

Figure 5.4 The reference data

5.20 UNCERTAINTY IN THE CALCULATION OF THE AVERAGE REFERENCE LINE

Before most parameters can be calculated a average reference line has to be fitted to the *x* and *z* data. The fitting equation is given by

$$z = a + bx \tag{5.43}$$

where *a* is the intercept on the *z* axis and *b* is the gradient. Uncertainties in *a* an *b* must be propagated through to the parameters.

To find $u(a)$ and $u(b)$ we must carry out a least-squares fit to the measured data assuming there are errors in both x and z. In the general case, this problem has no analytical solution, but when $u(x)$ can be assumed proportional to $u(z)$, as is the case with NanoSurf IV, the problem can be circumvented (Bruzzone & Moreno 1998). When only uncertainties in z are considered, the least-squares fitting requires the minimisation of

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(z_i - a - bx_i\right)^2}{u^2(z_i)} . \tag{5.44}$$

The problem has the solutions

$$b^* = \frac{SS_{xz} - S_x S_z}{SS_{xx} - S_x^2} \text{ and } a^* = \frac{S_{xx} S_z - S_x S_{xz}}{SS_{xx} - S_x^2} \tag{5.45}$$

where

$$S = \sum_{i=1}^{n} \frac{1}{u^2(z_i)} \qquad S_x = \sum_{i=1}^{n} \frac{x_i}{u^2(z_i)} \qquad S_z = \sum_{i=1}^{n} \frac{z_i}{u^2(z_i)}$$

$$S_{xx} = \sum_{i=1}^{n} \frac{x_i^2}{u^2(z_i)} \qquad S_{zz} = \sum_{i=1}^{n} \frac{z_i^2}{u^2(z_i)} \qquad S_{xz} = \sum_{i=1}^{n} \frac{x_i z_i}{u^2(z_i)} \tag{5.46}$$

The fit parameters' uncertainties are then given by

$$u(a^*) = \sqrt{\frac{S_{xx}}{SS_{xx} - S_x^2}} \text{ and } u(b^*) = \sqrt{\frac{S}{SS_{xx} - S_x^2}} . \tag{5.47}$$

If errors in both co-ordinates are considered, the effective variance method states that the expression (Barker & Diana 1974)

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(z_i - a - bx_i\right)^2}{u^2(z_i) + u^2(x_i)} \tag{5.48}$$

must be minimised. Equation (5.48) has no analytical solution in the general case. However, provided $u(x) = du(z)$, where d is a constant (unity in the case of NanoSurf IV), equation (5.48) reduces to

$$\chi^2 = \frac{1}{1+b^2d^2}\sum_{i=1}^{n}\frac{(z_i - a - bx_i)}{u^2(z_i)}. \tag{5.49}$$

Minimisation of equation (5.49) leads to a quadratic expression for b, but only the root given here is to be considered (Bruzzone & Moreno 1999)

$$db = \frac{1}{2}\left\{-\frac{1}{db^*} + \frac{db^*}{r^2} + \frac{1}{db^*}\left[\left(1 - \frac{(db^*)^2}{r^2}\right)^2 + 4(db^*)^2\right]^{1/2}\right\} \tag{5.50}$$

where r is the linear correlation coefficient, given by

$$r^2 = \frac{\left(SS_{xz} - S_xS_z\right)^2}{\left(SS_{xx} - S_x^2\right)\left(SS_{zz} - S_z^2\right)}. \tag{5.51}$$

Once the slope b has been obtained, it is possible to evaluate a by means of

$$a = \frac{S_z - S_xb}{S}. \tag{5.52}$$

For the case of proportional errors in x and z, the uncertainties in a and b can be found from the following

$$u^2(b) = u^2(b^*)f(db^*, r^2) \tag{5.53}$$

and

$$u^2(a) = \frac{1+b^2d^2}{S}\left\{1 + [u^2(a^*)S - 1]f(db^*, r^2)\right\} \tag{5.54}$$

where

$$f(db^*, r^2) = (1 + b^2 d^2)^2 \frac{1 + (db^*)^2 / r^2}{\left[1 + d^2 (2bb^* - b^{*2} / r^2)\right]^2} . \tag{5.55}$$

For the reference data set the uncertainties are $u(a)$ = 0.46 nm and $u(b)$ = 8.7 x 10^{-6}. Assuming these uncertainties are rectangularly distributed, they must be divided by $\sqrt{3}$. Once the calculated least-squares curve has been removed from the data, a given value of z_i is given by

$$z_i' = z_i - (a + bx_i) . \tag{5.56}$$

An uncertainty in z' is now given by the following equation

$$u^2(z') = u^2(z) + u^2(a) + x^2 u^2(b) + b^2 u^2(x) . \tag{5.57}$$

5.21 UNCERTAINTIES IN THE PARAMETERS

A list and short description of the surface texture parameters in ISO 4287: 1997 (*Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters*) is given in table 5.13. Where a parameter only applies to one length measurement, for example *Rp*, equation 5.41 should be applied appropriately. Where a parameter is the sum of parameters calculated for their corresponding sampling lengths over the entire evaluation length, a simple quadrature sum should be applied.

Name & symbol	**Short description**
profile peak height, *Zp*	distance between the *x* axis and the highest point of the profile peak
profile valley height, *Zv*	distance between the *x* axis and the lowest point of the profile valley
profile element height, *Zt*	sum of the height of the peak and depth of the valley of a profile element
profile element width, *Xs*	length of the *x* axis segment intersecting with the profile element

material length of profile at level *c*, *M(c)*	sum of the section lengths obtained, intersecting with the profile element by a line parallel to the *x* axis at a given level *c*
maximum profile peak height, *Rp*	largest profile peak height within a sampling length
maximum profile valley depth, *Rv*	largest profile valley depth within a sampling length
maximum height of profile, *Rz*	sum of height of the largest profile peak height and the largest profile valley within a sampling length
mean height of profile elements, *Rc*	mean value of the profile element heights *Zt* within a sampling length $Rc = \frac{1}{m}\sum_{i=1}^{m} Zt_i$
total height of profile, *Rt*	sum of the height of the largest profile peak height *Zp* and the largest profile valley depth *Zv* within the evaluation length
arithmetical mean deviation of the assessed profile, *Ra*	arithmetic mean of the absolute ordinate values *Z(x)* within a sampling length $Ra = \frac{1}{l}\int_0^l \lvert Z(x)\rvert dx$
root mean square deviation of the assessed profile, *Rq*	root mean square value of the ordinate values *Z(x)* with the sampling length $Rq = \sqrt{\frac{1}{l}\int_0^l Z^2(x)dx}$
skewness of the assessed profile, *Rsk*	quotient of the mean cube value of the ordinate values *Z(x)* and the cube of *Rq* respectively within the sampling length $Rsk = \frac{1}{Rq^3}\left[\frac{1}{l}\int_0^l Z^3(x)dx\right]$
kurtosis of the assessed profile, *Rku*	quotient of the mean quartic value of the ordinate values *Z(x)* and the fourth power of *Rq* respectively within the sampling length $Rku = \frac{1}{Rq^4}\left[\frac{1}{l}\int_0^l Z^4(x)dx\right]$
mean width of the profile elements, *RSm*	mean value of the profile element widths *Xs* within a sampling length

	$$RSm = \frac{1}{m}\sum_{i=1}^{m} Xs_i$$
root mean square slope of the assesses profile, $R\Delta q$	root mean square value of the ordinate slopes *dZ/dX*, within the sampling length
material ratio of the profile, *Rmr(c)*	ratio of the material length of the profile elements *Ml(c)* at a given level *c* to the evaluation length $$Rmr(c) = \frac{Ml(c)}{l}$$
profile section height difference, $R\delta c$	vertical distance between two section levels of given material ratio $$R\delta c = C(Rmr1) - C(Rmr2);\ (Rmr1 < Rmr2)$$
relative material ratio, *Rmr*	material ratio determined at a profile section $R\delta c$, related to reference *C*0 $$Rmr = Rmr(C1)$$ where $$C1 = C0 - R\delta c$$ $$C0 = C(Rmr0)$$

Table 5.14 Surface texture parameters

5.21.1 Uncertainty in *Ra*

The equation given in table 5.14 for *Ra* is for continuous data sampling within the sampling length. For the case of a real surface texture measuring instrument, with a finite sampling length, *Ra* is given by

$$Ra = \frac{1}{N}\sum_{i=1}^{N}\left|Z_i\right|. \tag{5.58}$$

To calculate the uncertainty, $u_c(Ra)$, equation (5.1) is applied to equation (5.58), *i.e.*

$$u_c^2(Ra) = c_{z_i}^2 u^2(z_i) = \frac{1}{N}\sum_{i=1}^{N} u^2(z_i) \tag{5.59}$$

where all the higher order terms are equal to zero. The combined standard uncertainty of the *Ra* parameter is simply the sum of the individual uncertainties divided by the number of samples, or the average uncertainty. There is, however, a subtlety here. By definition, it is not physically possible to have a negative *Ra*. But, if it is assumed that the measurement uncertainties are normally distributed, it is possible to have a confidence interval that allows negative *Ra* values. For example, *Ra* = 0.1 nm ± 0.5 nm could have values of *Ra* that vary from -0.4 nm to 0.6 nm. The problem has arisen due to the arbitrary assumption that the uncertainties in *Ra* are normally distributed about the "true value", whereas the mathematical definition of *Ra* rules this assumption out - any measurement noise will positively bias the value of *Ra*. As each surface will have a different distribution of surface heights, a value for *Ra* can only be stated with a standard uncertainty - to state an expanded uncertainty has implied that we have prior knowledge of the height distribution of the surface. Of course, the distribution could be calculated for each surface, but this would not be practical without rigorous software backup.

For the reference data set, *Ra* = 0.65 nm and its standard uncertainty is 0.5 nm.

5.21.2 Uncertainty in *Rq*

The equation for a sampled evaluation of *Rq* is given by

$$Rq = \sqrt{\frac{1}{N}\sum_{i=1}^{N} Z_i^2} \tag{5.60}$$

The associated uncertainty in *Rq* is given by

$$u_c^2(Rq) = c_{z_i}^2 u^2(z_i) = \frac{1}{N}\frac{1}{Rq}\sum_{i=1}^{N} z_i{}^2 u^2(z_i)\,. \tag{5.61}$$

The higher order terms are not equal to zero but will be negligibly small. For the reference data set *Rq* = 1.4 nm with a standard uncertainty of 0.30 nm. Again, because the value for *Rq* is always positive, the same points raised above for *Ra* apply for *Rq*.

5.21.3 Uncertainty in *Rsk* and *Rku*

The uncertainties in the skewness and kurtosis of a surface cannot be calculated using the guidelines laid down in the *GUM*. This is because they are defined parameters calculated from the data. There definitions lead to complexities with the higher order terms that give nonsensible results.

6. DISCUSSION

In §2 a number of methods, both historical and current, were described for calibrating a surface texture measuring instrument. No other area of dimensional metrology has such a vast armoury of methodologies and parameters available to choose from when applying metrology. This situation must be rationalised. Most instruments are calibrated using some form of specimen with a 'known' surface texture (or at least a 'known' value for a surface texture parameter). These specimens have not always been calibrated in both lateral and vertical directions.

NanoSurf IV is a surface texture measuring instrument that measures the co-ordinates of points on a surface in two-dimensions (assuming it is operating in its measurement bandwidth). The instrument is designed primarily to calibrate surface texture standard specimens that can be in-turn used to calibrate other instruments. The author sees this as the way forward.

Uncertainty analysis is a complicated and time-consuming process that must be applied, at the very least, to instruments in the calibration chain such as NanoSurf IV. This would make it easier for an instrument lower down the chain of accuracy to simply apply calibrated specimens as a simple check for instrument performance. NPL is currently developing a series of sinusoidal (in the first instance) samples to bridge the gap between instruments like NanoSurf IV and those in industry.

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Appendix B1

Reports of PTB

Measurement Report

Calibration method

On the calibration standards the measurement values were determined with a contact stylus instrument according to ISO 3274 (1996). Those were Taylor Hobson Nanostep1 with the acquisition of data by PTB, RMA (roughness measurement set-up) with Mahr PMK drive unit and acquisition of data by PTB. The evaluation was carried out by software developed partly in PTB and partly by UBM.
The instrument’s vertical sensitivity were calibrated by a reference calibration standard, that has traceability to the national length unit

Conditions of measurement

The measurements were carried out by means of a pick-up with independent datum. The stylus tip radius was approx. **2 µm**. The measuring force at Nanostep1 was 50µN and at RMA approx. 1mN.
Short wavelength filter wavelength λs and waviness cut-off filter wavelength λc were chosen appropriate to the features of the standard specimens.
Several measurements were carried out according to the measurement schemes that were agreed in the technical report of the round robin test. Mean value, maximum, minimum and standard deviation **s** were determined.

References for use of the calibration standards see /1/ and /2/.

Environmental conditions

The influences of the measuring set-up and of the environmental conditions were determined by roughness measurements on a smooth flat glass offering the same conditions of measurement as for the measurement standards. The Rz-value is 1,5 nm for Nanostep and 3 nm for RMA.

Uncertainty of Measurement

For the calculation of uncertainty of measurement according to GUM a model was applied, that includes the following uncertainty sources:

- uncertainty of reference calibration standard
- uncertainty of position on reference calibration standard
- contacting uncertainty
- influence of topography of measurement standard
- uncertainty of position on measurement standard
- straightness deviation of instrument’s datum
- noise of instrument by environment influence
- levelling of profile for evaluation

The complete derivation is given in the enclosure: Uncertainty of measurement in the calibration of roughness standards

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/1/ DKD-R 4-2: Richtlinie zum Kalibrieren von Tastschnittgeräten im Deutschen Kalibrierdienst (DKD). PTB-Mitt. 1/92, S. 23-26.
/2/ EAL – G20, Calibration of Stylus Instruments for Measuring Surface Roughness European cooperation for Accreditation of Laboratories, 8/96.

Annex A: Uncertainty of measurement in the calibration of roughness standards

1 Introduction

For a tracing system according to DIN EN ISO 3274 a model is set up by 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 computed from inside to outside what effects are exerted by the uncertainty of the input quantities on the uncertainty of the result value after application of the respective function. The result then is the input quantity for the uncertainty calculation for the next function.

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

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

In this order the functions will in the following be dealt with.

2 Device function G

2.1 Description of model

The data of the traced profile $z_e(x)$ are multiplied by a calibration factor C which is obtained from the calibration of the device against a calibrated depth-setting standard (reference standard) according to DIN EN ISO 5436-1 (Annex A Figure 1).

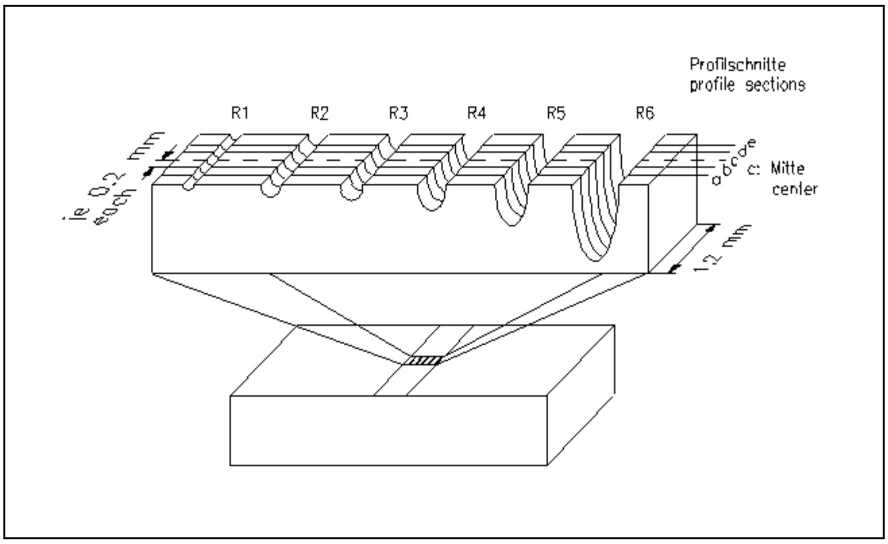


Figure 1: Depth-setting standard according to DIN EN ISO 5436-1 with six grooves and plan of points calibrated

The overall profile $z_g(x)$ covers the traced profile $z_e(x)$ (term according to DIN EN ISO 3274) as well as influences stemming from the device, its interaction with the object to be measured and the environment. The values of the overall profile $z_g(x)$ are the input data for signal processing. The following model is obtained:

$$z_g(x) = C \cdot [z_e(x) + z_{ref}(x) + z_0(x) + z_{pl}(x)+z_{sp}(x)] = C \cdot z_u \qquad (1)$$

where

C	calibration factor
z_e	profile traced
z_g	overall profile

z_{ref} profile of reference plane

z_0 background noise of device

z_{pl} plastic deformation of surface

z_{sp} profile variation due to stylus tip deviation

z_u uncorrected profile data

For the uncertainty of the profile points the following relation is obtained according to the product rule:

$$u^2(z_g) = u^2(C) \cdot z_u^2 + u^2(z_u) \cdot C^2 \qquad (2)$$

2.2 Calibration factor

2.2.1 Model for calibration factor

The calibration factor C is determined from the measured depth Pt_m or D_m, respectively, and the depth Pt_n or D_n, respectively, known from the calibration certificate for the depth-setting standard. The following model is valid:

$$C = \frac{Pt_n}{Pt_m} \text{ or } \mathrm{C} = \frac{D_n}{D_m}.$$

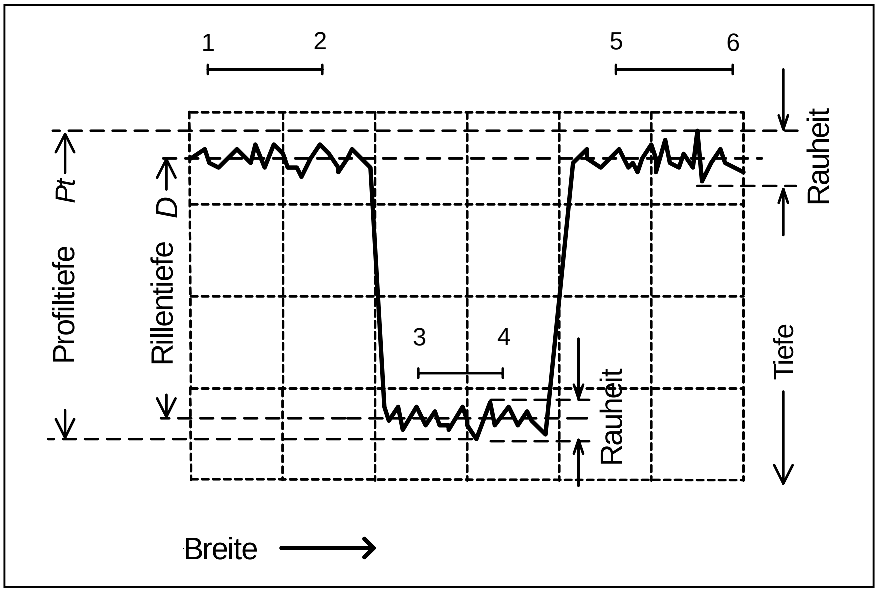


Figure 2: Profile evaluation on a depth-setting standard of type A1 (DIN EN ISO 5436 and DIN EN ISO 4287).
1-2, 5-6: profile line sections on reference plane, 3-4 profile line section in tread of groove

The quantities in the numerator and in the denominator each are uncertain so that

$$u^2(C) = \frac{1}{Pt_m^4} \cdot \left[Pt_n^2 \cdot u^2(Pt_m) + Pt_m^2 \cdot u^2(Pt_n)\right] \tag{3}$$

As $Pt_\mathrm{m} \approx Pt_\mathrm{n}$ is ($C = 1$), the following is obtained:

$$u^2(C) = \frac{1}{Pt_m^2} \cdot \left[u^2(Pt_m) + u^2(Pt_n)\right].$$

The first term of eq. 2 then is

$$u^2(C) \cdot z_u^2 = \frac{z_u^2}{Pt_m^2} \cdot \left[u^2(Pt_m) + u^2(Pt_n)\right].$$

Here it can be seen what effect too small a calibration groove has on the uncertainty of the calibration. The depth Pt_m of the reference standard is usually selected to the same amount as the expectation value z_u of the uncorrected profile points. Therefore the quotient $\frac{z_u^2}{Pt_m^2} = 1$ is set and the first term of eq. 2 becomes

$u^2(C) \cdot z_u^2 = u^2(Pt_m) + u^2(Pt_n)$. Thus eq. 2 is transformed into

$$u^2(z_g) = u^2(Pt_m) + u^2(Pt_n) + u^2(z_u) \tag{4}$$

$u^2(Pt_n)$ can be taken from the calibration certificate for the depth-setting standard.

2.2.2 Model for Pt_m

For the measurement of the total height of profile Pt_m the place where the groove was calibrated is not exactly met. The measured total height of profile Pt_m contains Pt_n as well as a part ΔPt (Annex A Figure 3), which is position-dependent in the y-direction, and a component b describing the repeatability of the tracing process.

$$Pt_m = Pt_n + \Delta Pt + b$$

The uncertainty of Pt_m is

$$u^2(Pt_m) = u^2(\Delta Pt) + u^2(b).$$

$u^2(b)$: repeatability of tracing process on calibration groove.

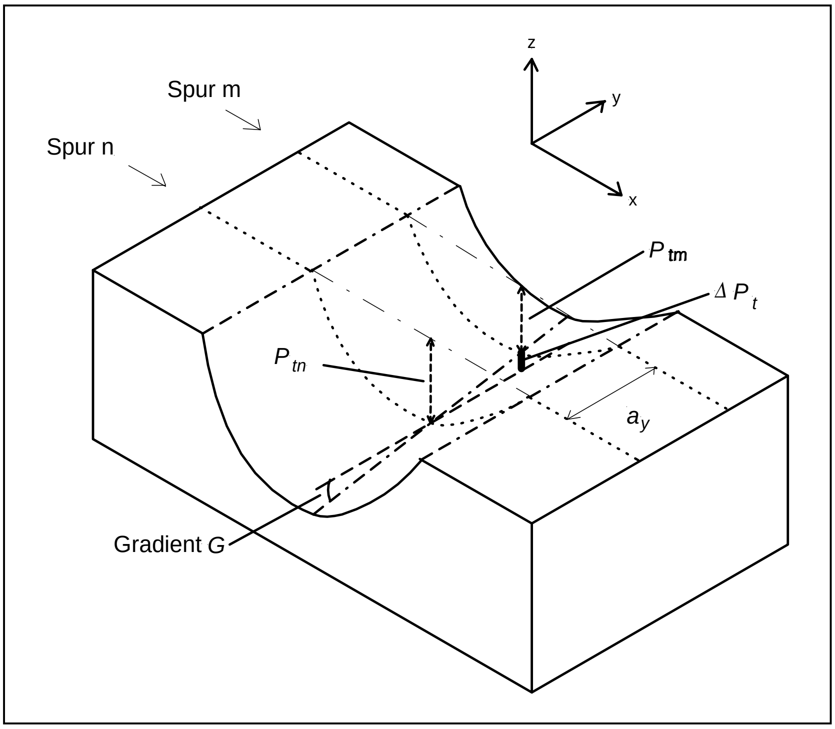


Figure 3: Uncertainty in the dissemination of the measure of depth

Trace n: Trace for calibrating the groove,
trace m: trace for dissemination,
$a_y = y_n - y_m$: deviation of trace positioning,
$\Delta Pt = Pt_n - Pt_m$: deviation in determination of depth

2.3 Uncertainty of overall profile

For the uncertainty $u^2(z_g)$ of the measurement points of the overall profile the following are obtained:

$u^2(z_g) =$

$u^2(Pt_n)$, uncertainty of reference standard (depth-setting standard) (5.1)

$+u^2(\Delta Pt)$, uncertainty of transfer from reference standard (5.2)

$+u^2(b)$, repeatability of tracing of reference standard (5.3)

$+u^2(z_e)$, uncertainty of obtained profile due to scatter on standard (5.4)

$+u^2(z_{ref})$, uncertainty of reference profile (5.5)

$+u^2(z_0)$, uncertainty due to background noise of device (5.6)

$+u^2(z_{pl})$, uncertainty due to insufficient knowledge of plastic deformation (5.7)

$+u^2(z_{sp})$, uncertainty due to insufficient knowledge of stylus tip geometry (5.8)

Chapter 3 gives numerical values or equations, respectively, for the calculation of these eight input quantities and describes the statistical properties of these quantities. As they have different effects according to the parameter to be calculated and the type of standard, the input quantities relevant to the specific case are compiled and the overall uncertainty is determined. An example of the case without λs is given in the table in section 7.1 and of the filtering with λs in section 7.2.

3 Determination of uncertainty of input quantities

3.1 Reference standard (depth-setting standard)

The uncertainty of measurement (U_n) of the total height of profile Pt_n of the reference standard is stated in the calibration certificate with the coverage factor k=2. This value is a statistically confirmed quantity. The empirical standard uncertainty therefore is:

$$u^2(Pt_n) = \frac{1}{4} \cdot U_n^2 .$$

Typical values are U_n = 10 nm at a groove depth of 250 nm to U_n = 50 nm at a groove depth of 10 µm.

3.2 Measuring point

The determination of the groove depth in the calibration of the device does not necessarily take place at the same point as in the calibration of the groove. Due to a gradient in the direction of the groove $G = \partial Pt/\partial y$, a position-dependent uncertainty in the y-direction leads to an uncertainty in depth measurement (Annex A Figure 3). Within 2a_y, every point is equally probable.

$$u^2(\Delta Pt) = \frac{1}{3} \cdot \left(a_y \cdot G\right)^2$$

According to depth and quality of the groove, the gradient *G* has values between 10 nm/mm und 40 nm/mm.

3.3 Repeatability of tracing in calibration

The standard uncertainty of the mean value in the depth determination for the calibration groove at the same point be $s(\overline{Pt_m})$.

The uncertainty due to the repeatability of the tracing process in calibration is

$$u^2(b) = s^2(\overline{Pt_m}).$$

Gaussian distribution is assumed.

3.4 Topography of standard

In spite of its uniform structure in the y-direction (Annex A Figure 4), the standard also has a statistical nature.

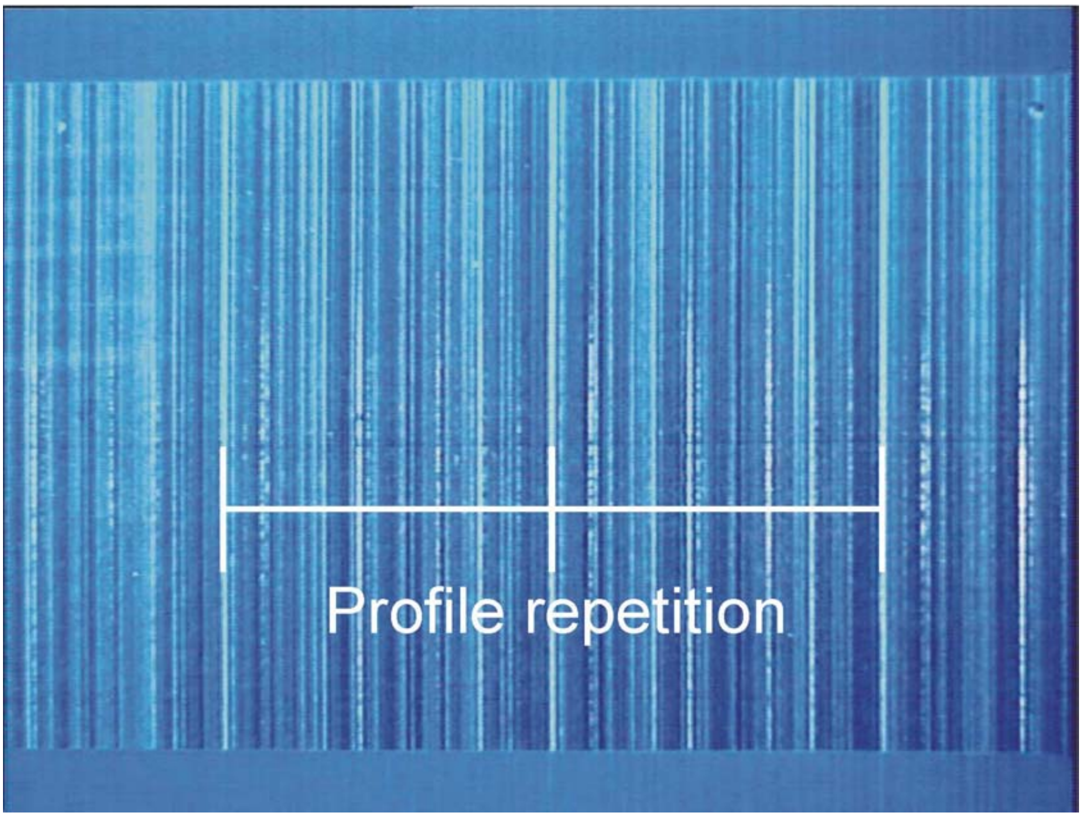


Figure 4: Type D1 roughness standard with profile repetition, DIN EN ISO 5436-1

This manifests itself by a statistical variation of the measured parameters in dependence on x and y. For the roughness standards this is taken into account in the measuring point plan (Annex A Figure 5) by spatial staggering of the measurements in the x- and y-directions.

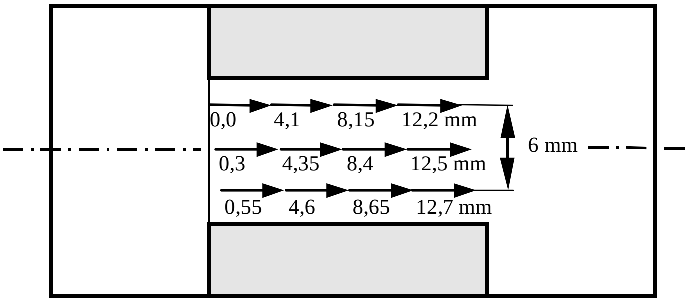


Figure 5: Measuring point plan for roughness standard (type D1, DIN EN ISO 5436-1)

For the number of profile sections, n = 12 is assumed. For the results Gaussian distribution is assumed.

In many evaluations the standard uncertainty of the individual values of the parameters is already frequently output. The standard deviation of the mean value $\frac{s(Rz)}{\sqrt{n}}$ can be taken as the estimated value for the uncertainty of the value of *Rz*. To obtain the uncertainty of the profile points needed here, it has to be taken into account that due to the averaging algorithm of *Rz* the uncertainty of *Rz* is smaller than the uncertainty of the profile points by the "smoothing factor" *S* of the algorithm. This is illustrated in chapter 6.

For the uncertainty component, eq. 5.4, of the overall profile, the following is obtained:

$$u^2(z_e) = \frac{1}{S^2} \cdot \frac{1}{n} \cdot s^2(Rz) .$$

3.5 Straightness deviation

The term according to eq. 5.5 contains the uncertainty influences due to deviations from straightness. The components of the long-wave deviations are dealt with in this section and those of the short-wave deviations in section 3.6.

The long-wave components of the straightness deviations are allowed for in the W-profile by the parameter *Wt,* as well as drifts during the time of measurement. A measuring section on an optical flat is measured with that part of the feed unit which is also used for the subsequent surface measurement. It must be mechanically aligned in the best possible way. The measurements are repeated five times at the same point of the standard and of the guide. The mean value Wt_0 from five measurements – determined at λc = 0,8 mm – is further used. On the assumption of uniform distribution, the following is valid:

$$u^2(z_{ref}) = \frac{1}{3}(\frac{Wt_0}{2})^2 .$$

3.6 Background noise

When a profile is measured, the background noise produced by guiding as well as by electrical and mechanical influence quantities is directly superposed upon the measurement profile. This effect is measured separately when the noise Rz_0 is measured on a good optical flat. Experience has shown that an Rz_0 below 10 nm can be achieved on good flats using good tracing systems. By averaging of several of these profile sections, the time variation of the background noise is also covered. This is why the R-profile of the optical flat measurement is evaluated for the determination of the term in eq. 5.6. In doing so, it has to be ensured that this measurement covers that part of the feed unit which is subsequently used for carrying out the measuring point plan on the standard. The mean value from five measurements $\overline{Rz_0}$ is further used. To obtain the uncertainty of the profile points, the "smoothing factor" of the Rz algorithm must again be taken into account. On the assumption of a uniformly distributed quantity, the following is valid:

$$u^2(z_0) = \frac{1}{S^2} \cdot \frac{1}{12} \cdot \left(\overline{Rz_0}\right)^2 .$$

3.7 Plastic deformation

During tracing, plastic deformation of the surface results in dependence on material, tracing force and stylus tip radius. As long as the deformation produced during the calibration and the subsequent measurement is the same, it would be negligible. Due to inaccurate repetition of the tracing point and its spatial surface conditions (hardness, existing trace, etc.), the inexact knowledge of the plastic deformation is to be allowed for as an uncertainty component for the profile.

Experience with the usual conditions of measurement (stylus tip radius = 2 µm, tracing force = 0,7 mN, hardness of standard = 450 HV) has shown plastic deformations between the boundary values of 10 nm to 20 nm, i.e. within a span of $2a_{pl}$ = 10 nm /2/. On the assumption of a uniformly distributed quantity, the following holds for the term in eq. 5.7:

$$u^2(z_{pl}) = \frac{a_{pl}^2}{3}$$

3.8 Stylus tip radius

The term in eq. 5.8 has effects in the case of standards sensitive to the stylus tip geometry, i.e., for example, standards of type D according to DIN EN ISO 5436-1. The profile traced differs from the true surface due to the finite stylus tip radius. According to DIN EN ISO 3274, this influence of the stylus tip with the nominal radius is already a component of the traced profile for further evaluation. Deviations from the stylus tip radius stated in the calibration certificate result in uncertain z-positions.

The simulation for the tracing of the same profile with different stylus tip radii yielded the relations represented in Figure 6. For *Rz* and *Rz1max* a variation of -20 nm per 1 µm of variation of the stylus tip radius and for *Ra* a dependence of -5 nm/µm can be seen.

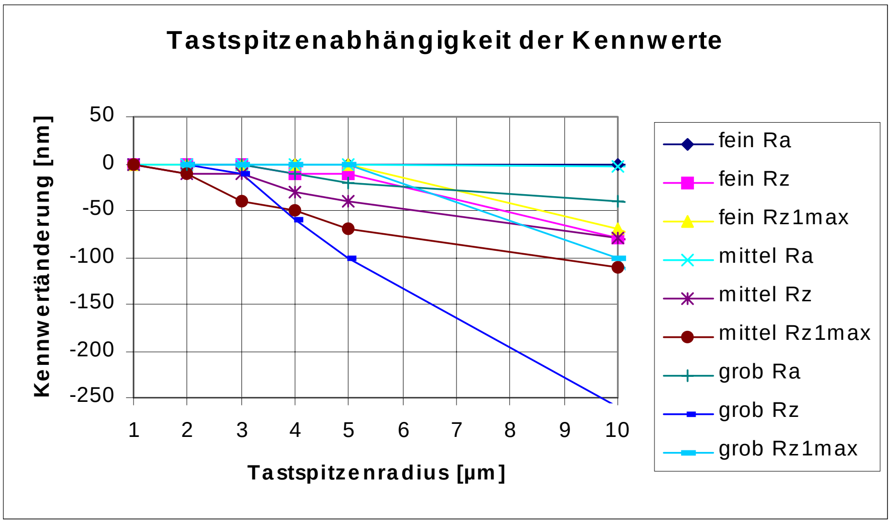


Figure 6: Dependence of the parameters on the stylus tip radius

Taking the "smoothing factor" of *Rz* into account, the following is obtained:

$$\frac{\partial z}{\partial r_t} = -\frac{1}{S} \cdot \frac{20\,\text{nm}}{\mu\text{m}}$$

The uncertainty of the stylus tip radius effective for the measurement is estimated at $u(r_t)$ = 1 µm and uniform distribution is assumed. The input quantity r is uncertain in the range r_{soll} ± 0,5 µm

$$u^2(z_{sp}) = \frac{1}{S^2} \cdot \frac{1}{3} \cdot \left(\frac{20\text{nm}}{\mu\text{m}} \cdot 0{,}5\mu\text{m} \right)^2 .$$

A compilation of the input quantities for the case without λs considered up to now is given in the table in section 7.1.

4 Short-wave low-pass filter for roughness

For the points z_s of the primary profile, the model in analogy to eq. 1 is valid, the reduction of the uncertainty of the λs-filtered primary profile data according to /1/ having an effect only on the profile data z_u currently measured:

$$z_s = Fs(z_g) = C \cdot Fs(z_u)$$

$$u^2(z_s) = u^2(C) \cdot Pt_n^2 + f_s^2 \cdot u^2(z_u) \qquad (6)$$

in the case of the ideal filter, with $f_s^2 = \frac{\Delta x}{\alpha \cdot \lambda s \cdot \sqrt{2}}$, Δx = spacing of measuring points,

$\alpha = \sqrt{\frac{\log 2}{\pi}} = 0{,}4697$ and $\lambda_s =$ cutoff wavelength of the short-wave low-pass filter.

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

At the values specified for λs and at the traversing lengths specified in DIN EN ISO 4287, the effect of the short-wave filter on the profile points thus is approximately equal: The uncertainty of the profile points of the filtered profile is reduced approximately by half. A compilation of the input quantities in this case is given in the table in section 7.2.

5 Short-wave low-pass filter for waviness

After the filtering with λc, the following is valid for the points of the waviness profile:

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

λc [µm]	f_c
250	0,055

800	0,031
2500	0,017

The following are valid: for the points of the roughness profile: $z_c = z_s - w$,

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

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

6 Parameter function

The points of the roughness profile $z_c(x)$ serve to calculate the value K of the parameter according to the algorithm of the parameter. The uncertainty u_{sys}(K) of a parameter can differ very strongly from the uncertainty of the profile points in dependence on their algorithm. This is described by, for example, $u_{sys}(Rz) = S(Rz) \cdot u(z_g)$, where *S(Rz)* is the "smoothing factor" of *Rz*. To show the influence of the algorithm, the effect of the algorithm of *Rz* is calculated as an example, uncorrelated profile data being assumed for simplification. For the averaged roughness depth *Rz* the following is valid:

$Rz = \frac{1}{5} \cdot \sum_{i=1}^{5} (p_i - v_i)$, where p_i and v_i are the maximum and minimum measurement values from five partial measuring sections. According to the sum rule, the uncertainty of the parameter is :

$$u^2(Rz) = \sum_{i=1}^{5} \left(\frac{\partial Rz}{\partial p_i} \right)^2 \cdot u^2(p_i) + \sum_{i=1}^{5} \left(\frac{\partial Rz}{\partial v_i} \right)^2 \cdot u^2(v_i) .$$

As $\frac{\partial Rz}{\partial p_i} = \frac{\partial Rz}{\partial v_i} = \frac{1}{5}$ is i for all,

$u^2(Rz) = \frac{1}{25} \left(\sum_{i=1}^{5} u^2(p_i) + \sum_{i=1}^{5} u^2(v_i) \right)$. As the uncertainties of the peak values $u(p_i) = u(v_i) = u(z_s)$ are equal to those of the individual values,

$u^2(Rz) = \frac{10}{25} \cdot u^2(z_s)$, or $u(Rz) = \sqrt{\frac{10}{25}} \cdot u(z_s) = \sqrt{\frac{10}{25}} \cdot f_s \cdot u(z_k)$, respectively.

As a result of the averaging effect of the algorithm of *Rz,* the uncertainty of the result quantity is smaller than the uncertainty of the profile points by the factor $S(Rz) = \sqrt{\frac{10}{25}}$.

7 Compilation of influence quantities

7.1 Without λs-filtering

In columns 4 and 7, typical values of the input quantities and their variance contributions are stated for a roughness standard with *Rz* = 3.

Table 7.1: Example of input quantitites and uncertainties, points of the profile, $u(z_g)$ = 27,6 nm

Section	Input quantity catchword	Calculation of input quantity	Exemplary values	Sensitivity coefficient	Method of determination, distribution	Variance [nm²]
3.1	Reference standard	$\frac{1}{4}\cdot U_n^2$	U_n = 15 nm (cal. cert.)	1	B Gaussian	56
3.2	Difference measuring point – calibration point	$\frac{1}{3}\cdot(a_y\cdot G)^2$	a_y = 100 µm G = 20 nm/mm	G	B uniform	1,3
3.3	Repeatability	$s^2(\overline{Pt_n})$	s = 3 nm	1	B Gaussian	9
3.4	Topography	$\frac{1}{S^2}\cdot\frac{s^2(Rz)}{n\cdot}$	$s(Rz)$ = 50 nm	1	A Gaussian	521
3.5	Straightness deviation	$\frac{Wt_0^2}{12}$	Wt_0 = 50 nm	1	B uniform	0
3.6	Background noise	$\frac{1}{S^2}\cdot\frac{1}{12}\cdot(\overline{Rz_0})^2$	$\overline{Rz_0} = 20$ nm	1	A uniform	83
3.7	Plastic deformation	$\frac{a_{pl}^2}{3}$	a_{pl} = 5 nm	1	B uniform	8,3
3.8	Stylus tip	$\frac{1}{3}\cdot\frac{1}{S^2}\cdot\left(\frac{20nm}{\mu m}\cdot u(r_{sp})\right)^2$	$u(r_{sp})$ = 0,5 µm	-20 nm/mm	B uniform	83
		$u^2(z_g)$				761,6

Remarks:

3.5 not applicable to R-parameters

3.7 not applicable to glass standards

If the complete equation for the systematic uncertainty component of *Rz* is formed, the following is obtained in the sum of column 3 in Table 7.1:

$$u_{sys}^2(Rz) = S^2 \cdot u^2(z_g) =$$

$$S^2 \times [\frac{1}{4} \cdot U_n^2 + \frac{1}{3} \cdot (a_y \cdot G)^2 + s^2(\overline{Pt_n}) + \frac{1}{S^2} \cdot \frac{s^2(Rz)}{n} + \frac{Wt_0^2}{12} + \frac{1}{S^2} \cdot \frac{1}{12} \cdot (\overline{Rz_0})^2 + \frac{a_{pl}^2}{3} +$$

$$\frac{1}{3} \cdot \frac{1}{S^2} \cdot \left(\frac{20nm}{\mu m} \cdot u(r_{sp}) \right)^2] \qquad (7)$$

As *S* is smaller than 1 and disregarding the input quantities which are regularly small, the following approximation can be made:

$$u_{sys}^2(Rz) \leq \frac{1}{4} \cdot U_n^2 + \frac{s^2(Rz)}{n} + \frac{Rz_0^2}{12}\,. \qquad (8)$$

7.2 With λs-filtering

In columns 4 and 7 typical values of the input quantities and their variance contributions are given for a roughness standard with $Rz = 3$.

Table 7.2: Example of input quantities and their uncertainties, points of the primary profile, $u(z_S) = 15$ nm

Section	Input quantity catchword	Calculation of input quantity	Exemplary value	Sensitivity coefficient	Method of determination, distribution	Variance [nm²]
3.1	Reference standard	$\frac{1}{4} \cdot U_n^2$	$U_n = 15$ nm (cal.cert.)	1	B Gaussian	56
3.2	Difference measuring point – calibration point	$\frac{1}{3} \cdot (a_y \cdot G)^2$	$a_y = 100$ µm $G = 20$ nm/mm	G	B uniform	1,3
3.3	Repeatability	$s^2(\overline{Pt_n})$	$s = 3$ nm	1	B Gaussian	9
3.4	Topography	$\frac{1}{S^2} \cdot \frac{s^2(Rz)}{f_s^2 \cdot n \cdot} \cdot f_s^2$	$s(Rz) = 50$ nm	1	A Gaussian	130
3.5	Straightness deviation	$\frac{Wt_0^2}{12} \cdot f_s^2$	$Wt_0 = 50$ nm	1	B uniform	0
3.6	Background noise	$\frac{1}{S^2} \cdot \frac{1}{12} \cdot \left(\frac{\overline{Rz_0}}{f_s} \right)^2 \cdot f_s^2$	$\overline{Rz_0} = 20$ nm	1	A uniform	25
3.7	Plastic deformation	$\frac{a_{pl}^2}{3} \cdot f_s^2$	$a_{pl} = 5$ nm	1	B uniform	2,5
3.8	Stylus tip	$\frac{1}{3} \cdot \frac{1}{S^2} \cdot \left(\frac{20nm}{\mu m} \cdot u(r_{sp}) \right)^2 \cdot f_s^2$	$u(r_{sp}) = 0{,}5$ µm	-20 nm/mm	B uniform	2,5
		$u^2(z_s)$				226,3

Remarks:

3.5 not applicable to R-parameters

3.7 not applicable to glass standards

If the complete equation for the systematic uncertainty component of *Rz* is formed, the following is obtained in the sum of column 3 in Table 7.2:

$$u_{sys}^2(Rz) = S^2 \times [\ \frac{1}{4} \cdot U_n^2 + \frac{1}{3} \cdot \left(a_y \cdot G\right)^2 + s^2(\overline{Pt_n}) + f_s^2 \times (\frac{1}{S^2} \cdot \frac{s^2(Rz)}{f_s^2 \cdot n \cdot} + \frac{Wt_0^2}{12} +$$

$$\frac{1}{S^2} \cdot \frac{1}{12} \cdot \left(\frac{\overline{Rz_0}}{f_s} \right)^2 + + \frac{a_{pl}^2}{3} + \frac{1}{3} \cdot \frac{1}{S^2} \cdot \left(\frac{20nm}{\mu m} \cdot u(r_{sp}) \right)^2)] .$$

(9)

In accordance with the considerations in sections 3.4, 3.6 and 3.8, the estimated values for the uncertainties of the profile points are determined from the estimated values of the surface parameters and the smoothing effect of λs-filtering is taken into account

As *S* is smaller than 1 and disregarding the input quantities which are regularly small, the following approximation can be made:

$$u_{sys}^2(Rz) \leq \frac{1}{4} \cdot U_n^2 + \frac{s^2(Rz)}{n} + \frac{Rz_0^2}{12} . \qquad (10)$$

This compilation is the same as in eq. 8, only with the difference that here λs-filtered estimated values are to be inserted.

8 Unknown systematic deviations

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

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

For the uncertainty calculation unknown systematic deviations must therefore be taken into account for the functions. Software standards according to DIN EN ISO 5436-2 would 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 DIN EN ISO 5436-1, with different devices and different realizations of the algorithms, if possible. The standard deviations of the mean values of the parameters serve as estimated value for the uncertainties, the averaging having been made over the participating laboratories. These uncertainties $u_V(K)$ are compiled in a table in dependence on parameter, type of standard, range of measurement and filtering and are added quadratically to the systematic uncertainty.

$$u^2(\mathrm{K}) = u_{sys}^2(\mathrm{K}) + u_v^2(\mathrm{K})$$

The reference uncertainties u_V(parameter) are stated in the table in chapter 11.
The expanded uncertainty of measurement of the parameter (coverage probability = 95%) is

$$U(K) = 2 \cdot [\ \frac{1}{4} \cdot U_n^2 + \frac{s^2(Rz)}{n} + \frac{Rz_0^2}{12} + u_v^2(\mathrm{K})]^{1\!/\!2}$$

This derivation confirms the calculation practised at the calibration laboratories of the DKD, which has been obtained from experience.

9 Literature

/1/ M. Krystek:

Einfluss des Wellenfilters auf die Unsicherheit eines Messergebnisses bei Rauheitsmessungen. Conference Volume of DIN Meeting "GPS 99“, Mainz, 05-06 May 1999, pp. 4-1–4-11. Beuth-Verlag, ISBN 3-410-14534-6

/2/ R. Krüger-Sehm, M. Krystek:

Uncertainty Analysis of Roughness Measurement

Proceedings of X. Int. Colloquium on Surfaces, Additional papers, Chemnitz, 31/01–02/02/2000

10 Reference uncertainties

Table of reference uncertainties u_v for the uncertainty calculation at DKD laboratories, values in % of the measurement value, in accordance with RV 97

			Parameters **with** λs								Parameters **without** λs							
Type		λc in mm	Ra	Rz1max	Rz	Rk	Rpk	Rvk	Mr1	Mr2	Ra	Rz1max	Rz	Rk	Rpk	Rvk	Mr1	Mr2
GN	G	2,5	0,2	0,3	0,2						0,5	0,3	0,3					
	G	0,8	0,2	0,3	0,4						0,4	0,3	0,3					
	M	0,8	0,3	0,4	0,4						0,2	0,2	0,2					
	F	0,8	0,4	0,3	0,4						0,5	0,3	0,5					
	F	0,25	0,6	0,6	0,5						0,5	0,5	0,5					
Number of labs			**9**								**4**							
RN	Gg	2,5	0,5	0,6	0,7	0,3	0,3	0,6	0,2	0,1	0,4	0,5	0,3	0,1	0,1	0,3	0,1	0,1
	G	0,8	0,5	0,6	0,5	0,3	0,5	0,5	0,2	0,3	0,5	0,5	0,4	0,2	0,1	0,1	0,1	0,1
	M	0,8	0,4	0,3	0,5	0,7	0,3	0,3	0,4	0,2	0,5	0,5	0,1	0,4	0,1	0,2	0,1	0,1
	F	0,8	0,3	0,7	0,7	0,3	0,3	0,4	0,2	0,1	1,1	0,3	0,9	0,1	0,2	0,2	0,1	0,1
Number of labs			**7**								**5**							
SFRN	G	0,25	0,3	1,3	0,5	0,4	1,6	0,2	0,6	0,2	0,6	1,5	0,6	0,3	0,3	0,1	0,2	0,1
	M	0,25	0,3	1,2	0,8	0,5	2,1	0,3	0,4	0,1	0,4	0,8	0,7	0,4	0,2	0,2	0,1	0,1
	F	0,25	0,9	2,1	1,9	1,1	1,6	0,8	0,4	0,5	1	2,4	1,9	0,6	0,3	0,2	0,2	0,2
Number of labs			**6**								**4**							

Appendix B1

Reports of SMU

EUROMET SUPPLEMENTARY COMPARISON

SURFACE TEXTURE

Project No. 600

Final Report

Elaborated by: M. Szmicskova
Bratislava, December 2002

CONTENT:

1 INTRODUCTION

Surface texture has a crucial influence onto the functional properties of devices and their individual parts. This quantity is of technical consequences, it has influence on the value of friction coefficient when two surfaces are in contact. Relief of the surface is a spacial formation, which we can measure and evaluate. In the case of SMU we are applying profile method using the contact profilometer.

Comparison measurements at the different levels of metrological assurance are being conducted in order to check a reliability and comparability of the measurement results.

This project was proposed at the EUROMET length contact persons meeting (Prague, 1999). The need of such comparison arose from the fact that the last international comparison in this field was completed in 1989 and the instrumental equipment, standards and software filtration have been improved since then. The pilot laboratories of this supplementary comparison are PTB Braunschweig and Center for Geometrical Metrology, Technical University of Denmark, Lyngby.

2 STANDARDS

In the frame of supplementary comparison (EUROMET #600 - pilot laboratories Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Center for Geometrical Metrology, Technical University of Denmark, Lyngby) the surface texture standards types C, D and A2 were delivered to the SMU.
They were packed in the special box, containing the following items:

1. Instructions in short version – 2 discs: a. Final.ZIP
   b. Test smd.ZIP
2. Copy of the Technical protocol
3. Data sheet with addresses of the participants
4. Photographs of standards in their initial state
5. 8 pieces of standards:

1	piece	depth setting standard of type A2
3	pieces	roughness standards of type C3
3	pieces	roughness standards of type D1
1	piece	roughness standard of type D2

The standards were delivered from IPG Portugal. Prior to the measurement itself, the standards were inspected for the damage and compared to the photographs documenting their initial state before the circulation.

Inspection was performed by the optical microscope in a clean environment. All damages (scratches, dots and dirt) were recorded. The coordinator was informed by fax and E-mail. The following damages has been recorded:

– surface texture standards were damaged only in those parts visible on photograps made at PTB, with the exception of standard No 1.006, which was damaged significantly -; grooves on the metal part could be observed by eye. .

3 Report

On the basis of instructions stated in Technical protocol Euromet Project 600 the laboratory of surface roughness SMU submits the report on measurement results to the pilot laboratory.
The report contains the following parts:

3.1 Introduction of the organisation
3.2 Description of the measurement equipment
3.3 Measurement itself
3.4 Measurement results, combined standard uncertainty
3.5 Uncertainty calculation and degrees of freedom
3.6 References

3.1 INTRODUCTION OF THE ORGANISATION

Slovak Institute of Metrology (SMU) as the national metrological institution is the contributory subject founded by the Office for standardisation, metrology and testing of the Slovak Republic (UNMS SR).

Statutary organ of the institute is the director, in the case of his absence represented by the deputy director general. Competence corresponding to the individual functions follow the Organisation order, Working order, internal documents, Instructions of directors of centres and the generally valid legal documents..

Activities of the SMU are related to the solution of research problems, development, improvement and maintanace of the national standards and harmonization of their quality with standards of other national metrological institutes. Besides SMU provides metrological services on the highest required level, performs research tasks and elaborates norms.
SMU has received the **Certificate of Quality Management System according to ISO 9001:2000** in October 11th, 2002 from the company LGA – InterCert.

3.2 DESCRIPTION OF THE MEASUREMENT EQUIPMENT

In the laboratory of surface roughness SMU, the contact profilometer TALYSURF 6 is being used for the measurement. A data transfer from the working standards to the standards of lower orders is realized by the method of direct comparison, where the calibrated and reference standards are of the same nominal values.

In the laboratory are calibrated measures and standards, while internal working procedures and corresponding national technical norms in the field of surface roughness are used.

SMU owns the following standards :

a/ type A – divided into types A_1 and A_2 :	groove depth is measured in the range (0,03÷10)µm with $u_c = (1\text{-}3)\%$
b/ type C – divided into types C_1, C_2, C_3, C_4:	parameter Ra is measured in the range (0,1÷6)µm with $u_c = (3 - 6)\%$
c/ type D :	parameters Rz, Ry (Rmax) ... are measured in the range (0,1÷ 10)µm with $u_c = (3 - 10)\%$

Contact profilometer TALYSURF 6, type S 112/1620 is used in the laboratory of surface roughness for the measurement of geometrical structure of surface by the contact profile method and transformation of the information about profile during the mechanical movement of the tip on the calibrated surface.

Mechanical signal generated by the stylus (sensor No 12/1620-1690 with reference plane and tip radius of 2,0 µm) follows the relief of the measured surface. The stylus is mounted onto arm, which can rotate around the plug of the sensing system. This makes possible for the stylus to follow the profile.

Mechanical signal from the mechanical part of the contact profilometer is transformed to the electrical one and then digitalized, or the output is a graphical record of the profile.
The value of force on the tip is 1 mN.

Data evaluation is being performed by the computer and programme TalyProfile 3.0.8. This programme enables the wide choice of parameters, setting of cut off, digitalization of the signal and the grafical record.

Measured values of the parameters d_m, Ra, Rz, Ry etc. are the resultant values stated from x measurement points equidistantly situated in the working aria of the calibrated standard and the expanded uncertainty of calibration U (k = 2) is valid for the whole working area. Uncertainties were estimated according TPM 0051-03 being in accordance with international standard for the unceratinty evaluation (GUM). The true value lies in the interval with probability of 95%.

The measurement system is situated on the antivibrating support.

3.3 MEASUREMENT

Preparation of the measurements:

- external inspection and checking for the labelling – firstly we observed the overall appearence of standards for their mechanical damage, traces of rust, scratches
- checking of the dimensions, whether they comply with those given in Technical protocol
- preparation of the contact profilometer for the measurement, situating the standard on the table with possibility of fine displacement, choice of measuring paths
- výber rýchlosti 1 mm/s
- choice of magnification 5000x and 10000x
- stylus of the profilometer 1
- standard of the profilometer 625 µm

The temperature of contact profilometer Talysurf 6 has to be stabilized at least one our before the measurement itself. Profilometer is adjusted according to the manual. The standard being in the accessories to the profilometer is used for the adjustment.

Measurement procedure:

The reference standard and the standard to be calibrated are subsequently located on the profilometer cross table and their profiles in the chosen areas are read – according to the technical protocol (area of measurement) of the individual standards.

The standard is placed on the table by such a way that a motion of the instrument sensor is in the direction of the highest values of vertical parameters. In these sections both $\mathbf{R_i}$ and $\mathbf{d_i}$ are measured, separately for each roughness characteristic. From the measured values the mean value and its standard deviation **s** is calculated.

In each section of calibrated standard, three repeated measurements were carried out with corresponding determination of the given parameter.

The reference standard was calibrated before the measurement and after completion of measurement (checking of the profilometer, whether it keeps its parameters).

Data evaluation is by computer and programme TalyProfile 3.0.8.

Evaluation of the measured values of parameters d, Ra, Rz, Rmax, Rk, Rpk, Rvk was done by the direct comparison, when both reference and calibrated standards had the same nominal values. The values of spatial parameters Pt, RSm and parameters reflecting the material characteritics Mr1, Mr2 are approximate.

Filtration of measured values of parameters d, Ra, Rz and Rmax was performed by the choice of Gaussian filter, Rk parameter was filtrated by the double Gaussian filtre.

Measurement conditions:

- ambient temperature was during measurements conditioned to (20 ± 1)°C,
- relative humidity during measurements didn‘t exceed 65 %,
- outside the measuring period the relative humidity in the air-conditioned laboratory didn‘t exceed 70 %

3.4 MEASUREMENT RESULTS, COMBINED STANDARD UNCERTAINTY

Table of measured values and uncertainties – Annex No. 1

3.5 UNCERTAINTY CALCULATION AND DEGREES OF FREEDOM

Measurement uncertainty is evaluated according to TPM 0051-93.
In the following table the uncertainty budget containing all components taken into account is given.

Reference standard:	serial number	0386421/2293
	nominal value	0,3 µm
	value given in the calibration certificate	d_E = 0,274 µm
	uncertainty given in the cal. certificate	0,002 µm

Measured values:	1	2	3
a	0,258 µm	0,255 µm	0,266 µm
b	0,258 µm	0,26 µm	0,267 µm
c	0,263 µm	0,259 µm	0,265 µm

D_E = 0,261 µm u_{BE} = 0,00139 µm

Calibrated standard:	serial number	0391806/2625
	nominal value	0,2 µm
	type	EN 806

Measured values:	1	2	3
a	0,243 µm	0,247 µm	0,242 µm
b	0,247 µm	0,249 µm	0,242 µm
c	0,251 µm	0,249 µm	0,249 µm
d	0,251 µm	0,25 µm	0,25 µm
e	0,244 µm	0,249 µm	0,243 µm

D = 0,247 µm u_A = 0,000864 µm

$$d = d_E \cdot \frac{D}{D_E} = 0{,}274 \cdot \frac{0{,}24706}{0{,}2612} = 0{,}259167 \Rightarrow 0{,}259\ \mu\text{m}$$

UNCERTAINTY BUDGET

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient	Uncertainty contribution $u_i(h)$ (nm)	Degrees of freedom ν_i
d	0,2 µm	0,86 nm	normal	1	0,86	14
d_E	0,274 µm	2 nm	normal	1	2	8
D_E	0,3 µm	1,4 nm	normal	1	1,4	8
Z_{ref}	0 nm	2 nm	normal	1	2	19
F	1 mN	0,05 mN	rectangular	28 nm/mN	1,4	9
Z_{tip}	0 nm	3 nm	rectangular	1	3	9

$$\nu_{eff} = (n+1)[1 + u_{BX}^2 / u_{AX}^2]^2 - 2 = (67+1)[1 + 4{,}57^2 / 0{,}86^2]^2 - 2 =$$
$$= 68(1 + 28{,}238)^2 - 2 = 58\,129$$

$$u_C = \sqrt{u_A^2 + u_{BE}^2 + u_{BAE}^2 + u_{BZref}^2 + u_{BF}^2 + u_{BTip}^2} =$$
$$= \sqrt{0{,}86^2 + 2{,}0^2 + 1{,}4^2 + 2{,}0^2 + 1{,}4^2 + 3{,}0^2} = 4{,}65\ \text{nm}$$

$$U = k \cdot u_C = 2 \cdot 4{,}65 = 9{,}3\ \text{nm}$$

Notes:

D – arithmetic mean of the profile height of measured standard from **n** measurements
D_E – profile height of the reference standard (comparative)
d – real profile height of the measured standard
d_E – real profile height of the reference standard (comparative)
Z_{ref} – the slideway profile
F – force of the tip to the surface
Z_{Tip} – deviation of the tip from sphericity
u_A – standard deviation of the arithmetic mean taken from the repeated measurements of the calibrated standard
u_{BE} – standard uncertainty of the surface roughness parameter determination corresponding to the reference standard (comparative) – given in the calibration certificate
u_{AE} - standard deviation of the arithmetic mean taken from the repeated measurements of the reference standard
u_{BZref} – uncertainty from the deviation from straightness of the slideway profile
u_{BF} – uncertainty from the stylus force
u_{BTip} – uncertainty from the deviation from sphericity of the tip

3.6 References

Related background documents, working procedures and metrological instructions on the basis of which the measurements were carried out:

Document	Title (all documents given bellow are in Slovak language)
ISO 4287-1	Surface roughness. Terminology. Surface and its parameters.
ISO 4287-2	Surface roughness. Terminology. Measurements of the surface texture parameters.
ISO 5436	Calibration patterns. Contact instruments, types, calibration and used patterns.
ISO 11562	Geometrical product specification (GPS). Character of the surface: Profile method -Metrological characteristics of the phase corrected filters.
ISO 12085	Geometrical product specification (GPS). Character of the surface: Profile method – Motive parameters.
ISO 13565-1	Geometrical product specification (GPS). Character of the surface: Profile method - Surfaces, the functional properties of which are related to the level. Part 1: Filtration and general measurement conditions.
ISO 13565-2	Geometrical product specification (GPS). Character of the surface: Profile method - Surfaces, the functional properties of which are related to the level. Part 1: Height characteristics by the linear par of the curve of material ratio.
TPM 7030-96	Surface roughness standards of type A. Technical requirements.
TPM 7031-96	Surface roughness standards of type A. Method of testing.
TPM 7032-97	Surface roughness standards of types C, D. Technical requirements.
TPM 7033-97	Surface roughness standards of types C, D. Method of testing.
TPM 0059-93	Estimation of calibration uncertainty, Parts 1 and .
PP 07/210/00	Working procedure for the calibration of surface roughness patterns of types C and D.
PP 08/210/00	Working procedure for the calibration of contact profilometer.
PP 09/210/00	Working procedure for the calibration of vertical magnification, type A.

Laboratory of surface roughness
Bratislava, 20. 12. 2002

Ing. Pavol Doršic
Director of the Centra of length and time

Maria Szmicskova
performed the calibration

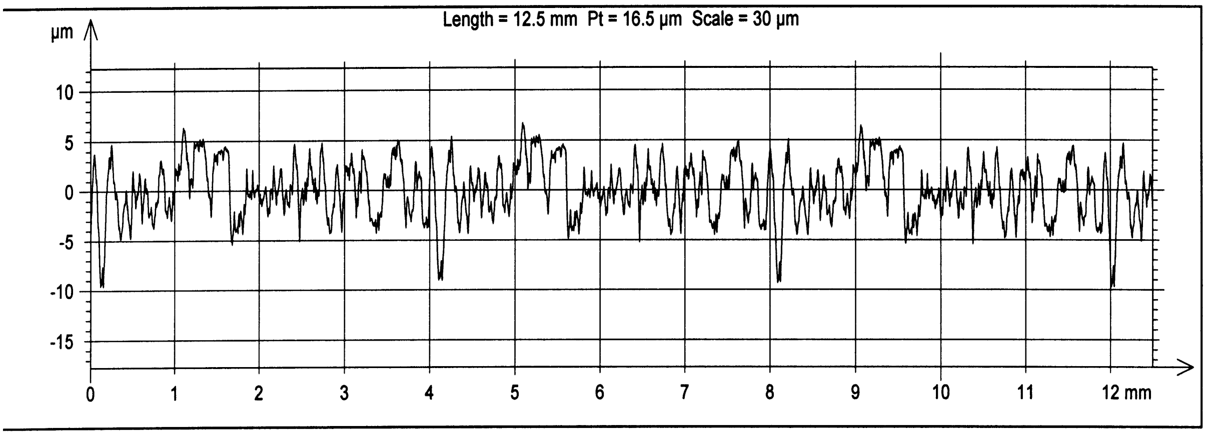
Comments to the Draft 1 – Euromet #600

1. Contact profilometer Talysurf 6 works with the programme TalyProfile 3.0.8, which was purchased in 2002 from the company Taylor-Hobson. Programme has it own parameters fixed, which can not be changed, since such a change might effect some other parameters (filtration). Our facility operates at the fixed value of speed 1 mm/s and this fact causes very quick sampling of surface points. In the case of parameters d – groove depth and standards of type D – random profile these have different parameters from the reference value.
2. Values of parameters Pt; RSm; Mr1 and Mr2 were measured by the instrument and their value has been influenced by the large speed of stylus
3. Error sources resulting from the fixed parameters of the measuring programme were not taken into account and our claimed uncertainties were underestimated.

In the following example are given parameters and results of calibration of the D type standard.

Owner of the standard: PTB Braunsweig
type : D
manufacturer: PTB 99/49
serial number: 686 sg
nominal values : Ra = 2.5 µm; Rz = 14 µm

Conditions of measurement:
temperature: 20.3 °C
speed: 1 mm/s
magnification: 5000 x
points: 12500
stylus tip radius 2 µm
λc = 2500 µm; λs = 8 µm
length: 12,5 mm



Parameters calculated on the profile Profile

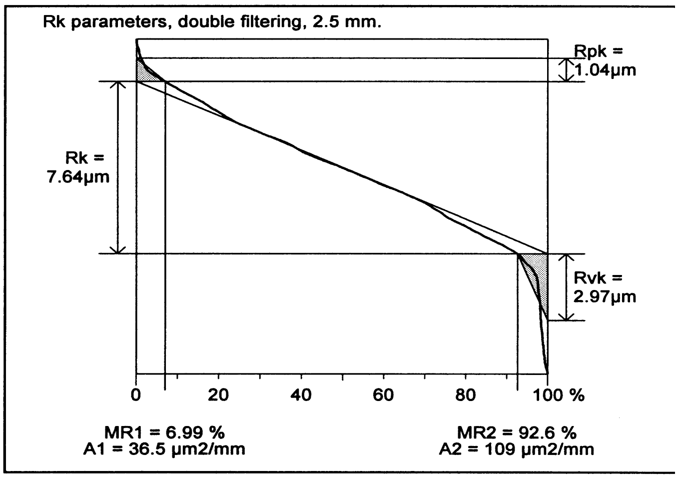
```
* Parameters calculated by mean of all the sampling
lengthes.
* A microroughness filtering is used, with a ratio of
2.5 µm.

Roughness Parameters, Gaussian filter, 2.5 mm

   Ra     = 2.1 µm
            Ra: Arithmetic Mean Deviation of the
roughness profile.
   Rmax   = 14.4 µm
            Rmax: Maximum Peak-to-Valley height of the
sampling lengthes on the roughness profile.
   Rz     = 12.8 µm
            Rz: Maximum Height of roughness profile.

Rk Parameters (ISO 13565-2), 2.5 mm

   Rk     = 7.64 µm
            Rk: Kernel Roughness Depth.
   Rpk    = 1.04 µm
            Rpk: Reduced Peak Height.
   Rvk    = 2.97 µm
            Rvk: Reduced Valley Depth.
   MR1    = 6.99 %
            MR1: Upper Material Ratio.
   MR2    = 92.6 %
            MR2: Lower Material Ratio.
```



Appendix B1

Report of SP

1 REPORT OF THE MEASUREMENTS MADE AT SP , SWEDEN

1.1 GENERAL

The intercomparison consisted of eight physical standards and three data files. The measurements were made according to the instructions regarding measurement positions, assessment lengths and filtering conditions, using a stylus instrument. The report consists of three parts: the description of the measurement set-up, a description of the uncertainty calculations and the measurement results in a separate excel-sheet.

1.2 DESCRIPTION OF MEASURING INSTRUMENT

Type of instrument Stylus instrument: RankTaylorHobson, FormTalysurf 120, inductive pic-up.

Kind of operation: moving stylus, the traverse unit is mounted at a column on a granite base.

Conditions of data collection: Vertical measurement ranges 0,1 mm and 0,02 mm were used. (Vertical resolution 3,2 nm, 0,64 nm). Scan length max 120 mm, stylus tip radius 2 µm.
In this intercomparison we made 5 measurements (without filtering) on the depth setting standard (A2). The reported value is the mean of five measurements.
On the roughness standards (C3, D1, D2) we made 12 measurements (with filtering). The reported mean value consists of 12 measurements, each measurement of 5 sampling lengths.

Conditions of evaluation: No compensation of reference plane.
Linearity correction for the vertical transmission has been used. A manual correction of +1,5% has been made on the reported results. This is due to a difference between the measuring ranges of the instrument.

Characterisation of instrument noise and deviation of ideal behaviour: The guideway error and the instrument noise have been evaluated for different evaluation lengths.

Environment characterisation: The instrument set-up is placed on a stable table in a calm underground laboratory with a thick concrete floor. The granite base of the instrument has rubber feet vibration isolation. We use no dust and/or noise protection cover during measurements. The laboratory has a thermal stability within +/- 0,3 ºC during measurement cycles.

1.3 RESULTS

All results are from stylus measurements with the FormTalysurf instrument. The results are presented in the enclosed excel-sheet. **Note:** For the specimen 8194 a change in the profile was detected at the position of measurement 4. Therefore results are presented both with and without measurement 4. Uncertainty calculations are included.

The measurands are stated for the reference temperature at 20°C.

Evaluation of datafiles (softgauges).

(This is not a service we offer to customers.)

The built in software of the formtalysurf was used for the evaluation. I order to adapt the data files to the software the following operations were performed. First we had to create datafiles with data separation (Δx) of 0,25 µm instead of 0,15 µm. This was done by linear interpolation. Second we took the x-values out of the files and recalculated the y-values into "number of steps" instead of absolute values, using our instrument resolution. Third we added a new heading to the files. Fourth we cut away 0,5 λc from each end. Then we put it into the Form-Talysurf software. When the data is processed and filtered by the software a remaining 0,5 λc is cut off from each end by the gaussian filter.

We have reported the parameter values that were produced by the software. In one case (file 7080) the software could not calculate the ISO 13565 parameters.

1.4 UNCERTAINTY

The uncertainty of the measurement has been estimated according to *the Guide to the Expression of Uncertainty in Measurement*.

For example, the step height h of the standards is expressed as a function of the input quantities X_i

$$h = f(x_i) \quad . \qquad (1)$$

The combined standard uncertainty $u_c(h)$ is the square sum of the standard uncertainties of the input quantities $u(x_i)$, each weighted by a sensitivity coefficient c_i

$$u_c^2(h) = \sum_i c_i^2 u^2(x_i) \text{ with } \qquad c_i = \frac{\partial h}{\partial x_i} \qquad (2)$$

quantity X_i	estimate x_i	Uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(h)$	degrees of freedom v_i
Amplification	+1,5%	0,0045	N	h	0,0045h	50
Guideway profile	0	7 nm	R	1,015	7,1 nm	50
Noise	0	3 nm	N	1,015	*	
Surface variation	0	s/√n	N	1,015		4
Contact deformation	0	3 nm	R	1,015	3 nm	100
Tip radius	0	0	?		0**	
Resolution	0	0,2 nm	R	1,015	0,2 nm	100

For the type of probability distribution: N = normal; R = rectangular; T = triangular; U = U-shaped.
* The noise component is included in the estimate of the guideway error and in the estimate of the surface variation, so it was not added a third time.
** The effect of the tip radius has been taken to be negligible for these surfaces and filter conditions.

This example is for the depth setting standard. The uncertainties for the other surfaces were calculated in a similar manner.

Comment from SP

We have the following comments regarding the results from SP.

1. Our software uses the wrong definition of the Rt parameter. We think therefore that our results for this parameter should not be used in the calculation of the reference values.

2. The deviation from the reference values of the parameters Rvk and Rpk in our case seem to be slightly dependent on the roughness of the surface. We have not yet found the reason for this, but we suspect it might be a software problem.

3. We have re-evaluated the uncertainty calculations for the parameters RSm, Mr1 and Mr2. In the case of RSm, we had underestimated the effect of the resolution of the x-axis. In the case of Mr1 and Mr2, we did not take into account the effect of truncation in the software. Please find the new values in the attached excel-sheet. We think it would be appropriate to include these new uncertainty-values in draft B of the report.

Euromet 600 SP results
Uncertainties in yellow boxes have been reevaluated.

Geom. Standard			RSm
Rub	P114A/528-RS 5	value/µm	50,03
		std. dev./nm	11
		U/nm (k=2)	50
PTB	7070/PGN10	value/µm	199,94
		std. dev./nm	20
		U/nm (k=2)	51
PTB	8194/PGN3	value/µm	119,98
		std. dev./nm	33
		U/nm (k=2)	54

Roughn.standard			Mr1/%*	Mr2/%*
very coars	686sg	value/µm	6,6	93,6
		std. dev./nm	1,3	0,5
		U/nm (k=2)	2,1	2,0
coarse	633g	value/µm	6	81,6
		std. dev./nm	0,9	0,9
		U/nm (k=2)	2,1	2,1
fine	629f	value/µm	8,4	88,1
		std. dev./nm	0,8	0,8
		U/nm (k=2)	2,1	2,1
SFRN 150	1.006	value/µm	10,8	87,4
		std. dev./nm	1,3	1,9
		U/nm (k=2)	2,1	2,3

Appendix B1

Reports of UME

MEASUREMENT REPORT
OF
NATIONAL METROLOGY INSTITUTE
OF TURKEY, UME

EUROMET SUPPLEMENTARY COMPARISON

SURFACE TEXTURE

Project No. 600

UME Dimensional Laboratory
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Contents

APPENDIX 2 Detail Explanations of All Uncertainty Calculations in EXCEL Sheets (see the file* “UME-Uncertainty.xls” *)

1. Description of the Measurement Method and Instrument

Type of instrument: Stylus instrument - Mahr Perthometer Concept (pick up is FRW-250, drive unit is PRK, xy table is PKT electronic)

Kind of operation: Moving stylus. A comercial column is not used. Instead, drive unit is located on a table with adjustable height to reduce vibration.

Conditions data collection: Stylus tip radius 2 µm, stylus tip angle 90°, vertical measurement range ± 25 µm

Conditions of evaluation: Measurements are performed according to the datum of PRK drive unit. No skid is used.

Characterisation of instrument noise and deviation of ideal behaviour: A PTB calibrated optical flat is used. The optical flat is set on the x-y table and different regions of the optical flat surface are measured.

> Rougness value on flat glass plate with lateral movement Rzo = 0.033 µm (Certificated Rz value of the optical flat is about 5 nm.)
> Rougness value on flat glass plate without lateral movement Rzo = 19 nm
> Waviness value on flat glass plate with lateral movement Wt = 30 nm
> Vertical resolution = Measuring range / 60000 step = 0,42 nm
> Horizontal resolution = Standart tracing length / up to 16000 point

Environment characterisation: No vibration isolation is used. Temperature of the laboratory is 20±0,3°C.

2. Results and Measurement Conditions

Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
	EN 806										mm	µm	mm/s	mN	µm
R1	0,2 µm	value/µm	0,316	0,282							-	2,67	0,1	0,9	0,1
		std. dev./nm	3,6	9,3							-	2,67	0,1	0,9	0,1
		U/nm (k=2)	40,9	20,2											
R3	1,5 µm	value/µm	1,405	1,364							-	2,67	0,1	0,9	0,1
		std. dev./nm	6,8	10,0							-	2,67	0,1	0,9	0,1
		U/nm (k=2)	45,2	22,0											
R6	8 µm	value/µm	8,399	8,363							-	2,67	0,1	0,9	0,1
		std. dev./nm	11,8	10,8							-	2,67	0,1	0,9	0,1
		U/nm (k=2)	105,5	25,9											
Geom. Standard			Ra	Rz	Rmax	RSm									
Rub	P114A/528-RS 5	value/µm	0,505	1,593	1,599	49,723					0,25	2,5	0,1	0,9	0,2
		std. dev./nm	1,2	4,9	7,1	75,4					0,25	2,5	0,1	0,9	0,2
		U/nm (k=2)	48,6	48,6	48,6	984,3									
PTB	7070/PGN10	value/µm	2,978	9,730	9,914	198,617					2,50	8,33	0,5	0,9	0,5
		std. dev./nm	11,9	46,8	49,1	21,1					2,50	8,33	0,5	0,9	0,5
		U/nm (k=2)	142,3	142,3	142,3	3920,4									
PTB	8194/PGN3	value/µm	0,901	3,096	3,113	119,149					0,80	2,67	0,5	0,9	0,35
		std. dev./nm	6,4	48,7	48,5	29,0					0,80	2,67	0,5	0,9	0,35
		U/nm (k=2)	113,9	113,9	113,9	2335,5									

Roughn. Standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
											mm	µm	mm/s	mN	µm
Very coarse	686sg	value/µm	2,346	14,300	15,534	8,137	1,231	3,110	6,948	92,850	2,50	8,33	0,5	0,9	0,5
		std. dev./nm	32,5	258,1	28,9	297,5	125,8	130,3	1,235	0,807		8,33	0,5	0,9	0,5
		U/nm (k=2)	497,6	497,6	497,6	634,4	634,4	634,4	0,306	4,085					
Coarse	633g	value/µm	1,533	7,608	9,041	4,464	0,739	2,529	6,196	81,968	0,80	2,67	0,5	0,9	0,35
		std. dev./nm	8,2	197,8	123,0	99,8	52,1	53,2	0,413	0,469		2,67	0,5	0,9	0,35
		U/nm (k=2)	399,7	399,7	399,7	523	523	523	0,428	5,656					
Fine	629f	value/µm	0,147	1,255	1,421	0,449	0,137	0,298	8,982	88,158	0,80	2,67	0,5	0,9	0,35
		std. dev./nm	2,9	40,7	51,5	11,8	5,7	7,6	0,860	0,654		2,67	0,5	0,9	0,35
		U/nm (k=2)	98,1	98,1	98,1	136,0	136,0	136,0	0,97	9,521					
SFRN 150	1.006	value/µm	0,024	0,138	0,175	0,069	0,029	0,036	12,606	83,232	0,25	2,50	0,1	0,9	0,1
		std. dev./nm	1,6	6,1	13,0	12,6	3,1	6,0	0,784	4,394		2,50	0,1	0,9	0,1
		U/nm (k=2)	42,8	42,8	42,8	72,4	72,4	72,4	6,618	43,697					

Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%
			ISO 4287							DIN 4768	ISO 13565-2				
file 1	505	value/µm	0,19	0,23	0,52	0,78	1,47	-0,28	1,30	1,47	0,14	0,65	0,25	7,43	89,92
file 2	1001	value/µm	0,09	0,11	0,24	0,24	0,63	0,00	0,48	0,57	0,07	0,28	0,10	11,56	87,81
file 3	7080	value/µm	0,43	0,49	0,76	0,74	1,52	0,01	1,5	1,52	-	-	-	-	-

*) ISO 13565-1

EXTRA
MEASUREMENTS

Roughn standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
											mm	µm	mm/s	mN	µm
Very coarse	686sg	value/µm	2,368	14,791	15,915	8,285	1,232	3,269	7,126	93,126	2,50	Lc/Ls=MAX	0,5	0,9	0,5
		std. dev./nm	29,7	302,2	50,9	223,9	102,4	217,2	1,003	0,505		Lc/Ls=MAX			
		U/nm (k=2)	497,6	497,6	497,6	634,4	634,4	634,4	0,306	4,085		Lc/Ls=MAX			
Coarse	633g	value/µm	1,538	7,717	9,082	4,482	0,733	2,537	6,243	81,963	0,80	Lc/Ls=MAX	0,5	0,9	0,35
		std. dev./nm	10,1	148,8	124,1	45,0	22,5	37,9	0,172	0,278		Lc/Ls=MAX			
		U/nm (k=2)	399,7	399,7	399,7	523,0	523,0	523,0	0,428	5,656		Lc/Ls=MAX			
Fine	629f	value/µm	0,148	1,277	1,451	0,457	0,136	0,292	8,593	88,235	0,80	Lc/Ls=MAX	0,5	0,9	0,35
		std. dev./nm	2,5	46,4	81,2	8,6	5,6	9,0	0,479	0,354		Lc/Ls=MAX			
		U/nm (k=2)	98,1	98,1	98,1	136,0	136,0	136,0	0,970	9,521		Lc/Ls=MAX			

3. Uncertainty Budgets of Measurements

A4 - Uncertainty of measurement

3.1 Step height standard with a nominal height of 200 nm - Identification (for D)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_m + z_{ref} + z_n)$$

$$D = \frac{1}{n_o} \sum_{i=1}^{n_o} z_{koi} - \frac{1}{n_u} \sum_{i=1}^{n_u} z_{kui} + 2AF$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove (Measured value of reference standard)
b : Reproducibility of tracing of the reference groove
z_m : Profile of test standard (Measured value of test standard)
z_{ref} : Profile of reference plane (Wt value determined using optical flat)
z_n : Background noise (Rz value determined using optical flat)
AF : Alingnment error due to roughness and flatness error on the test depth standard
n_o : Number of profile points of upper profile sections which is used to fit an upper straight line
n_u : Number of profile points of lower profile section which is used to fit a circle at the bottom of the groove
z_{koi} : z coordinate of ith point of upper profile sections
z_{kui} : z coordinate of ith point of lower profile section

Combined uncertainty equation:

$$u(D) = \sqrt{\left(\frac{1}{n_o} + \frac{1}{n_u} \right) \frac{z_m^2}{P_{tn}^2} \left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b) \right) + \left(\frac{1}{n_o} + \frac{1}{n_u} \right) \left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n) \right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.0040	0.154 nm	200
Ptmy	9870 nm	2 nm	R	0.0040	0.005 nm	200
b	10 nm	10 nm	N	0.0040	0.040 nm	100
z_m	282 nm	5 nm	N	0.1414	0.707 nm	4
z_{ref}	30 nm	15 nm	R	0.1414	1.225 nm	200
z_n	33 nm	16.50 nm	R	0.1414	1.347 nm	200
AF	10 nm	5 nm	R	1.4142	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.0000	0.121 nm	200
REP	9 nm	9 nm	N	1.0000	9.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(D)$ = 10.1 nm

Effective degrees of freedom: $v_{eff}(D)$ = 76.6

Expanded uncertainty: $U(D)$ = 20.2 nm with a coverage factor k=2

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A4 - Uncertainty of measurement

3.2 Step height standard with a nominal height of 1500 nm - Identification (for D)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b}\right)(z_m + z_{ref} + z_n)$$

$$D = \frac{1}{n_o}\sum_{i=1}^{n_o} z_{koi} - \frac{1}{n_u}\sum_{i=1}^{n_u} z_{kui} + 2AF$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove (Measured value of reference standard)
b : Reproducibility of tracing of the reference groove
z_m : Profile of test standard (Measured value of test standard)
z_{ref} : Profile of reference plane (Wt value determined using optical flat)
z_n : Background noise (Rz value determined using optical flat)
AF : Alingnment error due to roughness and flatness error on the test depth standard
n_o : Number of profile points of upper profile sections which is used to fit an upper straight line
n_u : Number of profile points of lower profile section which is used to fit a circle at the bottom of the groove
z_{koi} : z coordinate of i^{th} point of upper profile sections
z_{kui} : z coordinate of i^{th} point of lower profile section

Combined uncertainty equation:

$$u(D) = \sqrt{\left(\frac{1}{n_o} + \frac{1}{n_u}\right)\frac{z_m^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + \left(\frac{1}{n_o} + \frac{1}{n_u}\right)\left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n)\right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.020	0.743 nm	200
Ptmy	9870 nm	2 nm	R	0.020	0.023 nm	200
b	10 nm	10 nm	N	0.020	0.195 nm	100
z_m	1364 nm	5 nm	N	0.141	0.707 nm	4
z_{ref}	30 nm	15 nm	R	0.141	1.225 nm	200
z_n	33 nm	16.50 nm	R	0.141	1.347 nm	200
AF	10 nm	5 nm	R	1.414	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200
REP	10 nm	10 nm	N	1.000	10.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(D) = 11.0$ nm

Effective degrees of freedom: $v_{eff}(D) = 71.6$

Expanded uncertainty: $U(D) = 22.0$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.3 Step height standard with a nominal height of 8000 nm - Identification (for D)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_m + z_{ref} + z_n)$$

$$D = \frac{1}{n_o} \sum_{i=1}^{n_o} z_{koi} - \frac{1}{n_u} \sum_{i=1}^{n_u} z_{kui} + 2AF$$

Ptn	:	Depth of the reference setting standard known from PTB certificate
Ptmy	:	Locus dependent fraction of measured reference groove (Measured value of reference standard)
b	:	Reproducibility of tracing of the reference groove
z_m	:	Profile of test standard (Measured value of test standard)
z_{ref}	:	Profile of reference plane (Wt value determined using optical flat)
z_n	:	Background noise (Rz value determined using optical flat)
AF	:	Alingnment error due to roughness and flatness error on the test depth standard
n_o	:	Number of profile points of upper profile sections which is used to fit an upper straight line
n_u	:	Number of profile points of lower profile section which is used to fit a circle at the bottom of the groove
z_{koi}	:	z coordinate of i^{th} point of upper profile sections
z_{kui}	:	z coordinate of i^{th} point of lower profile section

Combined uncertainty equation:

$$u(D) = \sqrt{\left(\frac{1}{n_o} + \frac{1}{n_u} \right) \frac{z_m^2}{P_{tn}^2} \left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b) \right) + \left(\frac{1}{n_o} + \frac{1}{n_u} \right) \left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n) \right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.120	4.554 nm	200
Ptmy	9870 nm	2 nm	R	0.120	0.138 nm	200
b	10 nm	10 nm	N	0.120	1.198 nm	100
z_m	8363 nm	5 nm	N	0.141	0.707 nm	4
z_{ref}	30 nm	15 nm	R	0.141	1.225 nm	200
z_n	33 nm	16.50 nm	R	0.141	1.347 nm	200
AF	10 nm	5 nm	R	1.414	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200
REP	11 nm	11 nm	N	1.000	11.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(D) = 12.9$ nm

Effective degrees of freedom: $v_{eff}(D) = 92.9$

Expanded uncertainty: $U(D) = 25.9$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.4 Step height standard with a nominal height of 200 nm - Identification (for Pt)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_m + z_{ref} + z_n)$$

$$Pt = z_{ko} - z_{ku} + 2\,AF$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove (Measured value of reference standard)
b : Reproducibility of tracing of the reference groove
z_m : Profile of test standard (Measured value of test standard)
z_{ref} : Profile of reference plane (Wt value determined using optical flat)
z_n : Background noise (Rz value determined using optical flat)
AF : Alingnment error due to roughness and flatness error on the test depth standard
z_{ko} : Highest z-value at the top of the profile
z_{ku} : Lowest z-value at the bottom of the profile

Combined uncertainty equation:

$$u(P_t) = \sqrt{\frac{2z_m^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + 2\left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n)\right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.045	1.721 nm	200
Ptmy	9870 nm	2 nm	R	0.045	0.052 nm	200
b	10 nm	10 nm	N	0.045	0.453 nm	100
z_m	316 nm	5 nm	N	1.414	7.071 nm	4
z_{ref}	30 nm	15 nm	R	1.414	12.247 nm	200
z_n	33 nm	16.50 nm	R	1.414	13.472 nm	200
AF	10 nm	5 nm	R	1.414	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200
REP	4 nm	4 nm	N	1.000	4.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Pt) = 20.4$ nm

Effective degrees of freedom: $v_{eff}(P_t) = 381.1$

Expanded uncertainty: $U(P_t) = 40.9$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.5 Step height standard with a nominal height of 1500 nm - Identification (for Pt)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b}\right)(z_m + z_{ref} + z_n)$$

$$Pt = z_{ko} - z_{ku} + 2\,AF$$

Ptn	:	Depth of the reference setting standard known from PTB certificate
Ptmy	:	Locus dependent fraction of measured reference groove (Measured value of reference standard)
b	:	Reproducibility of tracing of the reference groove
z_m	:	Profile of test standard (Measured value of test standard)
z_{ref}	:	Profile of reference plane (Wt value determined using optical flat)
z_n	:	Background noise (Rz value determined using optical flat)
AF	:	Alingnment error due to roughness and flatness error on the test depth standard
z_{ko}	:	Highest z-value at the top of the profile
z_{ku}	:	Lowest z-value at the bottom of the profile

Combined uncertainty equation:

$$u(P_t) = \sqrt{\frac{2z_m^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + 2\left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n)\right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.201	7.650 nm	200
Ptmy	9870 nm	2 nm	R	0.201	0.233 nm	200
b	10 nm	10 nm	N	0.201	2.013 nm	100
z_m	1405 nm	5 nm	N	1.414	7.071 nm	4
z_{ref}	30 nm	15 nm	R	1.414	12.247 nm	200
z_n	33 nm	16.50 nm	R	1.414	13.472 nm	200
AF	10 nm	5 nm	R	1.414	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200
REP	7 nm	7 nm	N	1.000	7.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Pt)$ = 22.6 nm

Effective degrees of freedom: $v_{\text{eff}}(P_t)$ = 510.2

Expanded uncertainty: $U(P_t)$ = 45.2 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.6 Step height standard with a nominal height of 8000 nm - Identification (for Pt)

Equation used:

$$z_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_m + z_{ref} + z_n)$$

$$Pt = z_{ko} - z_{ku} + 2\,AF$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove (Measured value of reference standard)
b : Reproducibility of tracing of the reference groove
z_m : Profile of test standard (Measured value of test standard)
z_{ref} : Profile of reference plane (Wt value determined using optical flat)
z_n : Background noise (Rz value determined using optical flat)
AF : Alingnment error due to roughness and flatness error on the test depth standard
z_{ko} : Highest z-value at the top of the profile
z_{ku} : Lowest z-value at the bottom of the profile

Combined uncertainty equation:

$$u(P_t) = \sqrt{\frac{2z_m^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + 2\left(u^2(z_m) + u^2(z_{ref}) + u^2(z_n)\right) + 2u^2(AF) + u^2(RES) + u^2(REP)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	1.203	45.731 nm	200
Ptmy	9870 nm	2 nm	R	1.203	1.390 nm	200
b	10 nm	10 nm	N	1.203	12.034 nm	100
z_m	8399 nm	5 nm	N	1.414	7.071 nm	4
z_{ref}	30 nm	15 nm	R	1.414	12.247 nm	200
z_n	33 nm	16.50 nm	R	1.414	13.472 nm	200
AF	10 nm	5 nm	R	1.414	4.083 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200
REP	12 nm	12 nm	N	1.000	12.000 nm	49

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
REP: Repeatibility
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Pt)$ = 52.7 nm

Effective degrees of freedom: $v_{\text{eff}}\,(P_t)$ = 648.8

Expanded uncertainty: $U(P_t)$ = 105.5 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.7 Geometric standard Rub (P114A) - Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b}\right)(z_s + z_n + R_z)$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove
b : Reproducibility of tracing of the reference groove
z_s : Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n : Background noise
R_z : Measured Rz parameter carried out on the test standard
Rz_k : Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.161	6.133 nm	200
Ptmy	9870 nm	2 nm	R	0.161	0.186 nm	200
b	10 nm	10 nm	N	0.161	1.614 nm	100
z_s	36.1 nm	36.1 nm	R	1.000	20.842 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.526 nm	200
R_z	1593 nm	5 nm	N	1.000	5.000 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 24.3$ nm

Effective degrees of freedom: $v_{eff}\,(Rz) = 345.2$

Expanded uncertainty: $U(Rz) = 48.6$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.8 Geometric standard PTB (7070) -Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_s + z_n + R_z)$$

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2} \left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b) \right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.986	37.461 nm	200
Ptmy	9870 nm	2 nm	R	0.986	1.138 nm	200
b	10 nm	10 nm	N	0.986	9.858 nm	100
z_s	69.7 nm	69.7 nm	R	1.000	40.241 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.526 nm	200
R_z	9730 nm	43 nm	N	1.000	43.000 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 71.1$ nm

Effective degrees of freedom: $v_{\text{eff}}(Rz) = 212.1$

Expanded uncertainty: $U(Rz) = 142.3$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.9 Geometric standard PTB (8194) -Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_s + z_n + R_z)$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove
b : Reproducibility of tracing of the reference groove
z_s : Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n : Background noise
R_z : Measured Rz parameter carried out on the test standard
Rz_k : Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.314	11.9 nm	200
Ptmy	9870 nm	2 nm	R	0.314	0.4 nm	200
b	10 nm	10 nm	N	0.314	3.1 nm	100
z_s	41.3 nm	41.3 nm	R	1.000	23.8 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.5 nm	200
R_z	3096 nm	49 nm	N	1.000	49.0 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 56.7$ nm

Effective degrees of freedom: $v_{\text{eff}}(Rz) = 62.0$

Expanded uncertainty: $U(Rz) = 113.9$ nm with a coverage factor k=2.01

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A4 - Uncertainty of measurement
3.10 Roughness standard SFRN 150 (1,006) - Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_s + z_n + R_z)$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove
b : Reproducibility of tracing of the reference groove
z_s : Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n : Background noise
R_z : Measured Rz parameter carried out on the test standard
Rz_k : Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.014	0.531 nm	200
Ptmy	9870 nm	2 nm	R	0.014	0.016 nm	200
b	10 nm	10 nm	N	0.014	0.140 nm	100
z_s	31.5 nm	31.5 nm	R	1.000	18.187 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.526 nm	200
R_z	138 nm	6 nm	N	1.000	6.000 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 21.4$ nm

Effective degrees of freedom: $v_{eff}(Rz) = 335.3$

Expanded uncertainty: $U(Rz) = 42.8$ nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.11 Roughness standard Fine (629f) - Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_s + z_n + R_z)$$

Ptn	:	Depth of the reference setting standard known from PTB certificate
Ptmy	:	Locus dependent fraction of measured reference groove
b	:	Reproducibility of tracing of the reference groove
z_s	:	Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n	:	Background noise
R_z	:	Measured Rz parameter carried out on the test standard
Rz_k	:	Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.127	4.832 nm	200
Ptmy	9870 nm	2 nm	R	0.127	0.147 nm	200
b	10 nm	10 nm	N	0.127	1.272 nm	100
z_s	35 nm	35 nm	R	1.000	20.207 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.526 nm	200
R_z	1255 nm	43.1 nm	N	1.000	43.100 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 48.8$ nm

Effective degrees of freedom: $v_{eff}(Rz) = 57.0$

Expanded uncertainty: $U(Rz) = 98.1$ nm with a coverage factor k=2.01

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Date: .... 11.01.2002 .... Signature:..

A4 - Uncertainty of measurement
3.12 Roughness standard Coarse (633g) - Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right)(z_s + z_n + R_z)$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove
b : Reproducibility of tracing of the reference groove
z_s : Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n : Background noise
R_z : Measured Rz parameter carried out on the test standard
Rz_k : Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ptn	9870 nm	76 nm	N	0.771	29.291 nm	200
Ptmy	9870 nm	2 nm	R	0.771	0.890 nm	200
b	10 nm	10 nm	N	0.771	7.708 nm	100
z_s	61 nm	61 nm	R	1.000	35.218 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.526 nm	200
R_z	7608 nm	192.1 nm	N	1.000	192.100 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 197.9$ nm

Effective degrees of freedom: $v_{eff}(Rz) = 39.4$

Expanded uncertainty: $U(Rz) = 399.7$ nm with a coverage factor k=2.02

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A4 - Uncertainty of measurement
3.13 Roughness standard Very coarse (686sg) - Identification (for Rz, Ra, Rmax)

Equation used:

$$Rz_k = \left(\frac{P_{tn}}{P_{tmy} + b} \right) (z_s + z_n + R_z)$$

Ptn : Depth of the reference setting standard known from PTB certificate
Ptmy : Locus dependent fraction of measured reference groove
b : Reproducibility of tracing of the reference groove
z_s : Unknown systematic deviation. $z_s = a = Rz_{PTB} - Rz_{UME}$
z_n : Background noise
R_z : Measured Rz parameter carried out on the test standard
Rz_k : Calibrated Rz parameter

Combined uncertainty equation:

$$u(R_{z_k}) = \sqrt{\frac{R_z^2}{P_{tn}^2}\left(u^2(P_{tn}) + u^2(P_{tmy}) + u^2(b)\right) + u^2(z_s) + u^2(z_n) + u^2(R_z) + u^2(RES)}$$

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom ν_i
Ptn	9870 nm	76 nm	N	1.449	55.1 nm	200
Ptmy	9870 nm	2 nm	R	1.449	1.7 nm	200
B	10 nm	10 nm	N	1.449	14.5 nm	100
z_s	100 nm	100 nm	R	1.000	57.7 nm	200
z_n	33 nm	16.50 nm	R	1.000	9.5 nm	200
R_z	14300 nm	233.7 nm	N	1.000	233.7 nm	35
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz) = 247.6$ nm

Effective degrees of freedom: $\nu_{eff}(Rz) = 44.0$

Expanded uncertainty: $U(Rz) = 497.6$ nm with a coverage factor k=2.01

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A4 - Uncertainty of measurement
3.14 Geometric standard Rub (114A) - Identification (for RSm)

Equation used:

$$RSm = \frac{RSm_g}{PSm_L}\left(Ac + a_L + a_p + a\right) + RSm_g$$

Ac : Accuracy of HP laser
a_L : Repeatibility of measurements on the reference standard using laser.
a_p : Repeatibility of measurements on the reference standard using Perthometer.
a : The difference between the laser and Perthometer measurement results. (PSm_L - PSm_p)
PSm_L : Mean of the measured lengths of the profile elements using laser on the reference standard
PSm_p : Mean of the measured lengths of the profile elements using Perthometer on the reference standard
RSm_g : Mean of the measured lengths of the profile elements using Perthometer on the test standard

Note 1: We assume that the ratio RSm_g/PSm_L is constant.
Note 2: RSm_g is not corrected with the value ”a”. Instead, the value “a” is taken into account in the uncertainty budget.

Combined uncertainty equation:

$$u(RSm) = \sqrt{\frac{RSm_g^2}{PSm_L^2}\left(u^2(Ac) + u^2(a_L) + u^2(a_P) + u^2(a)\right) + u^2(RSm_g) + u^2(RES)}$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ac	0.12 nm	0.12 nm	N	0.420	0.05 nm	400
a_L	1341 nm	1341 nm	N	0.420	76.6 nm	53
a_p	510.7 nm	510.7 nm	N	0.420	214.4 nm	8
a	1768 nm	1768 nm	R	0.420	428.6 nm	200
RSm_g	49723 nm	75 nm	N	1.000	75 nm	11
RES	110 nm	55 nm	R	1.000	31.8 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz)$ = 492.1 nm

Effective degrees of freedom: v_{eff} (Rz) = 134.4

Expanded uncertainty: $U(Rz)$ = 984.3 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.15 Geometric standard PTB (7070) - Identification (for RSm)

Equation used:

$$RSm = \frac{RSm_g}{PSm_L}\left(Ac + a_L + a_p + a\right) + RSm_g$$

Ac : Accuracy of HP laser
a_L : Repeatability of measurements on the reference standard using laser.
a_p : Repeatability of measurements on the reference standard using Perthometer.
a : The difference between the laser and Perthometer measurement results. (PSm_L - PSm_p)
PSm_L : Mean of the measured lengths of the profile elements using laser on the reference standard
PSm_p : Mean of the measured lengths of the profile elements using Perthometer on the reference standard
RSm_g : Mean of the measured lengths of the profile elements using Perthometer on the test standard

Note 1: We assume that the ratio RSm_g/PSm_L is constant.
Note 2: RSm_g is not corrected with the value ”a”. Instead, the value “a” is taken into account in the uncertainty budget.

Combined uncertainty equation:

$$u(RSm) = \sqrt{\frac{RSm_g^2}{PSm_L^2}\left(u^2(Ac) + u^2(a_L) + u^2(a_P) + u^2(a)\right) + u^2(RSm_g) + u^2(RES)}$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ac	0.12 nm	0.12 nm	N	1.677	0.2 nm	400
a_L	1341 nm	1341 nm	N	1.677	306.1 nm	53
a_p	510.7 nm	510.7 nm	N	1.677	856.6 nm	8
a	1768 nm	1768 nm	R	1.677	1712.1 nm	200
RSm_g	198617 nm	21 nm	N	1.000	21.0 nm	11
RES	1000 nm	500 nm	R	1.000	288.7 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz)$ = 1960.2 nm

Effective degrees of freedom: v_{eff} (Rz) = 133.7

Expanded uncertainty: $U(Rz)$ = 3920.4 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.16 Geometric standard PTB (8194) - Identification (for RSm)

Equation used:

$$RSm = \frac{RSm_g}{PSm_L}\left(Ac + a_L + a_p + a\right) + RSm_g$$

Ac	:	Accuracy of HP laser
a_L	:	Repeatibility of measurements on the reference standard using laser.
a_p	:	Repeatibility of measurements on the reference standard using Perthometer.
a	:	The difference between the laser and Perthometer measurement results. (PSm_L - PSm_p)
PSm_L	:	Mean of the measured lengths of the profile elements using laser on the reference standard
PSm_p	:	Mean of the measured lengths of the profile elements using Perthometer on the reference standard
RSm_g	:	Mean of the measured lengths of the profile elements using Perthometer on the test standard

Note 1: We assume that the ratio RSm_g/PSm_L is constant.
Note 2: RSm_g is not corrected with the value ”a”. Instead, the value “a” is taken into account in the uncertainty budget.

Combined uncertainty equation:

$$u(RSm) = \sqrt{\frac{RSm_g^2}{PSm_L^2}\left(u^2(Ac) + u^2(a_L) + u^2(a_P) + u^2(a)\right) + u^2(RSm_g) + u^2(RES)}$$

quantity X_i	Estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
Ac	0.12 nm	0.12 nm	N	1.006	0.12 nm	400
a_L	1341 nm	1341 nm	N	1.006	183.6 nm	53
a_p	510.7 nm	510.7 nm	N	1.006	513.8 nm	8
a	1768 nm	1768 nm	R	1.006	1027.1 nm	200
RSm_g	119149 nm	29 nm	N	1.000	29.0 nm	11
RES	350 nm	175 nm	R	1.000	101.0 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rz)$ = 1167.8 nm

Effective degrees of freedom: v_{eff} (Rz) = 130.0

Expanded uncertainty: $U(Rz)$ = 2335.5 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.17 Roughness standard SFRN 150 (1.006) - Identification (for Rk, Rpk, Rvk)

Equation used:

$$R_k = \frac{\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}$$

z_i : Profile height of i^{th} point in the central region of material ratio curve
Mr_i : Material ratio of i^{th} point in the central region of material ratio curve
N : Number of points which are used to calculate the secant in the central region of material ratio curve using least square method.

Combined uncertainty equation:

$$u(R_k) = \sqrt{0{,}728u^2(z_k) + 0{,}00347u^2(Mr) + u^2(RES)}$$

Note 1: Please see Appendix 1 for detail explanation of above equation
Note 2: Uncertainty calculations for z_k are given in Excel sheets in Appendix 2

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
z_k	138 nm	41.8 nm	N	0.853	36.209 nm	286
Mr	50 %	10 %	N	0.059 nm	0.006 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
Note: Uncertainty of Mr are not calculated. The effect of the uncertainty of Mr is very small. The difference between the combined uncertainties for u(Mr)=0 and u(Mr)=100% is less than 1%. u(Mr) is estimated to be 10%.
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rk)$ = 36.2 nm

Effective degrees of freedom: v_{eff} (Rk) = 16055.3

Expanded uncertainty: $U(Rk)$ = 72.4 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.18 Roughness standard Fine (629f) - Identification (for Rk, Rpk, Rvk)

Equation used:

$$R_k = \frac{\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}$$

z_i : Profile height of i th point in the central region of material ratio curve
Mr_i : Material ratio of i th point in the central region of material ratio curve
N : Number of points which are used to calculate the secant in the central region of material ratio curve using least square method.

Combined uncertainty equation:

$$u(R_k) = \sqrt{0{,}728u^2(z_k) + 0{,}147u^2(Mr) + u^2(RES)}$$

Note 1: Please see Appendix 1 for detail explanation of above equation
Note 2: Uncertainty calculations for z_k are given in Excel sheets in Appendix 2

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
z_k	1255 nm	79.7136 nm	N	0.853	68.012 nm	20.5
Mr	50 %	10 %	N	0.383 nm	0.038 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
Note: Uncertainty of Mr are not calculated. The effect of the uncertainty of Mr is very small. The difference between the combined uncertainties for u(Mr)=0 and u(Mr)=100% is less than 1%. u(Mr) is estimated to be 10%.
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rk)$ = 68.0 nm

Effective degrees of freedom: v_{eff} (Rk) = 1150.8

Expanded uncertainty: $U(Rk)$ = 136.0 nm with a coverage factor k=2

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A4 - Uncertainty of measurement

3.19 Roughness standard Coarse (633g) - Identification (for Rk, Rpk, Rvk)

Equation used:

$$R_k = \frac{\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}$$

z_i : Profile height of i th point in the central region of material ratio curve
Mr_i : Material ratio of i th point in the central region of material ratio curve
N : Number of points which are used to calculate the secant in the central region of material ratio curve using least square method.

Combined uncertainty equation:

$$u(R_k) = \sqrt{0{,}728u^2(z_k) + 14{,}507u^2(Mr) + u^2(RES)}$$

Note 1: Please see Appendix 1 for detail explanation of above equation
Note 2: Uncertainty calculations for z_k are given in Excel sheets in Appendix 2

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
z_k	7608 nm	306.5 nm	N	0.853	261.5 nm	11.4
Mr	50 %	10 %	N	3.809 nm	0.381 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
Note: Uncertainty of Mr are not calculated. The effect of the uncertainty of Mr is very small. The difference between the combined uncertainties for u(Mr)=0 and u(Mr)=100% is less than 1%. u(Mr) is estimated to be 10%.
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rk)$ = 261.5 nm

Effective degrees of freedom: $v_{\mathrm{eff}}\,(Rk)$ = 640.0

Expanded uncertainty: $U(Rk)$ = 523.0 nm with a coverage factor k=2

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A4 - Uncertainty of measurement
3.20 Roughness standard Very coarse (686sg) - Identification (for Rk, Rpk, Rvk)

Equation used:

$$R_k = \frac{\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}$$

z_i : Profile height of i th point in the central region of material ratio curve
Mr_i : Material ratio of i th point in the central region of material ratio curve
N : Number of points which are used to calculate the secant in the central region of material ratio curve using least square method.

Combined uncertainty equation:

$$u(R_k) = \sqrt{0{,}728u^2(z_k) + 48{,}202u^2(Mr) + u^2(RES)}$$

Note 1: Please see Appendix 1 for detail explanation of above equation
Note 2: Uncertainty calculations for z_k are given in Excel sheets in Appendix 2

quantity X_i	estimate x_i	uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(d)$	degrees of freedom v_i
z_k	14300 nm	371.8 nm	N	0.853	317.2 nm	11.3
Mr	50 %	10 %	N	6.943 nm	0.694 nm	200
RES	0.42 nm	0.21 nm	R	1.000	0.121 nm	200

N = normal; R = rectangular; T = triangular; U = U-shaped.
RES: Resolution
Note: Uncertainty of Mr are not calculated. The effect of the uncertainty of Mr is very small. The difference between the combined uncertainties for u(Mr)=0 and u(Mr)=100% is less than 1%. u(Mr) is estimated to be 10%.
(Please see the Excel sheet)

Combined standard uncertainty: $u_c(Rk)$ = 317.2 nm

Effective degrees of freedom: $v_{\text{eff}}(Rk)$ = 634.4

Expanded uncertainty: $U(Rk)$ = 634.4 nm with a coverage factor k=2

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A4 - Uncertainty of measurement

3.21 Roughness standard SFRN 150 (1.006) - Fine (629f) – Coarse (633g) – Very coarse (686sg) - Identification (for Mr_1, Mr_2)

Uncertainty of Mr_1 and Mr_2 was not calculated. Instead, we assume that the relative uncertainty of Rk with respect to Rz is valid for Mr_1 and Mr_2 parameters.

Standard	Rz (nm)	U(Rk) (nm) k=2	$\frac{U(R_k)}{R_z}$	Mr_1 (%)	$U(Mr_1)$ (%) k=2	Mr_2 (%)	$U(Mr_2)$ (%) k=2
SFRN 150 (1.006)	138	72.4	0.525	12.606	6.618	83.232	43.697
Fine (629f)	1255	136.0	0.108	8.982	0.970	88.158	9.521
Coarse (633g)	7608	523.0	0.069	6.196	0.428	81.968	5.656
Very coarse (686sg)	14300	634.4	0.044	6.948	0.306	92.850	4.085

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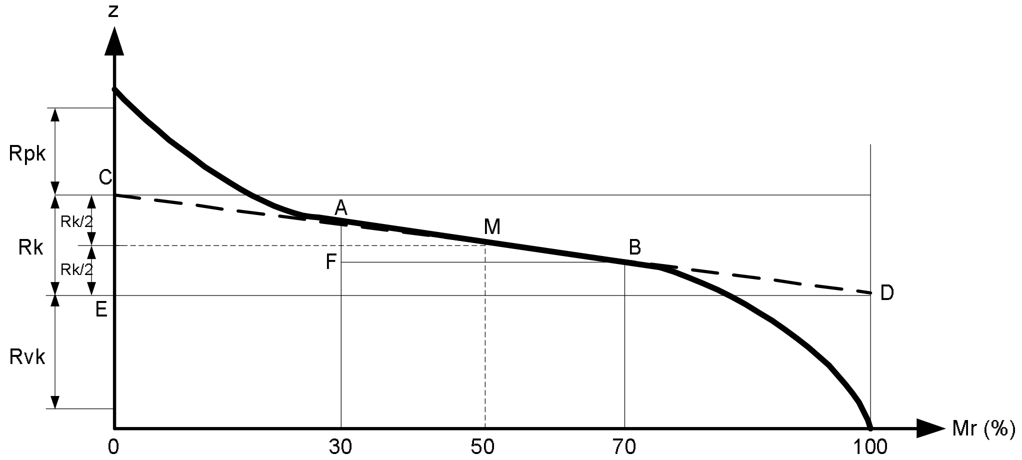
APPENDIX 1
A Model For Calculation of Uncertainty of Rk, Rpk, Rvk Parameters

The following uncertainty calculation is performed for Rk parameter. It can also be applied for R_{pk} and R_{vk} parameters.

According to ISO 13565-2, a line (secant) is fitted to the central region of material ratio curve in order to obtain R_k, R_{pk} and R_{vk} parameters. The length in horizontal projection of the secant is 40 %. The gradient of the secant is the smallest of the gradients of all secants which have the leng in horizontal projection th in horizontal projection 40 % .



Assumptions:

1) The secant AB which is fitted to the central region is on the center of the whole curve. So the abscissae of the middle point of the secant is Mr_M = 50 % (Mr_A = 30 % and Mr_B = 70 %)
2) z ordinate of middle point M of the secant is

$$z_M^* \cong R_{vk} + \frac{R_k}{2}$$

3) Vertical measuring range of the probe MFW-250 is ± 25 µm. This renge is sampled by 60000 steps. So it is assumed that at least 100 points can be used to do sampling in horizontal axis in calculation of Rk for almost all range of standards given. Therefore 100 points are used to calculate the least square best fit line.

There are N points between A and B points. 1st order polinomial (the secant) is following:

$$z^* = c_1 Mr + c_2 \qquad (1)$$

From the similarity of the triangles CED and AFB, following equation can be written:

$$\frac{R_k}{100\%} = \frac{z_A^* - z_B^*}{40\%} \tag{2}$$

z_A^* : Starting point of secant
z_B^* : End point of secant

When we substitute Eq(1) into Eq(2) we obtain:

$$\frac{R_k}{100\%} = \frac{(c_1 Mr_A + c_2) - (c_1 Mr_B + c_2)}{40\%}$$

$$\frac{R_k}{100\%} = \frac{c_1(Mr_A - Mr_B) + c_2 - c_2}{40\%}$$

$$R_k = c_1 \tag{3}$$

If we can determine c_1, Rk can be found as well as with its uncertainty. The secant can be determined (i.e. c_1 and c_2 in Eq.1) using “least square method”. The main formula for least square method is written as following:

$$F = \sum_{i=1}^{N} (z_i^* - z_i)^2 \tag{4}$$

z_i^*:Ordinate of i th point of fitted polynomial
z_i : Ordinate of i th point of the central region of material ratio curve
F : Sum of the square of the differences

There are two unknowns c_1 and c_2 in Eq.1 . For “F” be minimum, derivetives of F with respect to c_1 and c_2 must be zero. Thus,

$$\frac{\partial F}{\partial c_1} = 0 \qquad \Rightarrow \qquad 2\sum_{i=1}^{N} (c_1 Mr_i + c_2 - z_i) Mr_i = 0 \tag{5}$$

$$\frac{\partial F}{\partial c_2} = 0 \qquad \Rightarrow \qquad 2\sum_{i=1}^{N}(c_1 Mr_i + c_2 - z_i) = 0 \tag{6}$$

If we obtain c_2 from Eq.6 and substitute into Eq.5, we obtain:

$$c_1\sum_{i=1}^{N} Mr_i^2 + \frac{1}{N}\left[\sum_{i=1}^{N} z_i - c_1\sum_{i=1}^{N} Mr_i\right]\sum_{i=1}^{N} Mr_i - \sum_{i=1}^{N} z_i Mr_i = 0$$

After a simple arrangement we obtain:

$$R_k = c_1 = \frac{\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2} \tag{7}$$

Combined uncertainty of R_k :

$$u^2(R_k) = \left[\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial z_i}\right)^2\right]u^2(z_i) + \left[\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial Mr_i}\right)^2\right]u^2(Mr_i) \tag{8}$$

$$u^2(R_k) = \left(\frac{\mathrm{Mr}_1 - \frac{1}{N}\sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}\right)^2 u^2(z_1) + \left(\frac{\mathrm{Mr}_2 - \frac{1}{N}\sum_{i=1}^{N} Mr_i}{\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2}\right)^2 u^2(z_2) + \ldots\ldots$$

$$\ldots\ldots + \left(\frac{\left(\mathrm{z}_1 - \frac{1}{N}\sum_{i=1}^{N} z_i\right)\left(\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2\right)^2 - \left(2\,\mathrm{Mr}_1 - \frac{2}{N}\sum_{i=1}^{N} Mr_i\right)\left(\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i\right)}{\left(\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2\right)^2}\right)^2 u^2(Mr_1) + \ldots$$

$$\ldots\ldots + \left(\frac{\left(\mathrm{z}_2 - \frac{1}{N}\sum_{i=1}^{N} z_i\right)\left(\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2\right)^2 - \left(2\,\mathrm{Mr}_2 - \frac{2}{N}\sum_{i=1}^{N} Mr_i\right)\left(\sum_{i=1}^{N} z_i Mr_i - \frac{1}{N}\sum_{i=1}^{N} z_i \sum_{i=1}^{N} Mr_i\right)}{\left(\sum_{i=1}^{N} Mr_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} Mr_i\right)^2\right)^2}\right)^2 u^2(Mr_2) + \ldots\ldots$$

. (9)

Above coefficients are calculated for 4 different roughness standard by using a QBASIC computer program. The coefficients for N = 101 points are following:

Standard	$\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial z_i}\right)^2$	$\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial z_i}\right)^4$	$\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial Mr_i}\right)^2$	$\sum_{i=1}^{N}\left(\frac{\partial R_k}{\partial Mr_i}\right)^4$
686sg	0.728	0.00944	48.202	41.40
633g	0.728	0.00944	14.507	3.75
629f	0.728	0.00944	0.147	0.000384
1.006	0.728	0.00944	0.00347	0.000000214

Note: 4th order coefficients are used for calculation of effective degrees of freedom.

Verifying whether the extreme point of "F" function is a minimum or not

Second derivatives of F function:

$$f''_{c_1c_1} = \frac{\partial^2 F}{\partial c_1^2} = 2\sum_{i=1}^{N} Mr_i^2$$

Always positive

$$f''_{c_2c_2} = \frac{\partial^2 F}{\partial c_1^2} = 2N$$

Always positive

$$f''_{c_1c_2} = \frac{\partial^2 F}{\partial c_1^2} = 0$$

Discriminant:

$$D = \left(f''_{c_1c_2}\right)^2 - f''_{c_1c_1} f''_{c_2c_2}$$

Always negative

Because $f''_{c_1c_1}$ *is positive, the point is* ***real minimum***.

UME

(Only part of the comment related to changes of the uncertainty)
1) We calibrated our roughness instrument by using PTB calibrated depth setting standard with six grooves. We used only the deepest groove (Pt = 9870 and D = 9820 nm). The relative uncertainty is % 0.305 . Our uncertainty for R6 groove (D = 8363 nm) of the depth standard EN 806 is 25.6 nm, our relative uncertainty is % 0.306 (Section 3.1–3.3, P:8–10 in UME Report Appendix B1 in Draft A) . As can be seen, our relative uncertainty in the comparison is equal to the uncertainty of our reference standard. This is caused by an error in the uncertainty model used for D parameter. In the model, z values of measured profile were being averaged according to the assumption of randomly distributed z-values. We applied this for the uncertainty of reference standards as well as for our measurements on the sample. But Dr. Koenders explained that the uncertainty of our reference standard was systematic not random. So we can not apply averaging for the uncertainty of reference standard. The corrected uncertainty equations and the budgets for D parameters can be seen in the attachment. According to the equations in the attachment, uncertainties for D parameters were recalculated. The results are as following:

Groove R1 (D = 282 nm), U(D) = 20.2 nm (k = 2)
Groove R3 (D = 1364 nm), U(D) = 24.4 nm (k = 2)
Groove R6 (D = 8363 nm), U(D) = 70.8 nm (k = 2)

2) We calculated the uncertainty only for Rz parameter (Section 3.7–3.13, P:14–20 in UME Report Appendix B1 in Draft A) . And we used this calculated absolute uncertainty for Ra and Rz1max in order to be on a safe side, because background noise level is high in our laboratory (Rzo = 33nm). But our uncertainties for Ra parameters seem very large when compared to other countries in the comparison. So we think that two uncertainty contributions should be changed in the budget. One of them is the systematic deviation (the difference between UME and PTB) and the other is standard deviation of the parameter on the surface. The systematic deviation may be calculated for Ra instead of Rz. Standard deviation of Ra may be used instead of Rz on the surface. The corrected model equation, the uncertainty equation and the budget can be seen in the attachment. According to the equations in the attachment, uncertainties for Ra parameters were calculated. The results are as following:

Geometric Standard P114A	(Ra = 505 nm),	U(Ra) = 20.0 nm (k = 2)
Geometric Standard 7070	(Ra = 2978 nm),	U(Ra) = 46.0 nm (k = 2)
Geometric Standard 8194	(Ra = 901 nm),	U(Ra) = 25.2 nm (k = 2)
Roughness Standard 686sg	(Ra = 2346 nm),	U(Ra) = 73.4 nm (k = 2)
Roughness Standard 633g	(Ra = 1533 nm),	U(Ra) = 30.8 nm (k = 2)
Roughness Standard 629f	(Ra = 147 nm),	U(Ra) = 20.0 nm (k = 2)
Roughness Standard 1.006	(Ra = 24 nm),	U(Ra) = 19.4 nm (k = 2)

Appendix B2

MEASUREMENT RESULTS

Euromet
Project 600
Surface Texture

Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

14.12.2001

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value		0,285											
4			std. dev.		3,5											
5			Meas. Unc.		12											
6	R3	1,5 µm	value		1,366											
7			std. dev.		3,8											
8			Meas. Unc.		15											
9	R6	8 µm	value		8,357											
10			std. dev.		13											
11			Meas. Unc.		58											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value													
15			std. dev.													
16			Meas. Unc.													
17	PTB	7070/PGN10	value													
18			std. dev.													
19			Meas. Unc.													
20	PTB	8194/PGN3	value													
21			std. dev.													
22			Meas. Unc.													
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value													
27			std. dev.													
28			Meas. Unc.													
29	coarse	633g	value													
30			std. dev.													
31			Meas. Unc.													
32	fine	629f	value													
33			std. dev.													
34			Meas. Unc.													
35	SFRN 150	1.006	value													
36			std. dev.													
37			Meas. Unc.													

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Laboratory: BEV

Origin of template:
PTB Germany

Euromet
Project 600
Surface Texture

Results and Measurement Conditions
Measurement values in µm,
std -deviation and 2k-meas -uncertainty in nm

25.03.2003

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		**EN 806**										mm	µm	mm/s	mN	µm
3	**R1**	0,2 µm	value	**0,284**	**0,277**									0,1	**0,9**	0,5
4			std. dev.	**2**	**3**											
5			Meas. Unc.	**10**	**10**											
6	**R3**	1,5 µm	value	**1,360**	**1,358**									0,1	**0,9**	0,5
7			std. dev.	**0**	**2**											
8			Meas. Unc.	**10**	**10**											
9	**R6**	8 µm	value	**8,329**	**8,315**									0,1	**0,9**	0,5
10			std. dev.	**8**	**10**											
11			Meas. Unc.	**12**	**12**											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	**P114A/528-RS 5**	value	0,491	1,575	1,588	49,536					0,25	2,5	0,5	0,4	0,5
15			std. dev.	2	7	10	13,42									
16			Meas. Unc.	3,97	34,07	107,26	2860									
17	PTB	**7070/PGN10**	value	2,909	9,476	9,627	197,853					2,5	8	0,5	0,4	1,5
18			std. dev.	7	39	60	33									
19			Meas. Unc.	169,32	181,9	735,21	3807,69									
20	PTB	**8194/PGN3**	value	0,894	3,091	3,113	118,719					0,8	2,5	0,5	0,4	0,5
21			std. dev.	7,5	50,9	55,6	46,2									
22			Meas. Unc.	27,33	105,96	215,11	6854,25									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	**686sg**	value	2,303	14,046	15,297	7,93	1,275	3,11	8,065	92,839	2,5	8	0,5	0,4	1,5
27			std. dev.	31	195	47	237	95	193	1,011	0,665					
28			Meas. Unc.	169,41	189,75	1128,65	70	30	57	0,382	0,461					
29	coarse	**633g**	value	1,487	7,397	8,743	4,32	0,733	2,433	6,31	81,8	0,8	2,5	0,5	0,4	0,5
30			std. dev.	9,4	195	128	66	34	46	0,221	0,347					
31			Meas. Unc.	48,17	125,28	667,3	115	112	113	0,261	0,339					
32	fine	**629f**	value	0,146	1,248	1,428	0,442	0,133	0,29	9,33	87,69	0,8	2,5	0,5	0,4	0,5
33			std. dev.	3	45	99	8	6	10	0,494	0,461					
34			Meas. Unc.	11,89	102,85	224,6	23	15	17	0,288	0,332					
35	**SFRN 150**	1.006	value	0,02352	0,13329	0,1729	0,07256	0,0261	0,02983	11,86	86,42	0,25	2,5	0,1	0,4	0,5
36			std. dev.	0,55	4,5	16,6	3,25	1,17	2,07	0,683	0,688					
37			Meas. Unc.	25,66	31,45	36,99	26	27	29	0,2	0,2					

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Origin of template:
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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,307	0,286							none	none	0,05	1	0,1
4			std. dev./nm	5	4											
5			U/nm (k=2)	34	34											
6	R3	1,5 µm	value/µm	1,387	1,361							none	none	0,05	1	0,1
7			std. dev./nm	8	5											
8			U/nm (k=2)	43	43											
9	R6	8 µm	value/µm	8,404	8,356							none	none	0,05	1	0,1
10			std. dev./nm	16	14											
11			U/nm (k=2)	69	68											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,510	1,60	1,61	48					0,25	2,5	0,05	1	0,2
15			std. dev./nm	2	6	11	191									
16			U/nm (k=2)	35	45	46	648									
17	PTB	7070/PGN10	value/µm	2,94	9,60	9,77	198					2,5	8	0,1	1	1,5
18			std. dev./nm	10	34	84	140									
19			U/nm (k=2)	55	70	84	1376									
20	PTB	8194/PGN3	value/µm	0,901	3,07	3,09	118					0,8	2,5	0,1	1	0,5
21			std. dev./nm	10	48	50	1052									
22			U/nm (k=2)	51	64	65	1125									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,34	14,3	15,8	8,20	1,21	3,25	6,7	92,8	2,5	8	0,1	1	1,5
27			std. dev./nm	19	326	91	109	53	250	0,6	0,3					
28			U/nm (k=2)	57	200	86	86	64	155	2	2					
29	coarse	633g	value/µm	1,52	7,45	8,88	4,47	0,70	2,46	5,8	81,9	0,8	2,5	0,05	1	0,5
30			std. dev./nm	4	88	259	19	15	19	0,1	0,2					
31			U/nm (k=2)	55	84	164	59	56	57	2	2					
32	fine	629f	value/µm	0,152	1,24	1,40	0,464	0,137	0,299	8,5	87,9	0,8	2,5	0,05	1	0,5
33			std. dev./nm	4	41	91	12	7	12	0,7	0,4					
34			U/nm (k=2)	35	51	69	39	35	39	2	2					
35	SFRN 150	1.006	value/µm	0,026	0,137	0,173	0,076	0,028	0,032	11,9	86,6	0,25	2,5	0,05	1	0,2
36			std. dev./nm	1	6	8	6	3	2	1,1	1					
37			U/nm (k=2)	15	29	29	19	14	14	2	2					

Results and Measurement Conditions
Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,195	0,174							0,06		0,1	0,75	0,03
4			std. dev./nm	7	5											
5			U/nm (k=2)	72	90											
6	R3	1,5 µm	value/µm	1,422	1,385							0,1		0,1	0,75	0,05
7			std. dev./nm	29	17											
8			U/nm (k=2)	92	120											
9	R6	8 µm	value/µm	8,353	8,328							0,2		0,1	0,75	0,1
10			std. dev./nm	21	23											
11			U/nm (k=2)	130	114											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,499	1,580	1,598	50,2					0,25	2,5	0,5	0,75	0,13
15			std. dev./nm	2	7	11	1100									
16			U/nm (k=2)	24	128	154	12200									
17	PTB	7070/PGN10	value/µm	2,940	9,547	9,654	200,0					2,5	8	0,5	0,75	1,3
18			std. dev./nm	10	27	52	0									
19			U/nm (k=2)	172	248	288	4400									
20	PTB	8194/PGN3	value/µm	0,894	3,056	3,073	119,8					0,8	2,5	0,5	0,75	0,42
21			std. dev./nm	8	47	50	1700									
22			U/nm (k=2)	46	264	356	4200									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,328	13,597	15,328	8,027	1,226	3,214	7,6	92,7	2,5	8	0,5	0,75	1,3
27			std. dev./nm	35	438	62	242	59	362	0,8	0,9					
28			U/nm (k=2)	174	354	310	1698	212	260	1,2	2,2					
29	coarse	633g	value/µm	1,513	7,302	8,941	4,359	0,863	2,619	5,5	81,7	0,8	2,5	0,5	0,75	0,42
30			std. dev./nm	23	208	133	125	65	152	0,3	0,6					
31			U/nm (k=2)	174	276	316	1694	212	176	1,0	2,2					
32	fine	629f	value/µm	0,142	1,172	1,342	0,435	0,130	0,309	8,8	88,3	0,8	2,5	0,5	0,75	0,42
33			std. dev./nm	3	55	91	9	7	18	0,6	0,7					
34			U/nm (k=2)	18	132	202	52	14	42	0,6	1,2					
35	SFRN 150	1.006	value/µm	0,025	0,146	0,176	0,074	0,031	0,034	11,6	87,1	0,25	2,5	0,5	0,75	0,13
36			std. dev./nm	1	9	14	5	5	6	1,9	1,7					
37			U/nm (k=2)	18	128	196	52	14	22	1,2	1,4					

Euromet
Project 600
Surface Texture

Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

28.06.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,287	0,266									0,5	<1	0,25
4			std. dev./nm	2,4	2,7											
5			U/nm (k=2)	34	12											
6	R3	1,5 µm	value/µm	1,379	1,355									0,5	<1	0,25
7			std. dev./nm	2,9	2,3											
8			U/nm (k=2)	39	18											
9	R6	8 µm	value/µm	8,312	8,283									0,5	<1	0,25
10			std. dev./nm	6,8	5,8											
11			U/nm (k=2)	73	47											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,500	1,576	1,589	50,03					0,25	2,5	0,5	<1	0,25
15			std. dev./nm	1,5	4,8	10,7	9,8									
16			U/nm (k=2)	29	32	32	300									
17	PTB	7070/PGN10	value/µm	2,944	9,614	9,808	199,94					2,5	8	0,5	<1	0,25
18			std. dev./nm	12,4	45,5	57,6	19,6									
19			U/nm (k=2)	38	91	92	300									
20	PTB	8194/PGN3	value/µm	0,891	3,061	3,081	119,99					0,8	2,5	0,5	<1	0,25
21			std. dev./nm	6,5	53,5	5,7	29,1									
22			U/nm (k=2)	31	42	39	300									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,321	14,22	15,38	8,051	1,390	3,21	7,21	91,7	2,5	8	0,5	<1	0,25
27			std. dev./nm	21,1	291,8	30,0	56,2	51,7	339,2	0,37	0,54					
28			U/nm (k=2)	35	160	140	72	35	120	1	1					
29	coarse	633g	value/µm	1,500	7,473	8,752	4,371	0,833	2,735	6,5	79,5	0,8	2,5	0,5	<1	0,25
30			std. dev./nm	2,1	146,7	89,1	136,2	52,1	113,0	0,5	0,4					
31			U/nm (k=2)	32	84	86	64	35	52	1	1					
32	fine	629f	value/µm	0,147	1,252	1,423	0,456	0,162	0,302	8,3	87,5	0,8	2,5	0,5	<1	0,25
33			std. dev./nm	2,1	34,2	75,0	15,9	9,2	18,2	0,49	0,61					
34			U/nm (k=2)	30	33	40	31	30	31	2	2					
35	SFRN 150	1.006	value/µm	0,024	0,138	0,171	0,075	0,028	0,032	10,8	81,4	0,25	2,5	0,5	<1	0,25
36			std. dev./nm	0,6	3,2	9,7	3,2	2,9	4,4	1,35	1,25					
37			U/nm (k=2)	19	19	19	19	19	19	5,8	5,8					

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Results and Measurement Conditions

Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

Date:_2001/11/07

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value	0,314	0,29									0,5	0,75	0,5
4			std. dev.	5	7											
5			Meas. Unc.	17	17											
6	R3	1,5 µm	value	1,395	1,376									0,5	0,75	0,5
7			std. dev.	5	7											
8			Meas. Unc.	30	30											
9	R6	8 µm	value	8,419	8,402									0,5	0,75	0,5
10			std. dev.	9	9											
11			Meas. Unc.	60	60											
12																
13	Geom. Standard			Ra	Rz	(Rmax) Rt	RSm									
14	Rub	P114A/528-RS 5	value	0,504	1,598	1,609	50,04					0,25	2,5	0,5	0,75	0,25
15			std. dev.	1	6	12	12									
16			Meas. Unc.	16	64	65	500									
17	PTB	7070/PGN10	value	2,962	9,735	9,767	199,98					2,5	8	0,5	0,75	0,25
18			std. dev.	14	66	66	21									
19			Meas. Unc.	89	389	391	2000									
20	PTB	8194/PGN3	value	0,903	3,098	3,112	120,02					0,8	2,5	0,5	0,75	0,25
21			std. dev.	7	51	51	48									
22			Meas. Unc.	28	124	125	1200									
23																
24	Roughn.standard			Ra	Rz	(Rmax) Rt	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value	2,335	14,308	15,568	8,23	1,38	3,51	6,90	93,20	2,5	8	0,5	0,75	0,25
27			std. dev.	25	25	40	218	94	297	0,9	0,8					
28			Meas. Unc.	94	715	778	412	69	176	1,5	1,5					
29	coarse	633g	value	1,516	7,684	8,842	4,42	0,91	2,79	5,60	81,70	0,8	2,5	0,5	0,75	0,25
30			std. dev.	2	113	91	113	77	135	0,5	0,5					
31			Meas. Unc.	61	384	442	221	46	140	1,5	1,5					
32	fine	629f	value	0,146	1,299	1,512	0,46	0,14	0,32	8,40	88,40	0,8	2,5	0,5	0,75	0,25
33			std. dev.	3	34	49	15	15	12	1	0,9					
34			Meas. Unc.	8	65	76	24	10	17	1,5	1,5					
35	SFRN 150	1.006	value	0,0250	0,1460	0,2030	0,08	0,04	0,03	12,90	86,70	0,25	2,5	0,5	0,75	0,25
36			std. dev.	1	4	15	6	6	4	1,8	1,2					
37			Meas. Unc.	5,09901951	10,1138519	12,3297405	7,9649231	7,21543484	7,20347139	2	2					

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Laboratory:
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Results and Measurement Conditions

Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,301	0,283									0,025 / 0,0025	0,03	0,1
4			std. dev./nm	9	3,2											
5			U/nm (k=2)	16	5,5											
6	R3	1,5 µm	value/µm	1,382	1,367									0,025	0,045	0,3
7			std. dev./nm	6	3,4											
8			U/nm (k=2)	27	8											
9	R6	8 µm	value/µm	8,382	8,357									0,025	0,055	0,3
10			std. dev./nm	10	9,8											
11			U/nm (k=2)	42	28											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,508	1,596	1,61						0,25	1	0,025	0,045	1
15			std. dev./nm	1,3	5,7	15,2										
16			U/nm (k=2)	11	49	66										
17	PTB	7070/PGN10	value/µm													
18			std. dev./nm													
19			U/nm (k=2)													
20	PTB	8194/PGN3	value/µm													
21			std. dev./nm													
22			U/nm (k=2)													
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm													
27			std. dev./nm													
28			U/nm (k=2)													
29	coarse	633g	value/µm													
30			std. dev./nm													
31			U/nm (k=2)													
32	fine	629f	value/µm													
33			std. dev./nm													
34			U/nm (k=2)													
35	SFRN 150	1.006	value/µm	0,0259	0,148	0,2037						0,25	1	0,025	0,025	1
36			std. dev./nm	0,8	3,7	4,4										
37			U/nm (k=2)	3	8	10										

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Surface Texture

Results and Measurement Conditions
Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

16.12.2002

Depth standard			Pt	D							lambda-c	lambda-s***	Speed	Force	Sampl-dist***
	EN 806										mm	µm	mm/s		µm
R1	0,2 µm	value	0,34								0,08		0,1		
		std. dev.	10,00												
		Meas. Unc.	119,18												
R3	1,5 µm	value	1,49								0,08		0,1		
		std. dev.	20,00												
		Meas. Unc.	144,00												
R6	8 µm	value	8,83								0,08		0,1		
		std. dev.	20,00												
		Meas. Unc.	124,12												
Geom. Standard			Ra	Rz	Rz1max	RSm									
Rup	1114A/528-RS 5	value	0,50	1,62	1,63	49,84					0,25	2,5	0,1		0,5
		std. dev.	0,00	10,00	10,00	560,00									
		Meas. Unc.	40,82	73,26	77,89	1124,51									
PTB	7070/PGN10	value	2,96	9,69	9,85	198,41					2,5	8	0,5		1,5
		std. dev.	10,00	40,00	70,00	0,00									
		Meas. Unc.	48,3	116,05	159,79	1847,95									
PTB	8194/PGN3	value	0,90	3,14	3,16	119,70					0,8	2,5	0,5		0,5
		std. dev.	10,00	50,00	50,00	1850,00									
		Meas. Unc.	45,46	124,37	127,15	3736,52									
Roughn.standard			Ra	Rz	Rz1max*	Rk*	Rpk*	Rvk*	Mr1* [%]	Mr2* [%]					
very coarse	686sg	value	2,37	14,75	15,86	8,25	1,29	3,30	7,31	93,04	2,5	8	0,5		1,5
		std. dev.	30,00	270,00	30,00	150,00	80,00	170,00	0,67	0,31					
		Meas. Unc.	73,26	544,67	125,57	304,41	166,23	343,75							
coarse	633g	value	1,53	7,66	9,08	4,48	0,75	2,50	6,08	81,83	0,8	2,5	0,5		0,5
		std. dev.	0,00	180,00	100,00	30,00	20,00	20,00	0,13	0,18					
		Meas. Unc.	42,03	375,59	221,28	83,27	58,88	62,18							
fine	629f	value	0,15	1,32	1,51	0,47	0,15	0,3	8,66	87,53	0,8	2,5	0,5		0,5
		std. dev.	0,00	50,00	110,00	10,00	10,00	10,00	0,46	0,40					
		Meas. Unc.	40,82	122,20	232,74	50,33	46,16	46,19							
SFRN 150	1.006	value	0,03	0,17	0,22	0,08	0,03	0,04	10,13	86,58					
		std. dev.	0,00	0,00	20,00	10,00	0,00	10,00	0,89	1,14					
		Meas. Unc.	40,41	70,24	85,05	50,33	41,63	46,19							

Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,321	0,304								2,5	0,5	<1	
4			std. dev./nm	17	13								2,5	0,5	<1	
5			U/nm (k=2)	20	17								2,5	0,5	<1	
6	R3	1,5 µm	value/µm	1,408	1,383								2,5	0,5	<1	
7			std. dev./nm	9	3								2,5	0,5	<1	
8			U/nm (k=2)	15	13								2,5	0,5	<1	
9	R6	8 µm	value/µm	8,37	8,347								2,5	0,5	<1	
10			std. dev./nm	12	2								2,5	0,5	<1	
11			U/nm (k=2)	24	21								2,5	0,5	<1	
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,505	1,61		49,47					0,25	2,5	0,5	<1	
15			std. dev./nm	1	6		285					0,25	2,5	0,5	<1	
16			U/nm (k=2)	10	70		166					0,25	2,5	0,5	<1	
17	PTB	7070/PGN10	value/µm	2,96	9,63		198,6					2,5	8	0,5	<1	
18			std. dev./nm	10	30		512					2,5	8	0,5	<1	
19			U/nm (k=2)	56	397		301					2,5	8	0,5	<1	
20	PTB	8194/PGN3	value/µm	0,904	3,1		119,1					0,8	2,5	0,5	<1	
21			std. dev./nm	8	55		1084					0,8	2,5	0,5	<1	
22			U/nm (k=2)	18	134		627					0,8	2,5	0,5	<1	
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,36	14,45		8,04	1,26	3,02	7,4	92,2	2,5	8	0,5	<1	
27			std. dev./nm	22	297		186	52	352	0,5	0,7	2,5	8	0,5	<1	
28			U/nm (k=2)	76	895		275	83	274			2,5	8	0,5	<1	
29	coarse	633g	value/µm	1,52	7,58		4,24	0,88	2,57	7,1	79,3	0,8	2,5	0,5	<1	
30			std. dev./nm	3	188		159	144	324	0,7	1,2	0,8	2,5	0,5	<1	
31			U/nm (k=2)	48	474		163	99	244			0,8	2,5	0,5	<1	
32	fine	629f	value/µm	0,152	1,27		0,466	0,137	0,294	9	87,7	0,8	2,5	0,5	<1	
33			std. dev./nm	3	47		16	12	23	0,8	0,8	0,8	2,5	0,5	<1	
34			U/nm (k=2)	6	85		18	12	23			0,8	2,5	0,5	<1	
35	SFRN 150	1.006	value/µm	0,0247	0,15		0,076	0,03	0,03	12,6	87	0,25	2,5	0,5	<1	
36			std. dev./nm	0,7	6		6	3	7	1	1,5	0,25	2,5	0,5	<1	
37			U/nm (k=2)	2,5	23		5	3,5	5			0,25	2,5	0,5	<1	

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Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

21.02.2003

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,299										0,5	1	0,25
4			std. dev./nm	2,123										0,5	1	0,25
5			U/nm (k=2)	50										0,5	1	0,25
6	R3	1,5 µm	value/µm	1,386										0,5	1	0,25
7			std. dev./nm	6,852										0,5	1	0,25
8			U/nm (k=2)	100										0,5	1	0,25
9	R6	8 µm	value/µm	8,349										0,5	1	0,25
10			std. dev./nm	4,042										0,5	1	0,25
11			U/nm (k=2)	300										0,5	1	0,25
12														0,5	1	0,25
13	Geom. Standard			Ra	Rz	Rmax	RSm							0,5		0,25
14	Rub	P114A/528-RS 5	value/µm	0,504	1,607							0,25	2,5	0,5	1	0,25
15			std. dev./nm	0,217	6,916									0,5	1	0,25
16			U/nm (k=2)	50	150									0,5	1	0,25
17	PTB	7070/PGN10	value/µm	2,971	9,711							2,5	8	0,5	1	0,25
18			std. dev./nm	14,474	54,451									0,5	1	0,25
19			U/nm (k=2)	200	300									0,5	1	0,25
20	PTB	8194/PGN3	value/µm	0,905	3,087							0,8	2,5	0,5	1	0,25
21			std. dev./nm	11,708	56,450									0,5	1	0,25
22			U/nm (k=2)	100	200									0,5	1	0,25
23														0,5		0,25
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,352	14,341							2,5	8	0,5	1	0,25
27			std. dev./nm	23,324	274,755									0,5	1	0,25
28			U/nm (k=2)	160	500									0,5	1	0,25
29	coarse	633g	value/µm	1,515	7,575							0,8	2,5	0,5	1	0,25
30			std. dev./nm	2,563	177,247									0,5	1	0,25
31			U/nm (k=2)	100	400									0,5	1	0,25
32	fine	629f	value/µm	0,150	1,277							0,8	2,5	0,5	1	0,25
33			std. dev./nm	2,446	45,546									0,5	1	0,25
34			U/nm (k=2)	50	100									0,5	1	0,25
35	SFRN 150	1.006	value/µm	0,026	0,155							0,25	2,5	0,5	1	0,25
36			std. dev./nm	0,603	8,521									0,5	1	0,25
37			U/nm (k=2)	50	70									0,5	1	0,25

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MIKES

Results and Measurement Conditions
Measurement values in **µm**,
std. deviation and 2k meas. uncertainty in **nm**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,332	0,293									0,5	0,55	0,25
4			std. dev./nm	7	9											
5			U/nm (k=2)	26	23											
6	R3	1,5 µm	value/µm	1,396	1,371									0,5	0,55	0,25
7			std. dev./nm	6	10											
8			U/nm (k=2)	27	26											
9	R6	8 µm	value/µm	8,368	8,349									0,5	0,55	0,25
10			std. dev./nm	7	10											
11			U/nm (k=2)	62	61											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,504	1,592	1,604	49,805					0,25	2,5	0,5	0,55	0,25
15			std. dev./nm	2	5	9	176									
16			U/nm (k=2)	15	58	69	1023									
17	PTB	7070/PGN10	value/µm	2,961	9,655	9,823	199,937					2,5	8	0,5	0,55	0,25
18			std. dev./nm	13	44	56	24									
19			U/nm (k=2)	35	127	151	964									
20	PTB	8194/PGN3	value/µm	0,904	3,097	3,118	118,927					0,8	2,5	0,5	0,55	0,25
21			std. dev./nm	7	53	56	1138									
22			U/nm (k=2)	20	126	138	2470									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,351	14,330	15,567	8,075	1,276	3,121	7,4	92,5	2,5	8	0,5	0,55	0,25
27			std. dev./nm	24	272	36	143	66	89	0,6	0,5					
28			U/nm (k=2)	52	556	148	293	132	181	1,6	1,3					
29	coarse	633g	value/µm	1,515	7,464	8,905	4,487	0,732	2,483	5,8	81,8	0,8	2,5	0,5	0,55	0,25
30			std. dev./nm	1	174	121	26	14	25	0,1	0,1					
31			U/nm (k=2)	18	358	261	67	33	54	0,5	0,5					
32	fine	629f	value/µm	0,150	1,258	1,440	0,463	0,134	0,299	8,7	87,9	0,8	2,5	0,5	0,55	0,25
33			std. dev./nm	2	26	33	8	4	9	0,4	0,5					
34			U/nm (k=2)	15	85	103	35	17	24	1,5	1,6					
35	SFRN 150	1.006	value/µm	0,025	0,146	0,185	0,078	0,028	0,033	12,3	86,8	0,25	2,5	0,5	0,55	0,25
36			std. dev./nm	1	9	23	4	2	2	0,9	1,1					
37			U/nm (k=2)	14	59	81	31	15	16	8,6	8,7					

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Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

18.11.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,298	0,283									0,009	<0.1	0,1
4			std. dev./nm	3,5	2,8											
5			U/nm (k=2)	3,7	7,0											
6	R3	1,5 µm	value/µm	1,403	1,365									0,009	<0.1	0,17
7			std. dev./nm	20,1	3,3											
8			U/nm (k=2)	18,1	6,2											
9	R6	8 µm	value/µm	8,549	8,351									0,02	<0.1	0,3
10			std. dev./nm	170,4	6,3											
11			U/nm (k=2)	152,4	11,6											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,500	1,636	1,703	50,067					0,25	2,5	0,04	<0.1	0,5
15			std. dev./nm	4,2	35,8	70,7	57,7									
16			U/nm (k=2)	2,7	20,7	40,8	33,3									
17	PTB	7070/PGN10	value/µm	2,943	9,694	9,949	200,052					2,5	8	0,09	<0.1	1,5
18			std. dev./nm	92,6	43,9	95,2	72,6									
19			U/nm (k=2)	53,5	25,4	55,0	41,9									
20	PTB	8194/PGN3	value/µm	0,892	3,192	3,391	120,078					0,8	2,5	0,09	<0.1	0,5
21			std. dev./nm	12,0	52,0	69,1	139,6									
22			U/nm (k=2)	7,0	30,1	39,9	80,6									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,316	14,353	15,791	8,215	1,251	3,326	7,09	93,08	2,5	8	0,09	<0.1	1,5
27			std. dev./nm	49,5	305,1	120,7	289,2	56,9	299,6	1,00	0,94					
28			U/nm (k=2)	28,6	176,2	69,7	167,0	32,9	173,0	1,44	1,43					
29	coarse	633g	value/µm	1,479	7,485	9,027	4,688	0,869	2,191	4,66	83,25	0,8	2,5	0,09	<0.1	0,5
30			std. dev./nm	27,8	182,9	189,5	178,2	94,7	176,1	1,06	1,56					
31			U/nm (k=2)	16,1	105,6	109,4	102,9	54,7	101,7	1,45	1,60					
32	fine	629f	value/µm	0,156	1,236	1,545	0,464	0,136	0,289	9,17	88,03	0,8	2,5	0,09	<0.1	0,5
33			std. dev./nm	5,5	57,1	83,9	13,1	10,2	19,7	0,74	0,51					
34			U/nm (k=2)	3,4	33,0	48,5	7,7	6,0	11,4	1,39	1,35					
35	SFRN 150	1.006	value/nm **	24,98	140,14	189,36	79,63	27,24	30,57	11,06	86,17	0,25	2,5	0,04	<0.1	0,5
36			std. dev./nm	0,74	4,57	12,79	6,62	4,77	4,69	1,92	1,75					
37			U/nm (k=2)	1,39	3,06	7,5	4,04	3,05	3,01	1,72	1,66					

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Laboratory:NPL

Euromet
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Surface Texture

Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

2.10.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value	0,291	0,286											
4			std. dev.	1	1											
5			Meas. Unc.	8	7											
6	R3	1,5 µm	value	1,376	1,370											
7			std. dev.	4	4											
8			Meas. Unc.	9	9											
9	R6	8 µm	value	8,39	8,36									0,05	1	0,1
10			std. dev.	16	6											
11			Meas. Unc.	30	25											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rup	1114A/528-RS 5	value	0,506	1,59	1,60	50,03					0,25	2,5	0,05	0,025	0,15
15			std. dev.	3	20	20	10									
16			Meas. Unc.	5	32	32	100									
17	PTB	7070/PGN10	value	2,96	9,66	9,83	199,9					2,5	8	0,1	1	0,2
18			std. dev.	30	70	90	100									
19			Meas. Unc.	89	290	295	100									
20	PTB	8194/PGN3	value	0,903	3,08	3,10	120,0					0,8	2,5	0,1	1	0,2
21			std. dev.	7	60	70	50									
22			Meas. Unc.	36	123	124	100									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value	2,35	14,3	15,6	8,18	1,20	3,11	6,9	92,5	2,5	8	0,1	1	0,2
27			std. dev.	40	290	70	210	100	210	1,1	0,5					
28			Meas. Unc.	71	429	468	327	24	93	2	4					
29	coarse	633g	value	1,52	7,59	8,96	4,48	0,70	2,48	5,8	82,0	0,8	2,5	0,1	1	0,2
30			std. dev.	10	240	110	50	20	40	0,3	0,3					
31			Meas. Unc.	46	304	269	179	14	74	2	4					
32	fine	629f	value	0,149	1,26	1,42	0,46	0,132	0,301	8,9	87,9	0,8	2,5	0,1	1	0,2
33			std. dev.	4	70	90	10	6	20	0,8	0,7					
34			Meas. Unc.	7	88	85	18	3	9	2	4					
35	SFRN 150	1.006	value	0,025	0,139	0,177	0,077	0,027	0,031	12,6	86,6	0,25	2,5	0,05	0,025	0,15
36			std. dev.	0,9	2	11	3,9	1,3	1,9	0,7	0,7					
37			Meas. Unc.	1,8	9,7	15,9	4,6	1,4	1,6	3	3					

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PTB, 5.12

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,326	0,259									1	1	
4			std. dev./nm	0,8	0,9											
5			U/nm (k=2)	7,8	9,3											
6	R3	1,5 µm	value/µm	1,329	1,302									1	1	
7			std. dev./nm	0,9	1,3											
8			U/nm (k=2)	7,9	9,6											
9	R6	8 µm	value/µm	7,815	7,938									1	1	
10			std. dev./nm	10,4	1,5											
11			U/nm (k=2)	22,2	22,9											
12																
13	Geom. Standard			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,55	1,571	1,59	50,202					0,25	2,5	1	1	
15			std. dev./nm	0,3	1	1,7	109,9									
16			U/nm (k=2)	21,6	9,3	9,6	220									
17	PTB	7070/PGN10	value/µm	2,964	9,721	9,888	195,8					2,5	8	1	1	
18			std. dev./nm	2,2	15,5	11,5	190									
19			U/nm (k=2)	23,3	33,4	25,2	380,1									
20	PTB	8194/PGN3	value/µm	0,889	3,082	3,112	116,6					0,8	2,5	1	1	
21			std. dev./nm	0,9	7,9	12,4	223,4									
22			U/nm (k=2)	21,5	19,6	26,7	446,9									
23																
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	very coarse	686sg	value/µm	2,424	13,559	14,675	8,278	1,203	2,939	7,1	92,7	2,5	8	1	1	
27			std. dev./nm	6,2	123,7	189,3	27,4	10,6	66,1	125,1	82,4					
28			U/nm (k=2)	25,8	247,6	378,7	54,7	21,9	132,3							
29	coarse	633g	value/µm	1,525	7,003	7,913	4,161	0,764	2,237	6,9	79,7	0,8	2,5	1	1	
30			std. dev./nm	4,9	26,2	53,5	24,2	15,5	47,7	89,6	211,9					
31			U/nm (k=2)	24,2	40,9	107,4	40,9	21,9	95,9							
32	fine	629f	value/µm	0,151	1,191	1,352	0,455	0,139	0,299	9,8	87,8	0,8	2,5	1	1	
33			std. dev./nm	0,5	6,6	19,2	1,8	2,9	3,5	136,2	121,4					
34			U/nm (k=2)	21,5	15,3	39,2	9,7	11,2	11,3							
35	SFRN 150	1.006	value/µm	0,0256	0,1314	0,1555	0,0977	0,0194	0,0218	5,6	94,3	0,25	2,5	1	1	
36			std. dev./nm	0,1	3,1	3,9	0,3	0,8	2,9	290	261,9					
37			U/nm (k=2)	6,9	10,6	11,7	8,7	8,8	10,5							

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Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

10.02.2003

Depth standard			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
	EN 806										mm	µm	mm/s	mN	µm
R1	0,2 µm	value/µm	0,302	0,285							-	-	0,5	0,7	0,25
		std. dev./nm	1,4	2,1							-	-	0,5	0,7	0,25
		U/nm (k=2)	15	15							-	-	0,5	0,7	0,25
R3	1,5 µm	value/µm	1,378	1,358							-	-	0,5	0,7	0,25
		std. dev./nm	4,7	2,8							-	-	0,5	0,7	0,25
		U/nm (k=2)	19	19							-	-	0,5	0,7	0,25
R6	8 µm	value/µm	8,365	8,348							-	-	0,5	0,7	0,25
		std. dev./nm	7,3	3,9							-	-	0,5	0,7	0,25
		U/nm (k=2)	77	77											
Geom. Standard			Ra	Rz	Rmax	RSm									
Rub	P114A/528-RS 5	value/µm	0,505	1,591	1,603	50,03					0,25	2,5	0,5	0,7	0,25
		std. dev./nm	1	7	15	11									
		U/nm (k=2)	9	21	22	6									
PTB	7070/PGN10	value/µm	2,962	9,661	9,828	199,94					2,5	8	0,5	0,7	0,25
		std. dev./nm	12	41	58	20									
		U/nm (k=2)	30	95	100	12	Ra	Rz	Rmax						
PTB	8194/PGN3	value/µm	0,898	3,056	3,096	119,98	0,902	3,074	3,1		0,8	2,5	0,5	0,7	0,25
		std. dev./nm	15	73	41	33	7	38	40						
		U/nm (k=2)	14	55	42	19	12	41	42						
							without measurement no 4								
Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
											mm	µm	mm/s	mN	µm
very coarse	686sg	value/µm	2,319	14,19	15,466	8,361	1,372	3,701	6,6	93,6	2,5	8	0,5	0,7	0,25
		std. dev./nm	29	164	53	216	87	98	1,3	0,5					
		U/nm (k=2)	30	163	146	150	61	73	0,8	0,3					
coarse	633g	value/µm	1,513	7,505	8,868	4,382	0,896	2,672	6	81,6	0,8	2,5	0,5	0,7	0,25
		std. dev./nm	2	203	90	124	76	123	0,9	0,9					
		U/nm (k=2)	16	138	98	83	50	79	0,5	0,5					
fine	629f	value/µm	0,148	1,257	1,421	0,456	0,148	0,313	8,4	88,1	0,8	2,5	0,5	0,7	0,25
		std. dev./nm	2	43	63	17	9	19	0,8	0,8					
		U/nm (k=2)	8	34	44	23	21	23	0,5	0,5					
SFRN 150	1.006	value/µm	0,027	0,158	0,203	0,085	0,031	0,037	10,8	87,4	0,25	2,5	0,5	0,7	0,25
		std. dev./nm	1,4	12	22	6	4	7	1,3	1,9					
		U/nm (k=2)	8,16406653	15,9167234	19,2715143	14,6569173	14,4031654	14,7923704	0,75055535	1,09696551					

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std.-deviation and 2k-meas.-uncertainty in **nm**

13.11.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Depth standa			Pt	D							lambda-c	lambda-s	Speed	Force	Sampl-dist
2		EN 806										mm	µm	mm/s	mN	µm
3	R1	0,2 µm	value/µm	0,316	0,282							-	2,67	0,1	0,9	0,1
4			std. dev./nm	3,6	9,3							-	2,67	0,1	0,9	0,1
5			U/nm (k=2)	40,9	20,2											
6	R3	1,5 µm	value/µm	1,405	1,364							-	2,67	0,1	0,9	0,1
7			std. dev./nm	6,8	10							-	2,67	0,1	0,9	0,1
8			U/nm (k=2)	45,2	22											
9	R6	8 µm	value/µm	8,399	8,363							-	2,67	0,1	0,9	0,1
10			std. dev./nm	11,8	10,8							-	2,67	0,1	0,9	0,1
11			U/nm (k=2)	105,5	25,9											
12																
13	Geom. Standa			Ra	Rz	Rmax	RSm									
14	Rub	P114A/528-RS 5	value/µm	0,505	1,593	1,599	49,723					0,25	2,5	0,1	0,9	0,2
15			std. dev./nm	1,2	4,9	7,1	75,4					0,25	2,5	0,1	0,9	0,2
16			U/nm (k=2)	48,6	48,6	48,6	984,3									
17	PTB	7070/PGN10	value/µm	2,978	9,73	9,914	198,617					2,5	8,33	0,5	0,9	0,5
18			std. dev./nm	11,9	46,8	49,1	21,1					2,5	8,33	0,5	0,9	0,5
19			U/nm (k=2)	142,3	142,3	142,3	3920,4									
20	PTB	8194/PGN3	value/µm	0,901	3,096	3,113	119,149					0,8	2,67	0,5	0,9	0,35
21			std. dev./nm	6,4	48,7	48,5	29					0,8	2,67	0,5	0,9	0,35
22			U/nm (k=2)	113,9	113,9	113,9	2335,5									
23																
24	Roughn. Stan			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed	Force	Sampl-dist
25												mm	µm	mm/s	mN	µm
26	Very coarse	686sg	value/µm	2,346	14,3	15,534	8,137	1,231	3,11	6,948	92,85	2,5	8,33	0,5	0,9	0,5
27			std. dev./nm	32,5	258,1	28,9	297,5	125,8	130,3	1,235	0,807		8,33	0,5	0,9	0,5
28			U/nm (k=2)	497,6	497,6	497,6	634,4	634,4	634,4	0,306	4,085					
29	Coarse	633g	value/µm	1,533	7,608	9,041	4,464	0,739	2,529	6,196	81,968	0,8	2,67	0,5	0,9	0,35
30			std. dev./nm	8,2	197,8	123	99,8	52,1	53,2	0,413	0,469		2,67	0,5	0,9	0,35
31			U/nm (k=2)	399,7	399,7	399,7	523	523	523	0,428	5,656					
32	Fine	629f	value/µm	0,147	1,255	1,421	0,449	0,137	0,298	8,982	88,158	0,8	2,67	0,5	0,9	0,35
33			std. dev./nm	2,9	40,7	51,5	11,8	5,7	7,6	0,86	0,654		2,67	0,5	0,9	0,35
34			U/nm (k=2)	98,1	98,1	98,1	136	136	136	0,97	9,521					
35	SFRN 150	1.006	value/µm	0,024	0,138	0,175	0,069	0,029	0,036	12,606	83,232	0,25	2,5	0,1	0,9	0,1
36			std. dev./nm	1,6	6,1	13	12,6	3,1	6	0,784	4,394		2,5	0,1	0,9	0,1
37			U/nm (k=2)	42,8	42,8	42,8	72,4	72,4	72,4	6,618	43,697					

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Appendix B3

SOFTWARE RESULTS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1	1001.smd	value/µm	0,087	0,108	0,235	0,24	0,632	-0,008	0,475		0,568	0,077	0,279	0,095	11,8	87,6		
41	file 2	505.smd	value/µm	0,189	0,234	0,52	0,782	1,472	-0,284	1,302		1,47	0,131	0,661	0,252	6,9	90,1		
42	file 3	7080.smd	value/µm	0,422	0,482	0,755	0,73	1,501	0,012	1,486		1,501	0,116	1,407	0,012	10,4	99,9		

Results and Measurement Conditions

Measurement values in µm,
std.-deviation and 2k-meas.-uncertainty in nm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax(Rt)	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1		value																
41	file 2	505	value	0,176	0,217	0,492	0,756	1,248	-0,261	1,112		1,248	0,129	0,661	0,257	6	91	unfiltered	unfiltered
42	file 3		value																

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Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

3.06.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1	1001smd	value/µm	0,0869	0,1079	0,2324	0,238	0,6283	-0,009	0,4705								0,25	2,5
41	file 2	505smd	value/µm	0,1865	0,2306	0,5107	0,7257	1,4564	-0,258	1,2364								0,8	2,5
42	file 3	7080smd	value/µm	0,4238	0,4842	0,7538	0,721	1,4828	0,015	1,4748	99,80							0,25	2,5

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std.-deviation and 2k-meas.-uncertainty in **nm**

22.04.2003

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1	1001 *	value/µm	0,087	0,108	0,23	0,239	0,61	-0,014	0,47		0,61	0,066	0,264	0,096	10,4	89,5	0,25	2,5
41	file 2	505 **	value/µm	0,186	0,23	0,509	0,724	1,452	-0,258	1,233		1,419	0,13	0,64	0,244	7,4	90,3	0,8	2,5
42	file 3	7080 ***	value/µm	0,419	0,479	0,748	0,713	1,474	0,052	1,461	99,76	1,47						0,25	2,5

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std.-deviation and 2k-meas.-uncertainty in **nm**

18.11.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk#	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1	xz1001	value/µm	0,087	0,107	0,238	-0,232	0,625	0,16	0,47	65,252							0,25	2,5
41	file 2	xz505	value/µm	0,187	0,23	0,746	-0,496	1,422	0,24	1,242	99,21							0,8	2,5
42	file 3	xz7080	value/µm	0,423	0,483	0,725	-0,754	1,507	0	1,479	99,661							0,25	2,5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287							µm	DIN 4768	ISO 13565-2					mm	µm
40	file 1	1001	value [nm]	86,91	107,94	232,44	238,03	628,33	-0,162	470,47	48,88	561,37	76,65	276,42	97,05	11,75	87,59	0,25	2,5
41	file 2	505	value[nm]	187,02	231,05	498,26	747,64	1424,69	-0,222	1245,91	30,3	1421,99	134,68	636,93	254,13	7,72	89,86	0,8	2,5
42	file 3	7080	value[nm]	423,65	484,11	754,08	720,99	1484,21	0,014	1475,05	99,79	1480,35						0,25	2,5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287								DIN 4768	ISO 13565-2					mm	µm
40	file 1	1001	value/µm	54,7	70,1	159	135	572	0,286	294		470	110	205	84,6	16	88,8	0,8	2,5
41	file 2	505	value/µm	120	150	346	389	1430	-0,271	736		1150	184	448	144	13,2	89,6	0,8	2,5
42	file 3	7080	value/µm	216	250	401	425	947	-0,136	827	10,6	909	125	505	627	5,89	77,3	0,8	2,5

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std.-deviation and 2k-meas.-uncertainty in nm

10.02.2003

Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
			ISO 4287								DIN 4768	ISO 13565-2					mm	µm
file 1	1001	value/µm	0,0867	0,1077	0,2311	0,3293	0,5605	-0,0074	0,4601		0,5605	0,0761	0,2726	0,0911	10	88	0,25	2,5
file 2	505	value/µm	0,1868	0,2308	0,5237	0,8888	1,4125	-0,285	1,1983		1,4125	0,152	0,6571	0,251	8	90	0,8	2,5
file 3	7080	value/µm	0,4204	0,4805	0,7547	0,7182	1,4729	0,0138	1,4635	99,86	1,4672						0,25	2,5

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Surface Texture

Results and Measurement Conditions
Measurement values in **µm**,
std.-deviation and 2k-meas.-uncertainty in **nm**

13.11.2002

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
38	Data files			Ra	Rq	Rp	Rv	Rt	Rsk	Rz	RSm	Rmax	Rpk	Rk	Rvk	Mr1/%	Mr2/%	lambda-c	lambda-s
39				ISO 4287														mm	µm
40	file 1	1001	value/µm	0,09	0,11	0,24	0,24	0,63	0	0,48	63,90	0,57	0,07	0,28	0,1	11,56	87,81	0,25	0
41	file 2	505	value/µm	0,19	0,23	0,52	0,78	1,47	-0,28	1,3	45,98	1,47	0,14	0,65	0,25	7,43	89,92	0,8	0
42	file 3	7080	value/µm	0,43	0,49	0,76	0,74	1,52	0,01	1,5	99,92	1,52						0,25	0

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Appendix C

STABILITY OF STANDARDS

1 FINAL MEASUREMENTS AT PTB

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Depth standard			Pt	D							lambda-c	lambda-s
2		EN 806										mm	µm
3	R1	0,2 µm	value	0,288	0,284								
4			std. dev.	6	6								
5			Meas. Unc.	9	7								
6	R3	1,5 µm	value	1,371	1,367								
7			std. dev.	3	3								
8			Meas. Unc.	8	5								
9	R6	8 µm	value	8,356	8,353								
10			std. dev.	7	6								
11			Meas. Unc.	13	9								
12													
13	Geom. Standard			Ra/µm	Rz/µm	Rmax/µm	RSm/µm						
14	Rup	1114A/528-RS 5	value	0,505	1,59	1,60	50,07					0,25	2,5
15			std. dev.	0,003	0,01	0,02	0,03						
16			Meas. Unc.	0,010	0,032	0,032	0,06						
17	PTB	7070/PGN10	value	2,96	9,64	9,81	199,95					2,5	8,0
18			std. dev.	0,01	0,02	0,04	0,10						
19			Meas. Unc.	0,059	0,193	0,196	0,11						
20	PTB	8194/PGN3	value	0,900	3,08	3,10	119,98					0,8	2,5
21			std. dev.	0,007	0,05	0,06	0,11						
22			Meas. Unc.	0,018	0,062	0,062	0,12						
23													
24	Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1*	Mr2*	lambda-c	lambda-s
25				µm	µm	µm	µm	µm	µm	%	%	mm	µm
26	very coarse	686sg	value	2,34	14,3	15,7	8,02	1,281	3,14	7,8	92,4	2,5	8,0
27			std. dev.	0,04	0,23	0,04	0,21	0,095	0,13	1,1	0,5		
28			Meas. Unc.	0,047	0,429	0,314	0,160	0,026	0,063	2	2		
29	coarse	633g	value	1,502	7,45	8,80	4,38	0,748	2,47	6,4	81,7	0,8	2,5
30			std. dev.	0,014	0,16	0,13	0,08	0,041	0,06	0,4	0,4		
31			Meas. Unc.	0,030	0,224	0,176	0,131	0,015	0,049	2	2		
32	fine	629f	value	0,149	1,25	1,42	0,457	0,134	0,293	9,0	87,7	0,8	2,5
33			std. dev.	0,004	0,06	0,08	0,013	0,006	0,011	0,8	0,6		
34			Meas. Unc.	0,004	0,050	0,057	0,009	0,003	0,006	2	2		
35				nm	nm	nm	nm	nm	nm	%	%		
36	SFRN 150	1.006	value	25,1	138,8	178,2	76,7	27,0	31,3	12,4	86,2	0,25	2,5
37			std. dev.	0,8	3,4	17,2	3,6	1,1	2,0	0,9	0,9		
38			Meas. Unc.	0,75	6,94	14,26	3,07	1,08	0,94	2	2		

2 FIRST MEASUREMENTS AT PTB

Depth standard			Pt	D							lambda-c	lambda-s	Speed
	EN 806										mm	µm	mm/s
R1	0,2 µm	value	0,291	0,286									
		std. dev.	1	1									
		Meas. Unc.	8	7									
R3	1,5 µm	value	1,376	1,370									
		std. dev.	4	4									
		Meas. Unc.	9	9									
R6	8 µm	value	8,39	8,36									0,05
		std. dev.	16	6									
		Meas. Unc.	30	25									
Geom. Standard			Ra	Rz	Rmax	RSm							
Rup	1114A/528-RS 5	value	0,506	1,59	1,60	50,03					0,25	2,5	0,05
		std. dev.	3	20	20	10							
		Meas. Unc.	5	32	32	100							
PTB	7070/PGN10	value	2,96	9,66	9,83	199,9					2,5	8	0,1
		std. dev.	30	70	90	100							
		Meas. Unc.	89	290	295	100							
PTB	8194/PGN3	value	0,903	3,08	3,10	120,0					0,8	2,5	0,1
		std. dev.	7	60	70	50							
		Meas. Unc.	36	123	124	100							
Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1/%*	Mr2/%*	lambda-c	lambda-s	Speed
											mm	µm	mm/s
very coarse	686sg	value	2,35	14,3	15,6	8,18	1,20	3,11	6,9	92,5	2,5	8	0,1
		std. dev.	40	290	70	210	100	210	1,1	0,5			
		Meas. Unc.	71	429	468	327	24	93	2	4			
coarse	633g	value	1,52	7,59	8,96	4,48	0,70	2,48	5,8	82,0	0,8	2,5	0,1
		std. dev.	10	240	110	50	20	40	0,3	0,3			
		Meas. Unc.	46	304	269	179	14	74	2	4			
fine	629f	value	0,149	1,26	1,42	0,46	0,132	0,301	8,9	87,9	0,8	2,5	0,1
		std. dev.	4	70	90	10	6	20	0,8	0,7			
		Meas. Unc.	7	88	85	18	3	9	2	4			
SFRN 150	1.006	value	0,025	0,139	0,177	0,077	0,027	0,031	12,6	86,6	0,25	2,5	0,05
		std. dev.	0,9	2	11	3,9	1,3	1,9	0,7	0,7			
		Meas. Unc.	1,8	9,7	15,9	4,6	1,4	1,6	3	3			

3 DIFFERENCES BETWEEN LAST AND FIRST MEASUREMENTS

Depth standard			Pt	D							lambda-c	lambda-s	Speed
	EN 806										mm	µm	mm/s
R1	0,2 µm	**dxfinal-first/µm**	**-0,003**	**-0,002**									
		std. dev./nm	6	6									
		Meas. Unc./nm	9	7									
R3	1,5 µm	**dxfinal-first/µm**	**-0,005**	**-0,003**									
		std. dev./nm	3	3									
		Meas. Unc./nm	8	5									
R6	8 µm	**dxfinal-first/µm**	**-0,034**	**-0,007**									
		std. dev./nm	7	6									
		Meas. Unc./nm	13	9									
Geom. Standard			Ra/µm	Rz/µm	Rmax/µm	RSm/µm							
Rup	1114A/528-RS 5	**dxfinal-first**	**-0,001**	**0,000**	**0,000**	**0,04**					0,25	2,5	0,05
		std. dev.	0,003	0,01	0,02	0,03							
		Meas. Unc.	0,010	0,032	0,032	0,06							
PTB	7070/PGN10	**dxfinal-first**	**0,000**	**-0,02**	**-0,02**	**0,05**					2,5	8,0	0,1
		std. dev.	0,01	0,02	0,04	0,10							
		Meas. Unc.	0,059	0,193	0,196	0,11							
PTB	8194/PGN3	**dxfinal-first**	**-0,003**	**0,000**	**0,000**	**-0,02**					0,8	2,5	0,05
		std. dev.	0,007	0,05	0,06	0,11							
		Meas. Unc.	0,018	0,062	0,062	0,12							
Roughn.standard			Ra	Rz	Rmax	Rk*	Rpk*	Rvk*	Mr1*	Mr2*	lambda-c	lambda-s	Speed
			µm	µm	µm	µm	µm	µm	%	%	mm	µm	mm/s
very coarse	686sg	**dxfinal-first**	**-0,010**	**0,000**	**0,100**	**-0,160**	**0,081**	**0,030**	**0,9**	**-0,1**	2,5	8,0	0,1
		std. dev.	0,04	0,23	0,04	0,21	0,095	0,13	1,1	0,5			
		Meas. Unc.	0,047	0,429	0,314	0,160	0,026	0,063	2	2			
coarse	633g	**dxfinal-first**	**-0,018**	**-0,140**	**-0,160**	**-0,100**	**0,048**	**-0,010**	**0,6**	**-0,3**	0,8	2,5	0,1
		std. dev.	0,014	0,16	0,13	0,08	0,041	0,06	0,4	0,4			
		Meas. Unc.	0,030	0,224	0,176	0,131	0,015	0,049	2	2			
fine	629f	**dxfinal-first**	**0,000**	**-0,010**	**0,000**	**-0,003**	**0,002**	**-0,008**	**0,1**	**-0,2**	0,8	2,5	0,1
		std. dev.	0,004	0,06	0,08	0,013	0,006	0,011	0,8	0,6			
		Meas. Unc.	0,004	0,050	0,057	0,009	0,003	0,006	2	2			
			nm	nm	nm	nm	nm	nm	%	%			
SFRN 150	1.006	**dxfinal-first**	**0,1**	**-0,2**	**1,2**	**-0,3**	**0,0**	**0,3**	**-0,2**	**-0,4**	0,25	2,5	0,05
		std. dev.	0,8	3,4	17,2	3,6	1,1	2,0	0,9	0,9			
		Meas. Unc.	0,75	6,94	14,26	3,07	1,08	0,94	2	2			

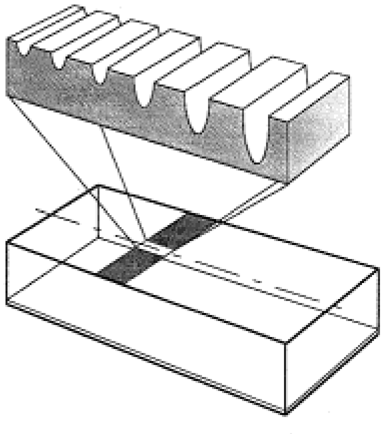
*) The first measurements were made with Nanostep U=30nm, the last with IM U=13 nm

686sg Rpk
1,281+/-0,026µm final
-1,200+/-0,024µm first
=0,081+/-0,050µm difference

633g Rpk
0,748+/-0,015µm final
-0,700+/-0,014µm first
=0,048+/-0,029µm difference

629f Rvk
0,293+/-0,006µm final
-0,301+/-0,009µm first
=0,008+/-0,015µm difference

Appendix D1



Depth Setting Standard

Type A

1 DEPTH STANDARD EN806 R1 0,2 µM

Results of *Pt*

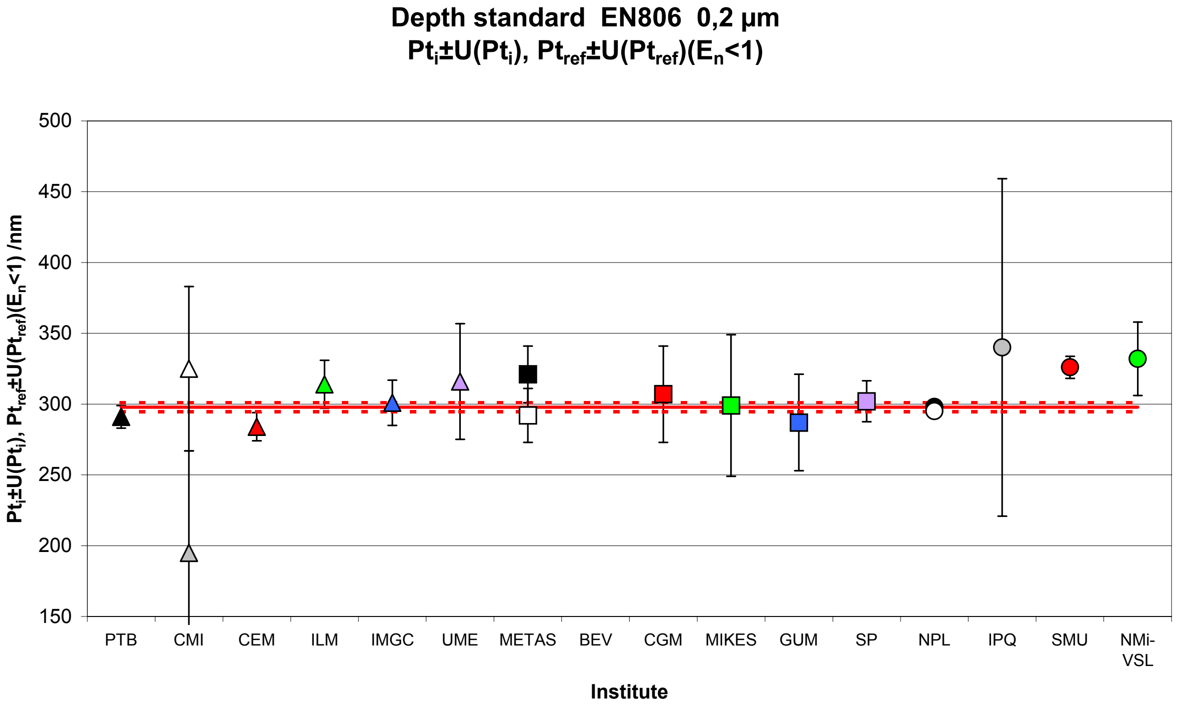
Institute	Pt	Country	Instrument	Measured Date						Depth standard EN 806 R1 0,2 µm						
					λc	λs	Speed	Force	Sampl-dist	Pt	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01						291	1	8	4	0,80	6,90	7,33
CMI	n	CZ	HT	Jun 01	0,06		0,1	0,75	0,03	195	7	72			102,90	71,93
CEM	n	ES	DT	Jan 03			0,1	0,9	0,5	284	2	10			13,90	9,47
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	314	5	17	8,5	0,93	16,10	16,70
IMGC		IT	TS	Aug 01			0,025 / 0,0025	0,03	0,1	301	9	16	8	0,19	3,10	15,68
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	316	3,6	40,9	20,45	0,44	18,10	40,77
METAS	n	CH	FTS	Oct 01		2,5	0,5	<1		321	17	20			23,10	19,74
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	307	5	34	17	0,27	9,10	33,85
MIKES		FI	FTS	Feb 02			0,500	1,000	0,250	299	2,123	50	25	0,02	1,10	49,90
GUM		PL	FTS	Apr 02			0,5	<1	0,25	287	2,4	34	17	0,32	10,90	33,85
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	302	1,4	14,522	7,2608981	0,28	4,10	14,16
NPL		UK	NS4	Jul 02			0,0	<0.1	0,1	298	3,5	3,7	1,85	0,02	0,10	1,86
IPQ		PT	S8P	Sep 02	0,08		0,1			340	10	119,18	59,59	0,35	42,10	119,14
SMU	n	CS	FTS	Nov 02			1	1		326	0,8	7,8			28,10	7,11
NMi-VSL	n	NL	FTS	Mrz 03			0,5	0,55	0,25	332	7	26			34,10	25,80
									Mean	300,87	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	33,56	nm	297,9	1,6	3,2	1,00	10

0=not measured

i=incomplete

n=excluded (En>1)

1. SMU	**En = 3,02**
2. CMI	**En = 1,42**
3. Nmi-VSL	**En = 1,31**
4. CEM	**En = 1,26**
5. METAS	**En = 1,12**



 # open symbol shows corrected value of

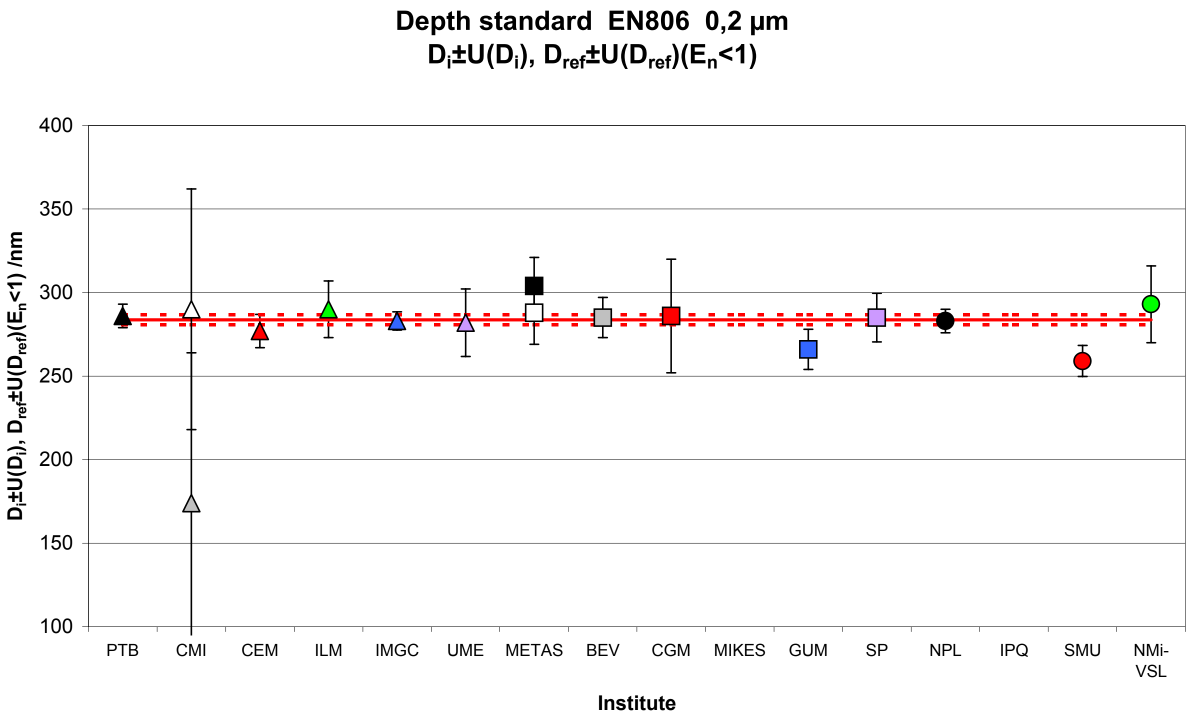
CMI	*Pt* = (325 +/- 58) nm
METAS	*Pt* = (292 +/- 19) nm
NPL	*Pt* = (295 +/- 3,3) nm

Results of *D*

Institute	D	Country	Instrument	Measured Date						Depth standard EN 806 R1 0,2 µm						
					λc	λs	Speed	Force	Sampl-dist	D	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01						286	1	7	3,5	0,30	2,30	6,32
CMI	n	CZ	HT	Jun 01	0,06		0,1	0,75	0,03	174	5	90			109,70	89,95
CEM		ES	DT	Jan 03			0,1	0,9	0,5	277	3	10	5	0,64	6,70	9,54
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	290	7	17	8,5	0,36	6,30	16,73
IMGC		IT	TS	Aug 01			0,025 / 0,0025	0,03	0,1	283	3,2	5,5	2,75	0,11	0,70	4,61
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	282	9,3	20,2	10,1	0,08	1,70	19,98
METAS	n	CH	FTS	Oct 01		2,5	0,5	<1		304	13	17			20,30	16,73
BEV		A	IM	Nov 01						285	3,5	12	6	0,11	1,30	11,62
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	286	4	34	17	0,07	2,30	33,87
MIKES	0	FI	FTS	Feb 02			0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02			0,5	<1	0,25	266	2,7	12			17,70	11,62
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	285	2,1	14,563	7,2817076	0,09	1,30	14,25
NPL		UK	NS4	Jul 02			0,0	<0.1	0,1	283	2,8	7	3,5	0,09	0,70	6,32
IPQ	0	PT	S8P	Sep 02	0,08		0,1									
SMU	n	CS	FTS	Nov 02			1	1		259	0,9	9,3			24,70	8,80
NMi-VSL		NL	FTS	Mrz 03			0,5	0,55	0,25	293	9	23	11,5	0,40	9,30	22,80
									Mean	275,21	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	31,07	nm	283,7	1,5	3,0	0,64	10

0=not measured
i=incomplete
n=excluded (En>1)

1. SMU	**En = 2,25**
2. GUM	**En = 1,38**
3. CMI	**En = 1,22**
4. METAS	**En = 1,14**


Depth standard EN806 0,2 µm
$D_i \pm U(D_i)$, $D_{ref} \pm U(D_{ref})(E_n<1)$

 # open symbol shows corrected value of

CMI *D* = (290 +/- 72) nm
METAS *D* = (288 +/- 19) nm

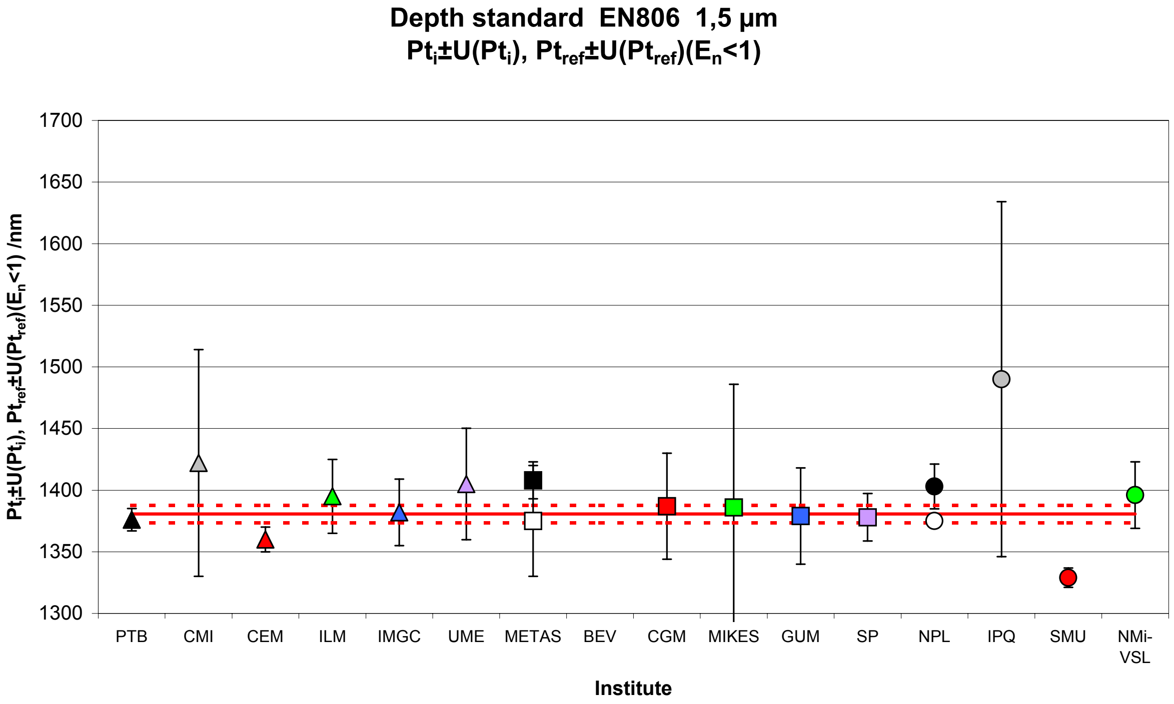
2 DEPTH STANDARD EN806 R2 1,5 µM

Results of *Pt*

Institute	Pt	Country	Instrument	Measured Date	λc	λs	Speed	Force	Sampl-dist	Depth standard EN 806 R3 1,5 µm Pt	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01						1376	4	9	4,5	0,40	4,60	5,66
CMI		CZ	HT	Jun 01	0,1		0,1	0,75	0,05	1422	29	92	46	0,45	41,40	91,73
CEM	n	ES	DT	Jan 03			0,1	0,9	0,5	1360	0	10			20,60	7,14
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	1395	5	30	15	0,47	14,40	29,17
IMGC		IT	TS	Aug 01			0,025	0,045	0,3	1382	6	27	13,5	0,05	1,40	26,08
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	1405	6,8	45,2	22,6	0,53	24,40	44,65
METAS	n	CH	FTS	Oct 01		2,5	0,5	<1		1408	9	15			27,40	13,27
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	1387	8	43	21,5	0,15	6,40	42,43
MIKES		FI	FTS	Feb 02			0,500	1,000	0,250	1386	6,852	100	50	0,05	5,40	99,75
GUM		PL	FTS	Apr 02			0,5	<1	0,25	1379	2,9	39	19,5	0,04	1,60	38,37
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	1378	4,7	19,336	9,6681405	0,13	2,60	18,02
NPL	n	UK	NS4	Jul 02			0,0	<0.1	0,2	1403	20,1	18,1			22,40	16,69
IPQ		PT	S8P	Sep 02	0,08		0,1			1490	20	144	72	0,76	109,40	143,83
SMU	n	CS	FTS	Nov 02			1	1		1329	0,9	7,9			51,60	3,66
NMi-VSL		NL	FTS	Mrz 03			0,5	0,55	0,25	1396	6	27	13,5	0,55	15,40	26,08
									Mean	1393,07	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	34,67	nm	1380,6	3,5	7,0	0,88	11

0=not measured
i=incomplete
n=excluded (En>1)

1. SMU	**En = 4,03**
2. CEM	**En = 1,79**
3. METAS	**En = 1,28**
4. NPL	**En = 1,02**



 # open symbol shows corrected value of

METAS *Pt* = (1375 +/- 40) nm
NPL *Pt* = (1375 +/- 5,2) nm

Results of *D*

Institute	D	Country	Instrument	Measured Date						Depth standard EN 806 R3 1,5 µm						
					λc	λs	Speed	Force	Sampl-dist	D	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01						1370	4	9	4,5	0,53	5,10	8,25
CMI		CZ	HT	Jun 01	0,1		0,1	0,75	0,05	1385	17	120	60	0,17	20,10	119,95
CEM		ES	DT	Jan 03			0,1	0,9	0,5	1358	2	10	5	0,65	6,90	9,33
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	1376	7	30	15	0,37	11,10	29,78
IMGC		IT	TS	Aug 01			0,025	0,045	0,3	1367	3,4	8	4	0,24	2,10	7,14
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	1364	10	22	11	0,04	0,90	21,70
METAS	n	CH	FTS	Oct 01		2,5	0,5	<1		1383	3	13			18,10	12,49
BEV		A	IM	Nov 01						1366	3,8	15	7,5	0,07	1,10	14,56
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	1361	5	43	21,5	0,09	3,90	42,85
MIKES	0	FI	FTS	Feb 02			0,500	1,000	0,250							
GUM		PL	FTS	Apr 02			0,5	<1	0,25	1355	2,3	18	9	0,54	9,90	17,64
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	1358	2,8	18,913	9,4567098	0,36	6,90	18,57
NPL		UK	NS4	Jul 02			0,0	<0.1	0,2	1365	3,3	6,2	3,1	0,01	0,10	5,05
IPQ	0	PT	S8P	Sep 02	0,08		0,1									
SMU	n	CS	FTS	Nov 02			1	1		1302	1,3	9,6			62,90	8,90
NMi-VSL		NL	FTS	Mrz 03			0,5	0,55	0,25	1371	10	26	13	0,23	6,10	25,75
									Mean	1362,93	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	19,68	nm	1364,9	1,8	3,6	0,75	12

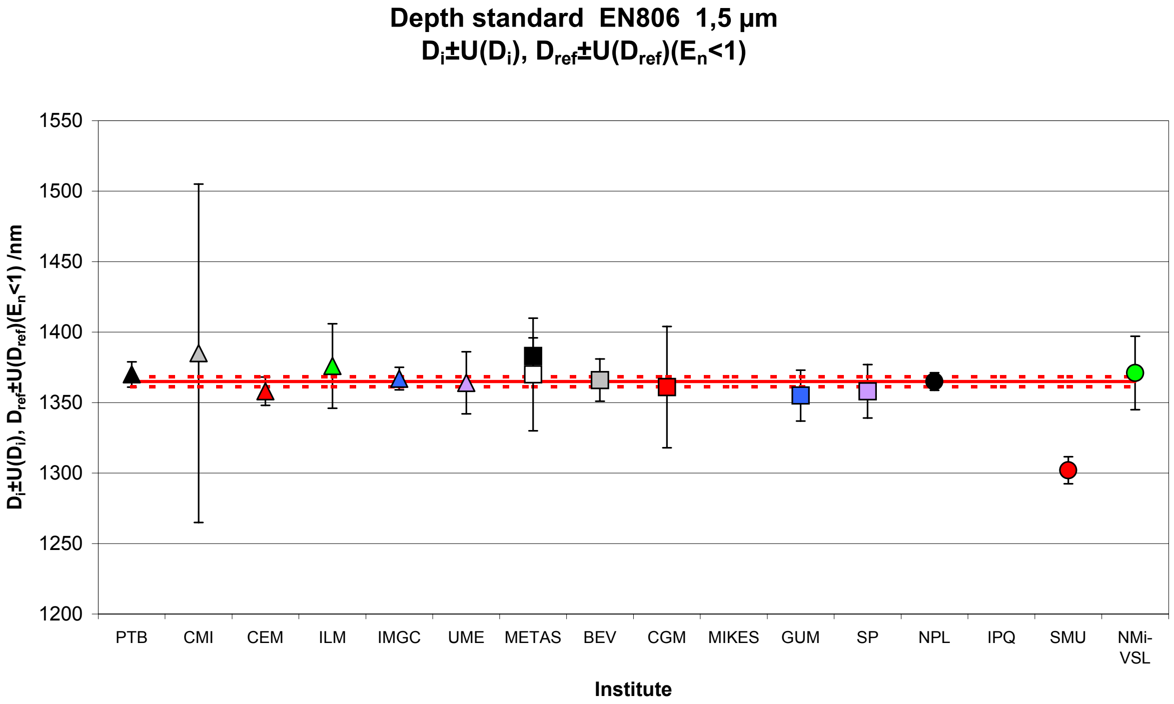
0=not measured

i=incomplete

n=excluded (En>1)

1. SMU En = 5,63

2. METAS En = 1,25



 # open symbol shows corrected value of

METAS *D* = (1370 +/- 40) nm

corrected value but not shown, because only U changed
UME *D* = (1364 +/- 24,4) nm

3 DEPTH STANDARD EN806 R3 8,0 µM

Results of *Pt*

Institute	Pt	Country	Instrument	Measured Date						Depth standard EN 806 R6 8 µm						
					λc	λs	Speed	Force	Sampl-dist	Pt	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01			0,05	1	0,1	8390	16	30	15	0,35	11,70	26,21
CMI		CZ	HT	Jun 01	0,2		0,1	0,75	0,1	8353	21	130	65	0,19	25,30	129,18
CEM	n	ES	DT	Jan 03			0,1	0,9	0,5	8329	8	12				
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	8419	9	60	30	0,66	40,70	58,20
IMGC		IT	TS	Aug 01			0,025	0,055	0,3	8382	10	42	21	0,08	3,70	39,38
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	8399	11,8	105,5	52,75	0,19	20,70	104,48
METAS		CH	FTS	Oct 01		2,5	0,5	<1		8370	12	24	12	0,30	8,30	19,05
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	8404	16	69	34,5	0,36	25,70	67,44
MIKES		FI	FTS	Feb 02			0,500	1,000	0,250	8349	4,042	300	150	0,10	29,30	299,64
GUM		PL	FTS	Apr 02			0,5	<1	0,25	8312	6,8	73	36,5	0,89	66,30	71,53
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	8365	7,3	76,9	38,45004	0,17	13,30	75,50
NPL	n	UK	NS4	Jul 02			0,0	<0.1	0,3	8549	170,4	152,4			170,70	151,70
IPQ	n	PT	S8P	Sep 02	0,08		0,1			8830	20	124,12			451,70	123,26
SMU	n	CS	FTS	Nov 02			1	1		7815	10,4	22,2			563,30	16,72
NMi-VSL		NL	FTS	Mrz 03			0,5	0,55	0,25	8368	7	62	31	0,16	10,30	60,26
									Mean	8375,60	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	200,35	nm	8378,3	7,3	14,6	0,86	11

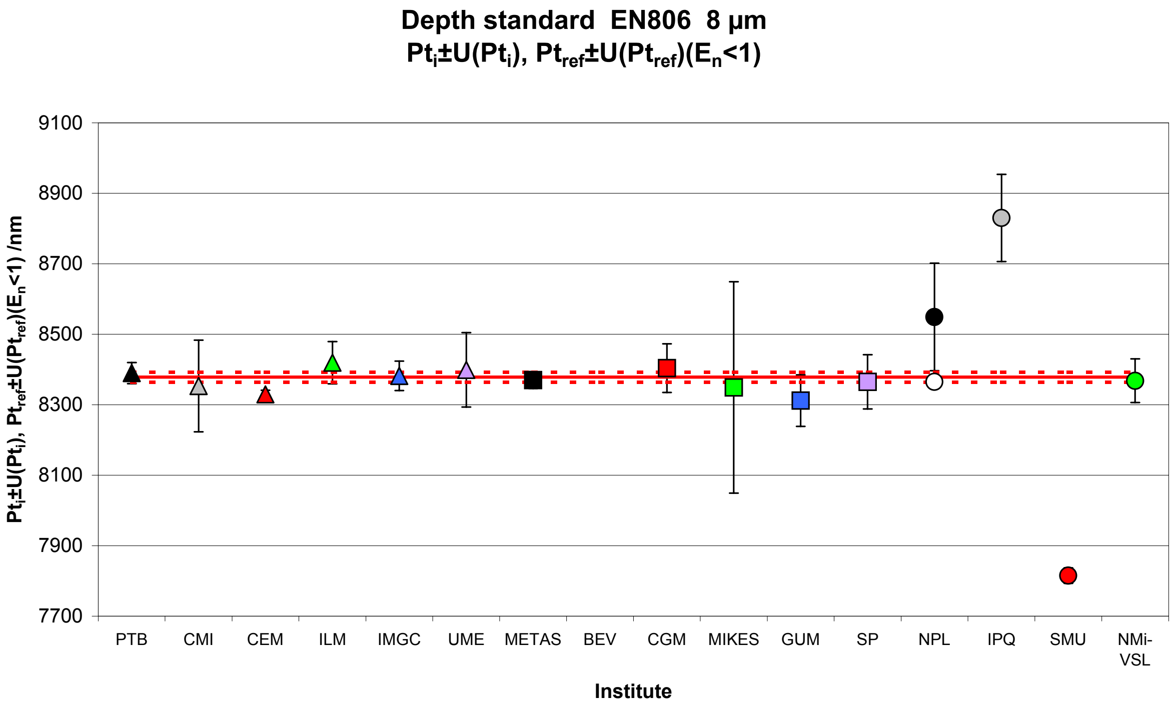
0=not measured

i=incomplete

n=excluded (En>1)

1. SMU	**En = 19,24**
2. IPQ	**En = 3,84**
3. CEM	**En = 1,36**
4. NPL	**En = 1,10**

*) DoE(*U*ir) for CEM cannot be calculated, since $u_i < u_{ref}$



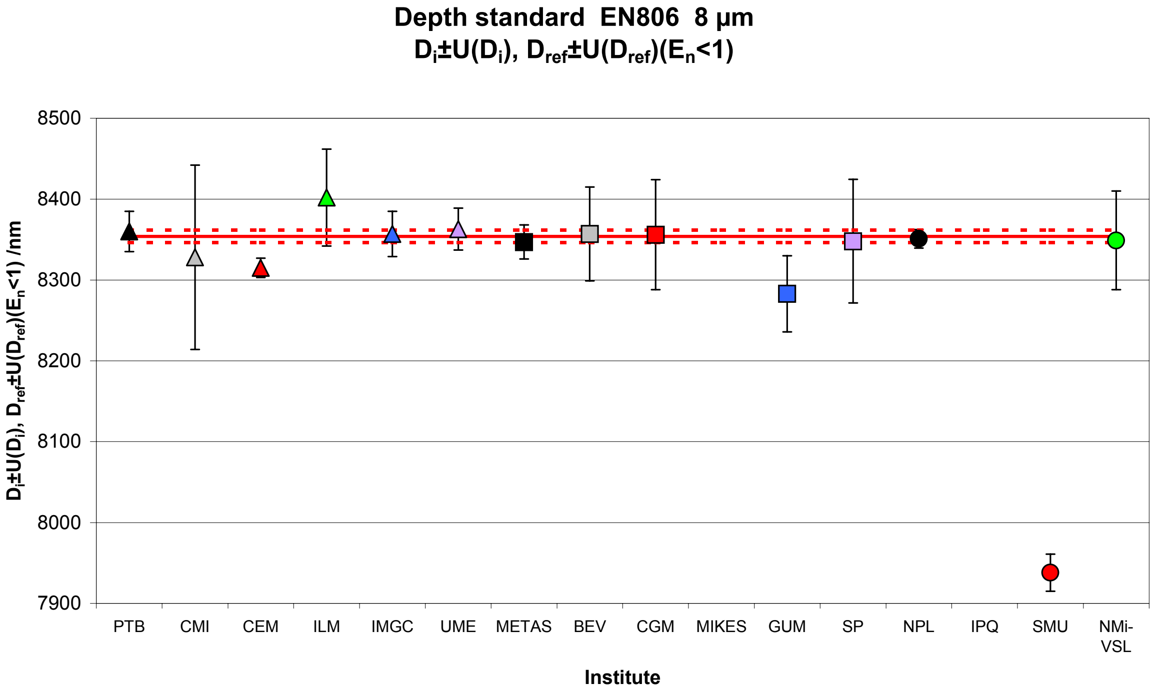
 # open symbol shows corrected value of

NPL *Pt* = (8365 +/- 14,4) nm

Results of *D*

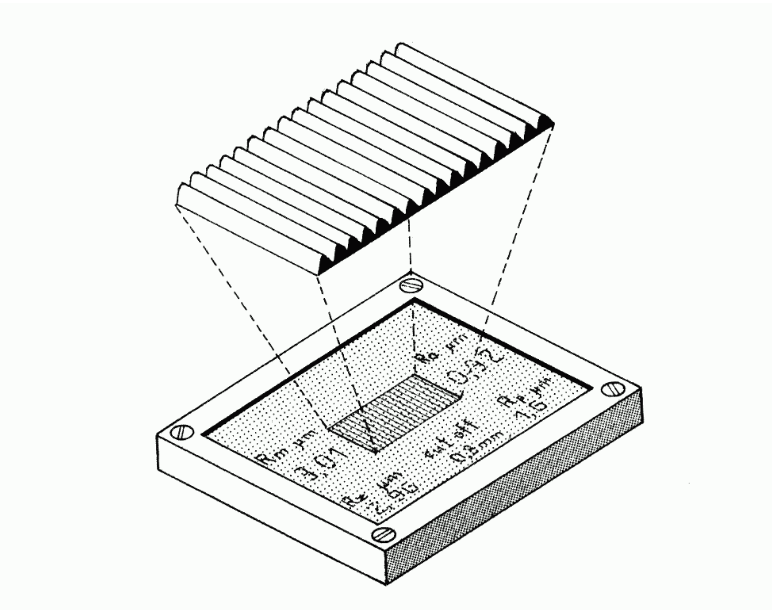
Institute	D	Country	Instrument	Measured Date						Depth standard EN 806 R6 8 µm						
					λc	λs	Speed	Force	Sampl-dist	D	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	IM	May 01			0,05	1	0,1	8360	6	25	12,5	0,23	6,10	23,69
CMI		CZ	HT	Jun 01	0,2		0,1	0,75	0,1	8328	23	114	57	0,23	25,90	113,72
CEM	n	ES	DT	Jan 03			0,1	0,9	0,5	8315	10	12			38,90	8,94
ILM		IT	FTS	Aug 01			0,5	0,75	0,5	8402	9	60	30	0,79	48,10	59,46
IMGC		IT	TS	Aug 01			0,025	0,055	0,3	8357	9,8	28	14	0,11	3,10	26,83
UME		TR	MPC	Sep 01	-	2,67	0,1	0,9	0,1	8363	10,8	25,9	12,95	0,34	9,10	24,63
METAS		CH	FTS	Oct 01		2,5	0,5	<1		8347	2	21	10,5	0,31	6,90	19,42
BEV		A	IM	Nov 01						8357	13	58	29	0,05	3,10	57,45
CGM		DK	FTS	Jan 02	none	none	0,05	1	0,1	8356	14	68	34	0,03	2,10	67,53
MIKES	0	FI	FTS	Feb 02			0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02			0,5	<1	0,25	8283	5,8	47			70,90	46,31
SP		SE	FTS	May 02	-	-	0,5	0,7	0,25	8348	3,9	76,546	38,272805	0,08	5,90	76,13
NPL		UK	NS4	Jul 02			0,0	<0.1	0,3	8351	6,3	11,6	5,8	0,21	2,90	8,40
IPQ	0	PT	S8P	Sep 02	0,08		0,1									
SMU	n	CS	FTS	Nov 02			1	1		7938	1,5	22,9			415,90	21,46
NMi-VSL		NL	FTS	Mrz 03			0,5	0,55	0,25	8349	10	61	30,5	0,08	4,90	60,47
									Mean	8318,14	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	112,61	nm	8353,9	4,0	8,0	0,66	11

0=not measured
i=incomplete
n=excluded (En>1)
1. SMU En = 15,62
2. CEM En = 1,87
2. GUM En = 1,45



corrected value but not shown, because only U changed
UME *D* = (8363 +/- 70,8) nm

Appendix D2



Roughness Standard
Type C

1. ROUGHNESS STANDARD P114A/528-RS5

Results of *Ra*

Institute	Ra	Country	Instrumen	Measured Date						P114A	P114A	P114A	P114A	P114A	P114A	P114A
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	506	3	5	2,5	0,71	3,90	4,49
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	499	2	24	12	0,13	3,10	23,90
CEM	n	ES	MPC	Jul 01	0,25	2,5	0,5	0,4	0,5	491	2	3,97			11,10	3,30
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	504	1	15,925	7,9626378	0,12	1,90	15,77
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,045	1	508	1,3	11	5,5	0,53	5,90	10,78
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,2	505	1,2	48,6	24,3	0,06	2,90	48,55
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		505	1	10	5	0,28	2,90	9,75
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	510	2	35	17,5	0,23	7,90	34,93
MIKES		FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	504	0,217	50	25	0,04	1,90	49,95
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	500	1,5	29	14,5	0,07	2,10	28,92
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	505	1	9,3231	4,6615544	0,30	2,90	9,06
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	500	4,2	2,7	1,35	0,60	2,10	1,57
IPQ		PT	S8P	Sep 02	0,25	2,5	0,1		0,5	500	0	40,82	20,41	0,05	2,10	40,76
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		550	0,3	21,6			47,90	21,49
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	504	2	15	7,5	0,13	1,90	14,84
									Mean	506,07	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	12,96	nm	502,1	1,1	2,2	0,8	13

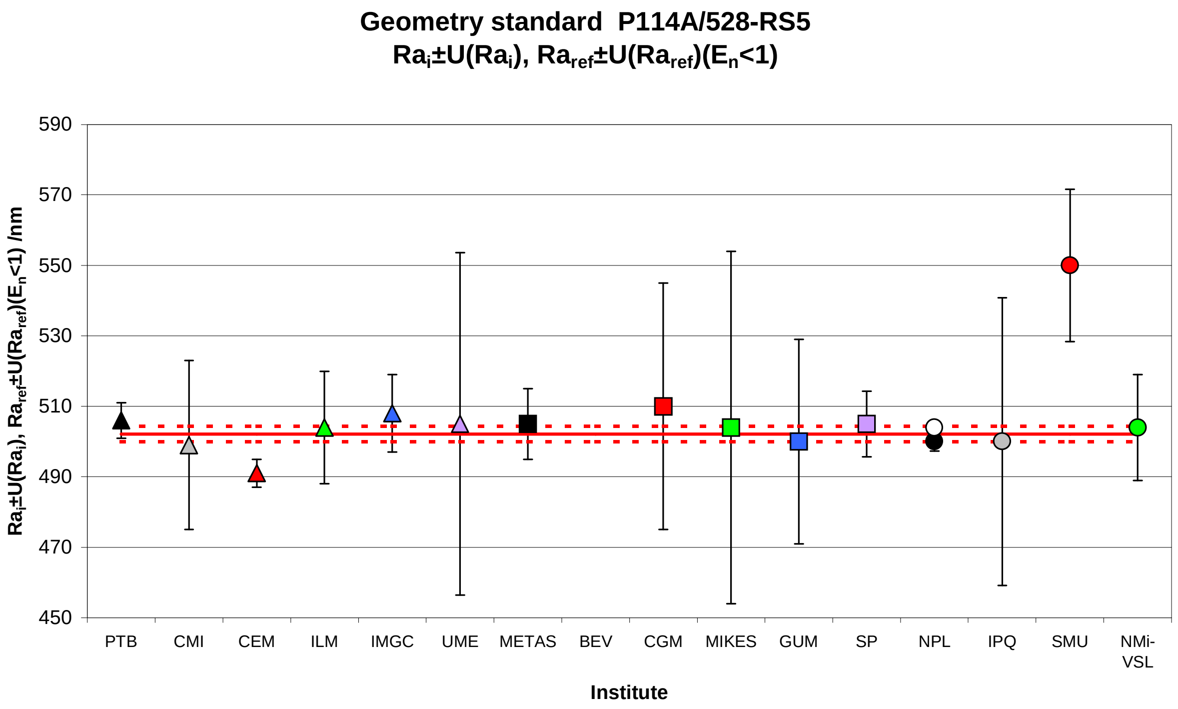
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. CEM En = 1,97



 # open symbol shows corrected value of

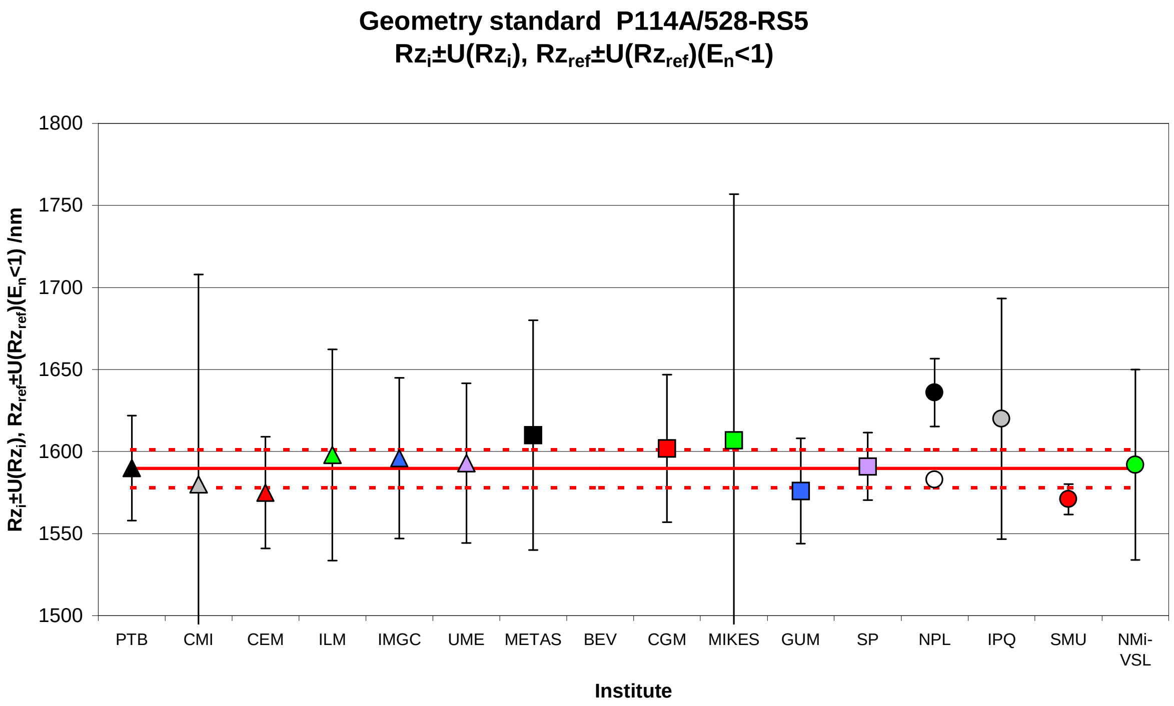
NPL *Ra* = (504 +/- 1,7) nm

Results of *Rz*

Institute	Rz	Country	Instrumen	Measured Date						P114A	P114A	P114A	P114A	P114A	P114A	P114A
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	1590	20	32	16	0,01	0,30	29,82
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	1580	7	128	64	0,08	9,70	127,47
CEM		ES	MPC	Jul 01	0,25	2,5	0,5	0,4	0,5	1575	7	34,07	17,035	0,41	14,70	32,03
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	1598	6	64,302	32,151075	0,13	8,30	63,25
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,045	1	1596	5,7	49	24,5	0,13	6,30	47,61
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,2	1593	4,9	48,6	24,3	0,07	3,30	47,20
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		1610	6	70	35	0,29	20,30	69,03
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	1602	6	45	22,5	0,26	12,30	43,48
MIKES		FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	1607	6,916	150	75	0,11	17,30	149,55
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	1576	4,8	32	16	0,40	13,70	29,82
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	1591	7	20,585	10,292438	0,06	1,30	17,01
NPL	n	UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	1636	35,8	20,7			46,30	17,14
IPQ		PT	S8P	Sep 02	0,25	2,5	0,1		0,5	1620	10	73,26	36,63	0,41	30,30	72,34
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		1571	1	9,3				
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	1592	5	58	29	0,04	2,30	56,83
									Mean	1595,80	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	17,61	nm	1589,7	5,8	11,6	0,5	13

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. NPL En = 1,54

DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$



 # open symbol shows corrected value of

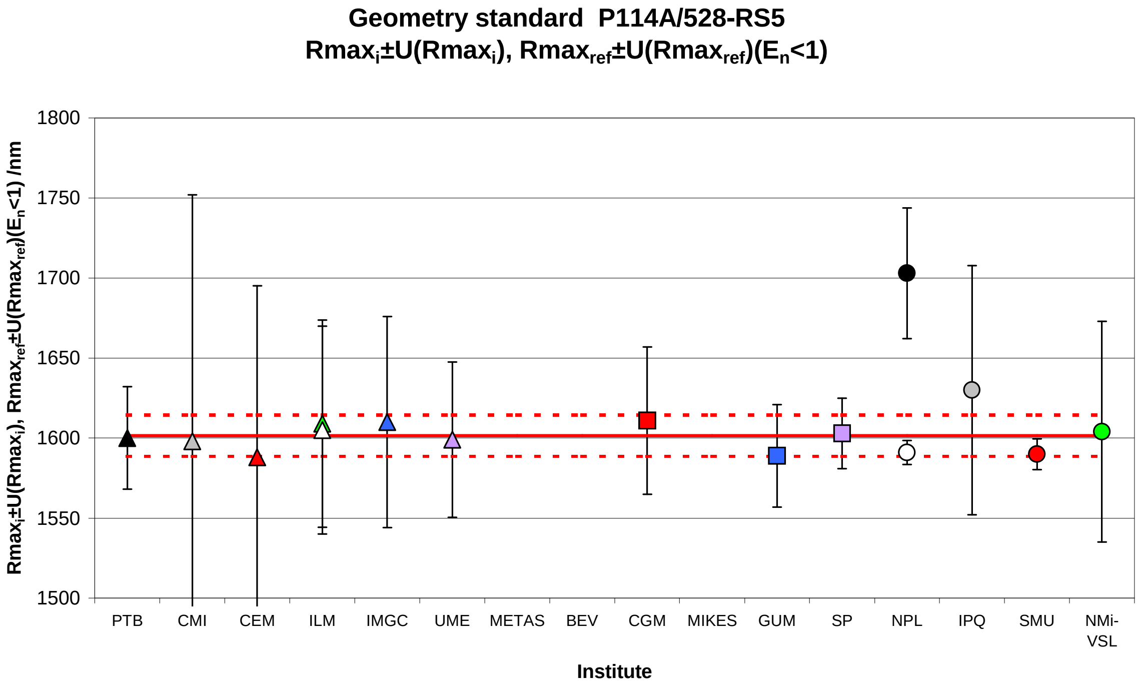
NPL *Rz* = (1583 +/- 3) nm

Results of *Rmax*

Institute	Rmax	Country	Instrumen	Measured Date	λc	λs	Speed	Force	Sampl-dist	P114A	P114A	P114A	P114A	P114A	P114A	P114A
										Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	1600	20	32	16	0,05	1,60	29,24
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	1598	11	154	77	0,02	3,60	153,45
CEM		ES	MPC	Jul 01	0,25	2,5	0,5	0,4	0,5	1588	10	107,26	53,63	0,13	13,60	106,47
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	1609	12	64,74	32,369776	0,11	7,40	63,42
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,045	1	1610	15,2	66	33	0,12	8,40	64,71
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,2	1599	7,1	48,6	24,3	0,05	2,60	46,83
METAS	0	CH	FTS	Oct 01	0,25	2,5	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	1611	11	46	23	0,20	9,40	44,12
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	1589	10,7	32	16	0,36	12,60	29,24
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	1603	15	22,074	11,037078	0,05	1,40	17,84
NPL	n	UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	1703	70,7	40,8			101,40	38,67
IPQ		PT	S8P	Sep 02	0,25	2,5	0,1		0,5	1630	10	77,89	38,945	0,36	28,40	76,80
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		1590	1,7	9,6				
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	1604	9	69	34,5	0,03	2,40	67,76
									Mean	1610,31	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	30,03	nm	1601,6	6,5	13,0	0,4	11

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. NPL En = 2,16

DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$



 # open symbol shows corrected value of

ILM	*Rmax* = (1605 +/- 65) nm
NPL	*Rmax* = (1591 +/- 7,6) nm

Results of *RSm*

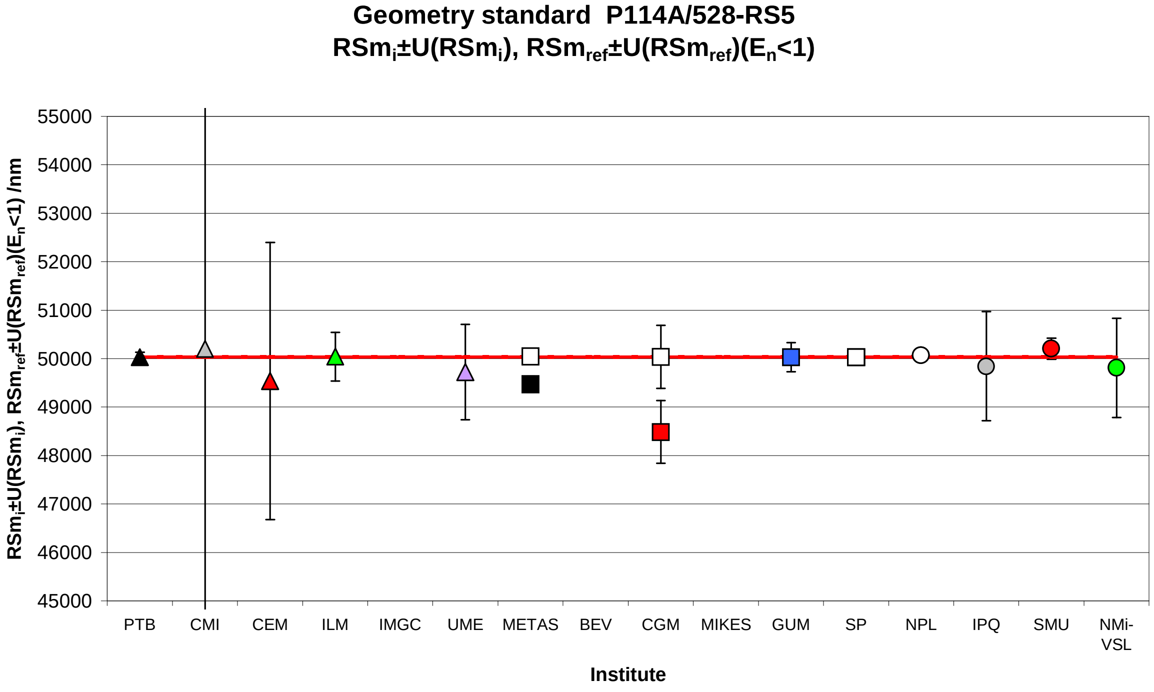
Institute	RSm	Country	Instrumen	Measured Date						P114A	P114A	P114A	P114A	P114A	P114A	P114A
					λc	λs	Speed	Force	Sampl-dist	RSm	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	50030	10	100	50	0,00	0,00	99,79
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	50200	1100	12200	6100	0,01	170,00	12200,00
CEM		ES	MPC	Jul 01	0,25	2,5	0,5	0,4	0,5	49536	13,42	2860	1430	0,17	494,00	2859,99
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	50040	12	500,4	250,2	0,02	10,00	500,36
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,045	1							
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,2	49723	75,4	984,3	492,15	0,31	307,00	984,28
METAS	n	CH	FTS	Oct 01	0,25	2,5	0,5	<1		49470	285	166			560,00	165,88
BEV	0	A	IM	Nov 01												
CGM	n	DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	48486	191	648			1544,00	647,97
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	50030	9,8	300	150	0,00	0,00	299,93
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	50030	11	6,4	3,2	0,00	0,00	0,00
NPL	n	UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	50067	57,7	33,3			37,00	32,68
IPQ		PT	S8P	Sep 02	0,25	2,5	0,1		0,5	49840	560	1124,51	562,255	0,17	190,00	1124,49
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		50202	109,9	220			172,00	219,91
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	49805	176	1023	511,5	0,22	225,00	1022,98
									Mean	49804,54	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	458,41	nm	50030,0	3,2	6,4	0,3	9

0=not measured

i=incomplete

n=excluded (En>1)

SMU	**excluded see Main ch 8.1**
1. METAS	**En = 3,37**
2. CGM	**En = 2,38**
3. NPL	**En = 1,05**


Geometry standard P114A/528-RS5

$RSm_i \pm U(RSm_i)$, $RSm_{ref} \pm U(RSm_{ref})(E_n<1)$

 # open symbol shows corrected value of

CGM	*RSm* = (50036 +/- 649) nm
METAS	*RSm* = (50044 +/- 28) nm
NPL	*RSm* = (50067 +/- 11,6) nm
SP	*RSm* = (50030 +/- 50) nm

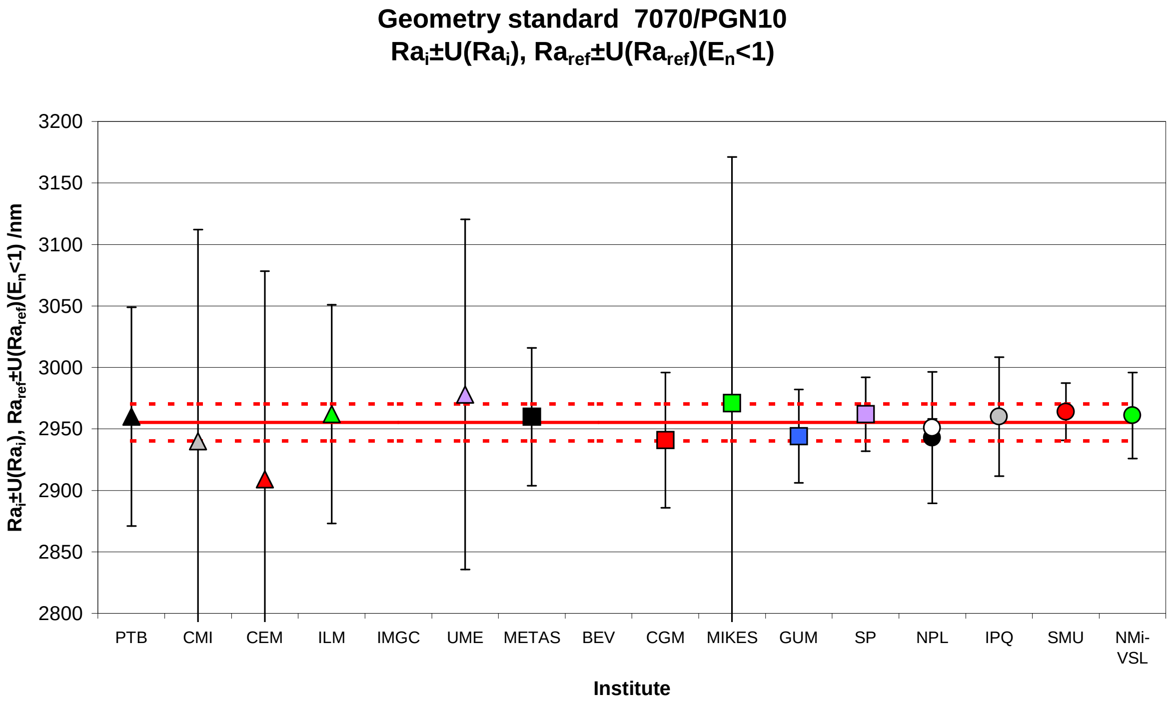
2. ROUGHNESS STANDARD 7070/PGN10

Results of *Ra*

Institute	Ra	Country	Instrumen	Measured Date						7070	7070	7070	7070	7070	7070	7070
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	2960	30	89	44,5	0,05	4,80	87,73
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	2940	10	172	86	0,09	15,20	171,34
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	2909	7	169,32	84,66	0,27	46,20	168,65
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	2962	14	89,001	44,50028	0,08	6,80	87,73
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	2978	11,9	142,3	71,15	0,16	22,80	141,51
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		2960	10	56	28	0,08	4,80	53,95
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	2941	10	55	27,5	0,25	14,20	52,92
MIKES		FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250	2971	14,47	200	100	0,08	15,80	199,44
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	2944	12,4	38	19	0,27	11,20	34,91
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	2962	12	30,14	15,069912	0,20	6,80	26,14
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	2943	92,6	53,5	26,75	0,22	12,20	51,35
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	2960	10	48,3	24,15	0,09	4,80	45,91
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		2964	2,2	23,3			8,80	17,83
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	2961	13	35	17,5	0,15	5,80	31,62
0=not measured									Mean	2953,93	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
i=incomplete									Stdev	17,23	nm	2955,2	7,5	15,0	0,4	13

n=excluded (En>1)

SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Ra* = (2951 +/- 7,3) nm

Results of *Rz*

Institute	Rz	Country	Instrumen	Measured Date	λc	λs	Speed	Force	Sampl-dist	7070 Rz	7070 s	7070 U(k=2)	7070 uc=U/2	7070 E_n	7070 DoE/|Xir|	7070 DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	9660	70	290	145	0,09	25,60	289,15
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	9547	27	248	124	0,56	138,60	247,00
CEM	n	ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	9476	39	181,9			209,60	180,54
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	9735	66	389,46	194,73146	0,13	49,40	388,83
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	9730	46,8	142,3	71,15	0,31	44,40	140,56
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		9630	30	397	198,5	0,14	55,60	396,38
BEV	0	A	IM	Nov 01												
CGM	n	DK	FTS	Jan 02	2,5	8	0,1	1	1,5	9599	34	70			86,60	66,39
MIKES		FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250	9711	54,45	300	150	0,08	25,40	299,18
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	9614	45,5	91	45,5	0,76	71,60	88,25
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	9661	41	95,206	47,603235	0,25	24,60	92,58
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	9694	43,9	25,4	12,7	0,25	8,40	12,34
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	9690	40	116,05	58,025	0,04	4,40	113,91
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		9721	15,5	33,4			35,40	24,95
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	9655	44	127	63,5	0,24	30,60	125,04
									Mean	9651,64	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	74,07	nm	9685,6	11,1	22,2	0,7	11

0=not measured

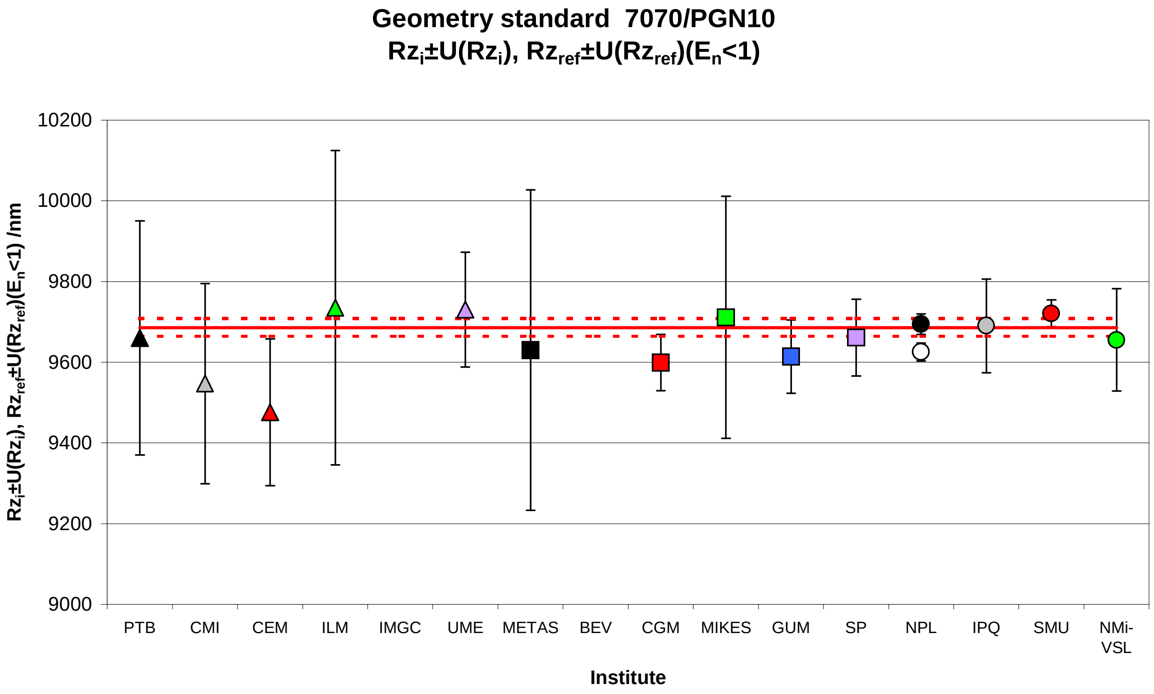
i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. CEM En = 1,09

2. CGM En = 1,07



 # open symbol shows corrected value of

NPL Rz = (9625 +/- 22,2) nm

Results of *Rmax*

Institute	Rmax	Country	Instrumen	Measured Date						7070	7070	7070	7070	7070	7070	7070
					λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	9830	90	295	147,5	0,06	17,50	291,76
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	9654	52	288	144	0,54	158,50	284,68
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	9627	60	735,21	367,605	0,25	185,50	733,92
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	9767	66	390,74	195,37135	0,12	45,50	388,30
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	9914	49,1	142,3	71,15	0,68	101,50	135,46
METAS	0	CH	FTS	Oct 01	2,5	8	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	9773	84	84	42	0,42	39,50	71,80
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	9808	57,6	92	46	0,04	4,50	81,01
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	9828	58	99,528	49,763766	0,14	15,50	89,47
NPL	n	UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	9949	95,2	55			136,50	33,53
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	9850	70	159,79	79,895	0,23	37,50	153,73
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		9888	11,5	25,2				
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	9823	56	151	75,5	0,07	10,50	144,57
									Mean	9809,25	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	95,23	nm	9812,5	21,8	43,6	0,7	10

0=not measured

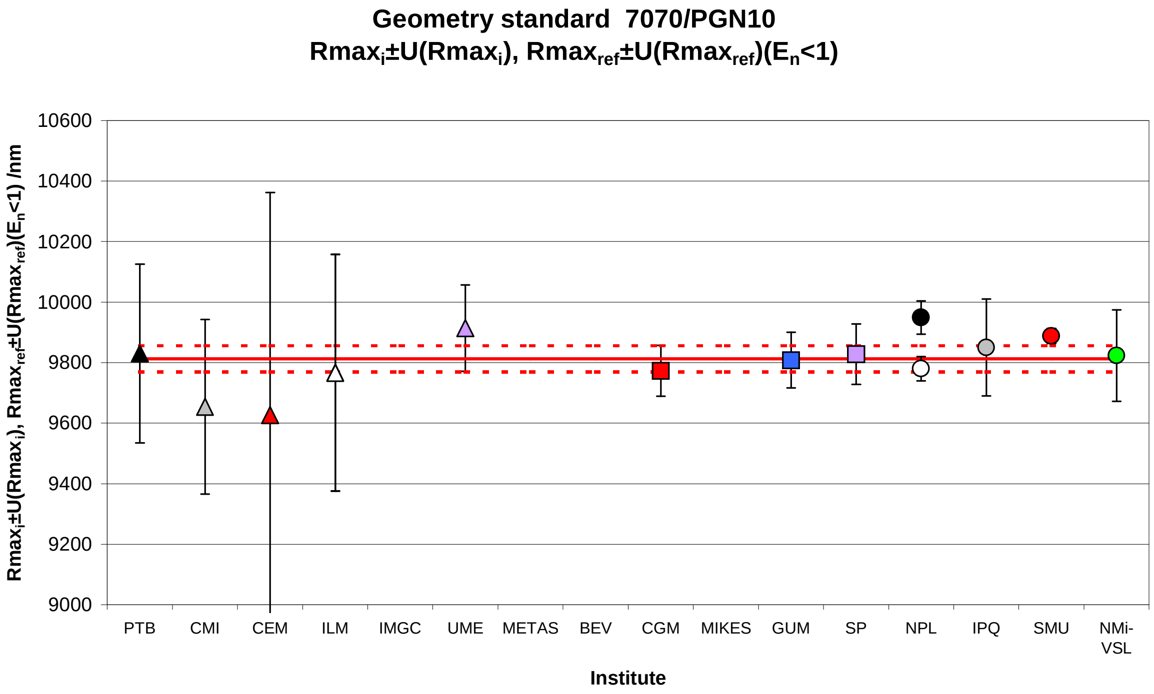
i=incomplete

n=excluded (En>1)

SMU **excluded see Main ch 8.1**

1. NPL **En = 1,29**

DoE (Uir) for SMU cannot be calculated, since $U_i < U_{ref}$



 # open symbol shows corrected value of

ILM	*Rmax* = (9766 +/- 391) nm
NPL	*Rmax* = (9780 +/- 40) nm

Results of *RSm*

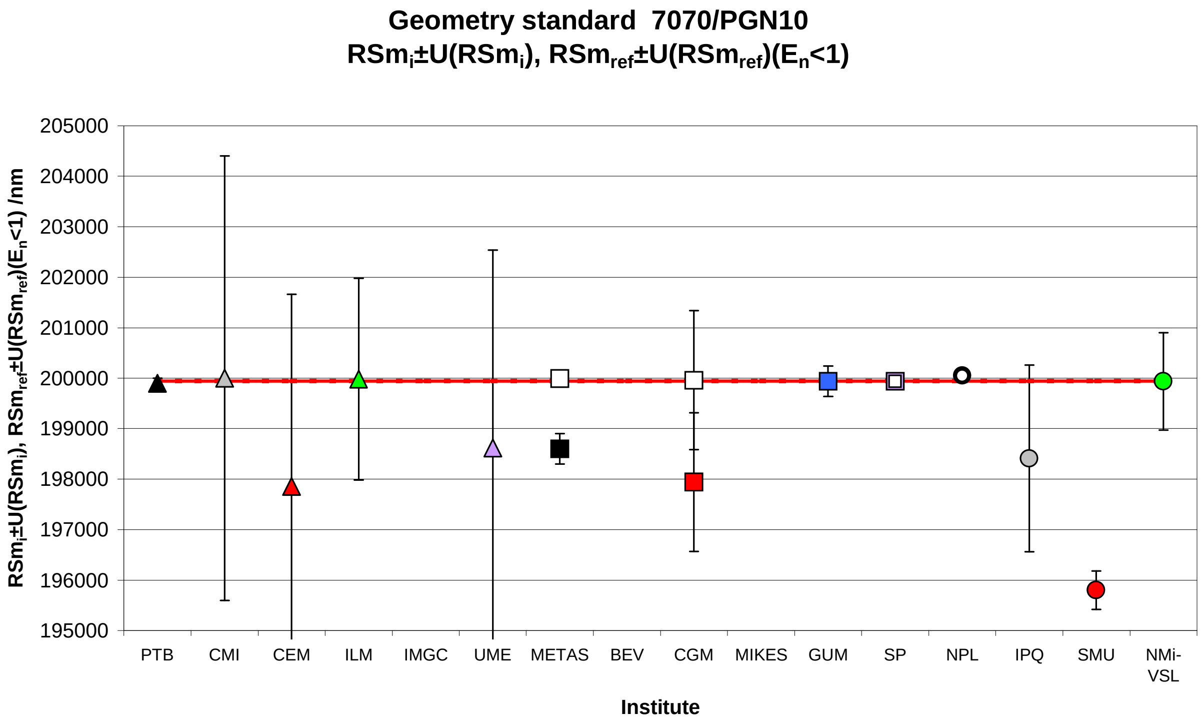
Institute	RSm	Country	Instrumen	Measured Date						7070	7070	7070	7070	7070	7070	7070
					λc	λs	Speed	Force	Sampl-dist	RSm	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	199900	100	100	50	0,39	39,40	99,35
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	200000	0	4400	2200	0,01	60,60	4399,99
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	197853	33	3807,69	1903,845	0,55	2086,40	3807,67
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	199980	21	1999,8	999,9	0,02	40,60	1999,77
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	198617	21,1	3920,4	1960,2	0,34	1322,40	3920,38
METAS	n	CH	FTS	Oct 01	2,5	8	0,5	<1		198600	512	301			1339,40	300,78
BEV	0	A	IM	Nov 01												
CGM	n	DK	FTS	Jan 02	2,5	8	0,1	1	1,5	197942	140	1376			1997,40	1375,95
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	199940	19,6	300	150	0,00	0,60	299,78
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	199940	20	11,54701	5,7735027	0,04	0,60	1,84
NPL	n	UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	200052	72,6	41,9			112,60	40,32
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	198410	0	1847,95	923,975	0,83	1529,40	1847,91
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		195800	190	380,1			4139,40	379,93
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	199937	24	964	482	0,00	2,40	963,93
									Mean	198997,77	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	1286,21	nm	199939,4	5,7	11,4	0,8	9

0=not measured

i=incomplete

n=excluded (En>1)

SMU	**excluded see Main ch 8.1**
1. METAS	**En = 4,47**
2. NPL	**En = 2,42**
3. CGM	**En = 1,45**



 # open symbol shows corrected value of

CGM	*RSm* = (199960 +/- 1376) nm
METAS	*RSm* = (199987 +/- 70) nm
NPL	*RSm* = (200049 +/- 30,2) nm
SP	*RSm* = (199940 +/- 51) nm

3. ROUGHNESS STANDARD 8194/PGN3

Results of *Ra*

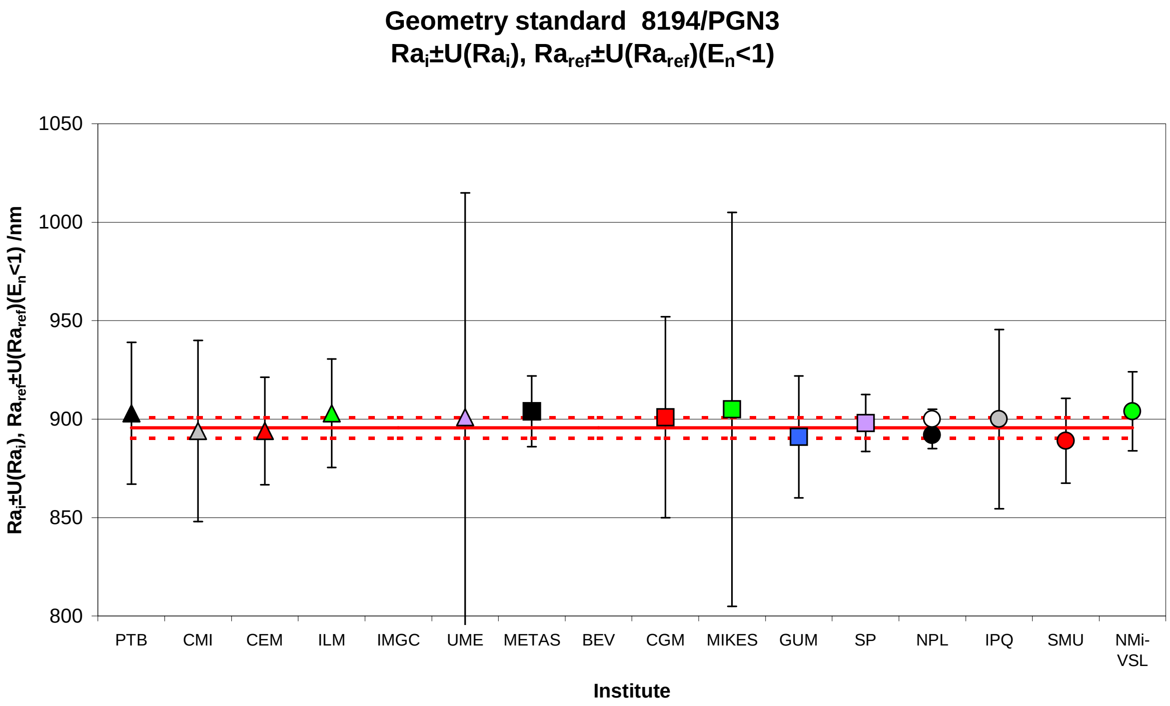
Institute	Ra	Country	Instrumen	Measured Date						8194	8194	8194	8194	8194	8194	8194
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	903	7	36	18	0,20	7,40	35,62
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	894	8	46	23	0,03	1,60	45,71
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	894	7,5	27,33	13,665	0,06	1,60	26,83
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	903	7	27,548	13,77378	0,26	7,40	27,05
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	901	6,4	113,9	56,95	0,05	5,40	113,78
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		904	8	18	9	0,45	8,40	17,23
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,1	1	0,5	901	10	51	25,5	0,11	5,40	50,73
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	905	11,71	100	50	0,09	9,40	99,86
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	891	6,5	31	15,5	0,15	4,60	30,56
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	898	15	14,439	7,2195693	0,16	2,40	13,47
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	892	12	7	3,5	0,41	3,60	4,69
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	900	10	45,46	22,73	0,10	4,40	45,16
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		889	0,9	21,5			6,60	20,86
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	904	7	20	10	0,41	8,40	19,31
									Mean	898,50	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	5,46	nm	895,6	2,6	5,2	0,5	13

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

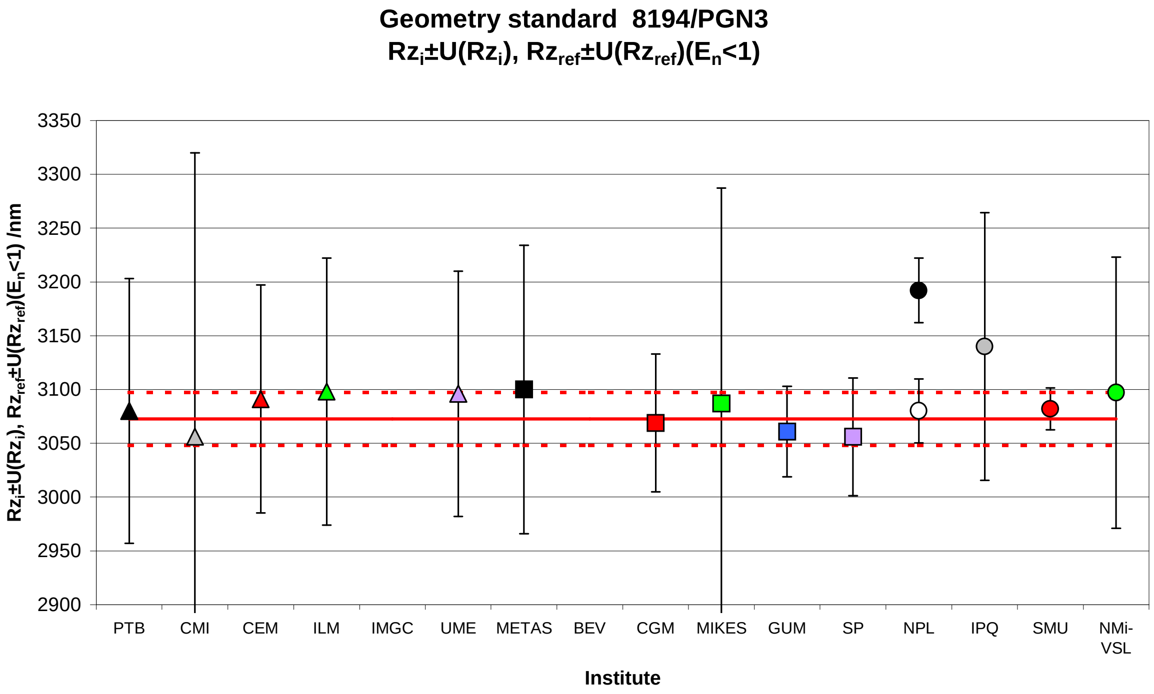
NPL *Ra* = (900 +/- 5,1) nm

Results of *Rz*

Institute	Rz	Country	Instrumen	Measured Date						8194	8194	8194	8194	8194	8194	8194
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	3080	60	123	61,5	0,06	7,30	120,51
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	3056	47	264	132	0,06	16,70	262,85
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	3091	50,9	105,96	52,98	0,17	18,30	103,06
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	3098	51	124,12	62,058775	0,20	25,30	121,66
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	3096	48,7	113,9	56,95	0,20	23,30	111,21
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		3100	55	134	67	0,20	27,30	131,72
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,1	1	0,5	3069	48	64	32	0,05	3,70	59,08
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	3087	56,45	200	100	0,07	14,30	198,48
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	3061	53,5	42	21	0,24	11,70	34,04
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	3056	73	54,755	27,377424	0,28	16,70	48,92
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	3192	52	30,1			119,30	17,35
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	3140	50	124,37	62,185	0,53	67,30	121,91
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		3082	7,9	19,6				
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	3097	53	126	63	0,19	24,30	123,58
									Mean	3093,21	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	35,92	nm	3072,7	12,3	24,6	0,5	12

0=not measured
i=incomplete
n=excluded (En>1)
SMU **excluded see Main ch 8.1**
1. NPL **En = 2,01**

DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$



 # open symbol shows corrected value of

NPL *Rz* = (3080 +/- 29,7) nm

Results of *Rmax*

Institute	Rmax	Country	Instrumen	Measured						8194	8194	8194	8194	8194	8194	8194
				Date	λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	3100	70	124	62	0,05	6,30	121,77
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	3073	50	356	178	0,06	20,70	355,23
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	3113	55,6	215,11	107,555	0,09	19,30	213,83
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	3112	51	124,68	62,338332	0,14	18,30	122,46
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	3113	48,5	113,9	56,95	0,17	19,30	111,47
METAS	0	CH	FTS	Oct 01	0,8	2,5	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,1	1	0,5	3087	50	65	32,5	0,10	6,70	60,64
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	3081	5,7	39	19,5	0,28	12,70	31,20
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	3096	41	42,018	21,009199	0,05	2,30	34,90
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	3391	69,1	39,9			297,30	32,32
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	3160	50	127,15	63,575	0,51	66,30	124,98
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		3112	12,4	26,7			18,30	12,86
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	3118	56	138	69	0,17	24,30	136,00
									Mean	3129,67	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	85,25	nm	3093,7	11,7	23,4	0,5	10

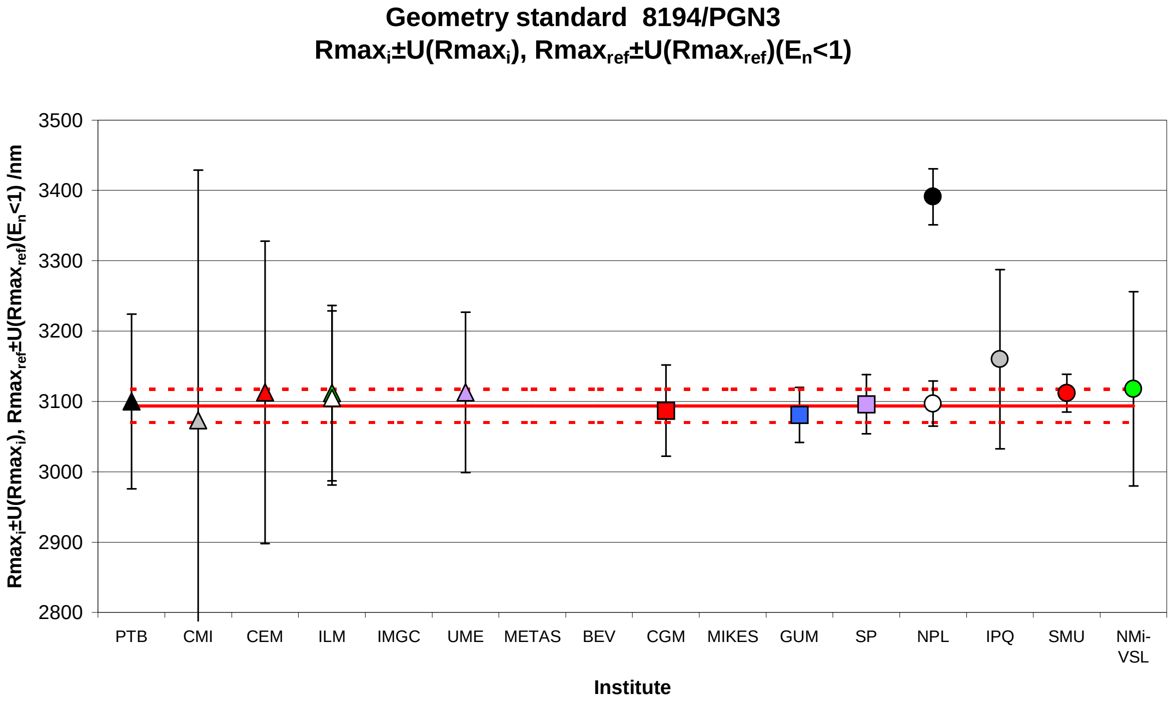
0=not measured

i=incomplete

n=excluded (En>1)

SMU **excluded see Main ch 8.1**

1. NPL **En = 4,93**



 # open symbol shows corrected value of

ILM *Rmax* = (3105 +/- 124) nm

NPL *Rmax* = (3097 +/- 32,3) nm

Results of *RSm*

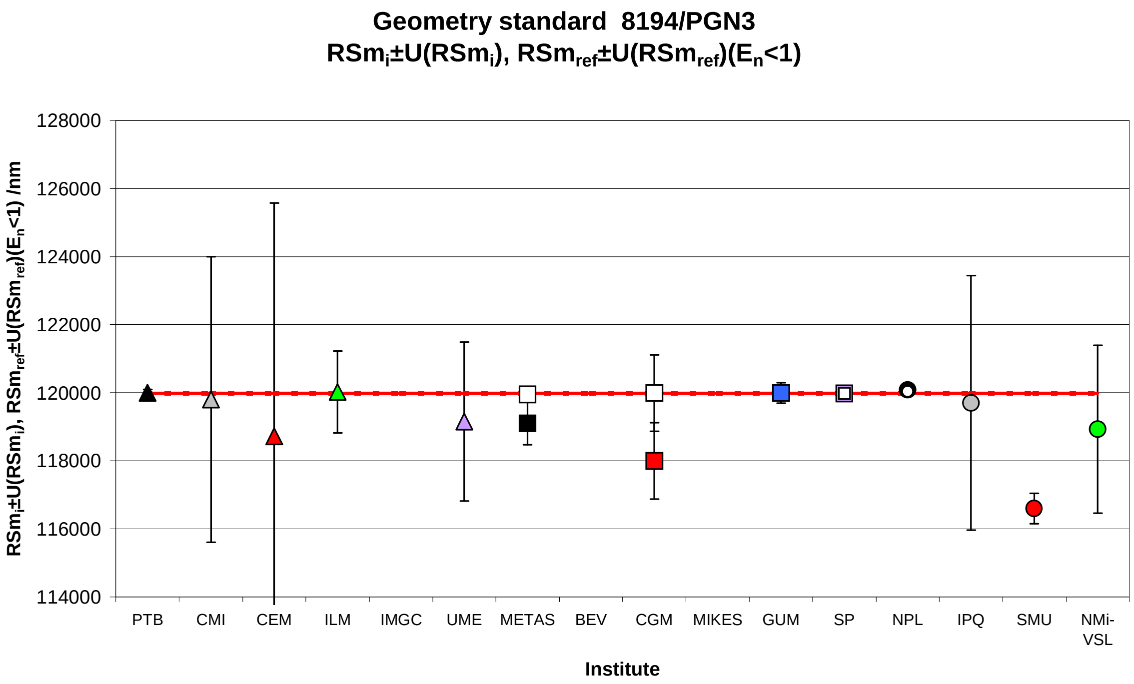
Institute	RSm	Country	Instrumen	Measured Date						8194	8194	8194	8194	8194	8194	8194
					λc	λs	Speed	Force	Sampl-dist	RSm	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	120000	50	100	50	0,19	19,40	98,25
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	119800	1700	4200	2100	0,04	180,60	4199,96
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	118719	46,2	6854,25	3427,125	0,18	1261,60	6854,22
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	120020	48	1200,2	600,1	0,03	39,40	1200,06
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	119149	29	2335,5	1167,75	0,36	831,60	2335,43
METAS	n	CH	FTS	Oct 01	0,8	2,5	0,5	<1		119100	1084	627			880,60	626,72
BEV	0	A	IM	Nov 01												
CGM	n	DK	FTS	Jan 02	0,8	2,5	0,1	1	0,5	117996	1052	1125			1984,60	1124,85
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	119990	29,1	300	150	0,03	9,40	299,42
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	119980	33	19,052559	9,5262794	0,02	0,60	4,13
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	120078	139,6	80,6			97,40	78,42
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	119700	1850	3736,52	1868,26	0,08	280,60	3736,47
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		116600	223,4	446,9			3380,60	446,51
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	118927	1138	2470	1235	0,43	1053,60	2469,93
									Mean	119235,31	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	1018,07	nm	119980,6	9,3	18,6	0,4	9

0=not measured

i=incomplete

n=excluded (En>1)

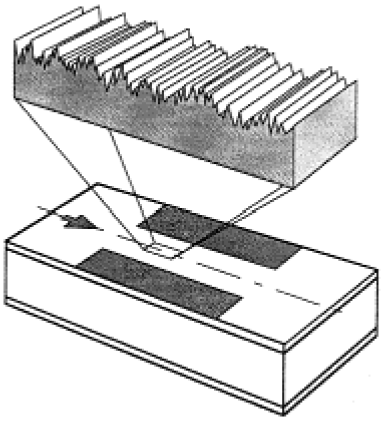
SMU	**excluded see Main ch 8.1**
1. CGM	**En = 1,77**
2. METAS	**En = 1,41**
3. NPL	**En = 1,12**



 # open symbol shows corrected value of

CGM	*RSm* = (119990 +/- 1125) nm
METAS	*RSm* = (119955 +/- 52) nm
NPL	*RSm* = (120030 +/- 25,1) nm
SP	*RSm* = (119980 +/- 54) nm

Appendix D3



Roughness Standard Type D

1 ROUGHNESS STANDARD 686SG

Results of *Ra*

Institute	Ra	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	2350	40	71	35,5	0,30	21,80	69,48
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	2328	35	174	87	0,00	0,20	173,39
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	2303	31	169,41	84,705	0,15	25,20	168,78
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	2335	25	93,534	46,766869	0,07	6,80	92,39
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	2346	32,5	497,6	248,8	0,04	17,80	497,39
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		2360	22	76	38	0,41	31,80	74,58
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	2342	19	57	28,5	0,23	13,80	55,10
MIKES		FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250	2352	23,324	160	80	0,15	23,80	159,33
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	2321	21,1	35	17,5	0,19	7,20	31,81
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	2319	29	29,541	14,770426	0,28	9,20	25,68
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	2316	49,5	28,6	14,3	0,38	12,20	24,59
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	2370	30	73,26	36,63	0,56	41,80	71,79
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		2424	6,2	25,8			95,80	21,27
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	2351	24	52	26	0,42	22,80	49,91
									Mean	2344,07	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	29,67	nm	2328,2	7,3	14,6	0,6	13

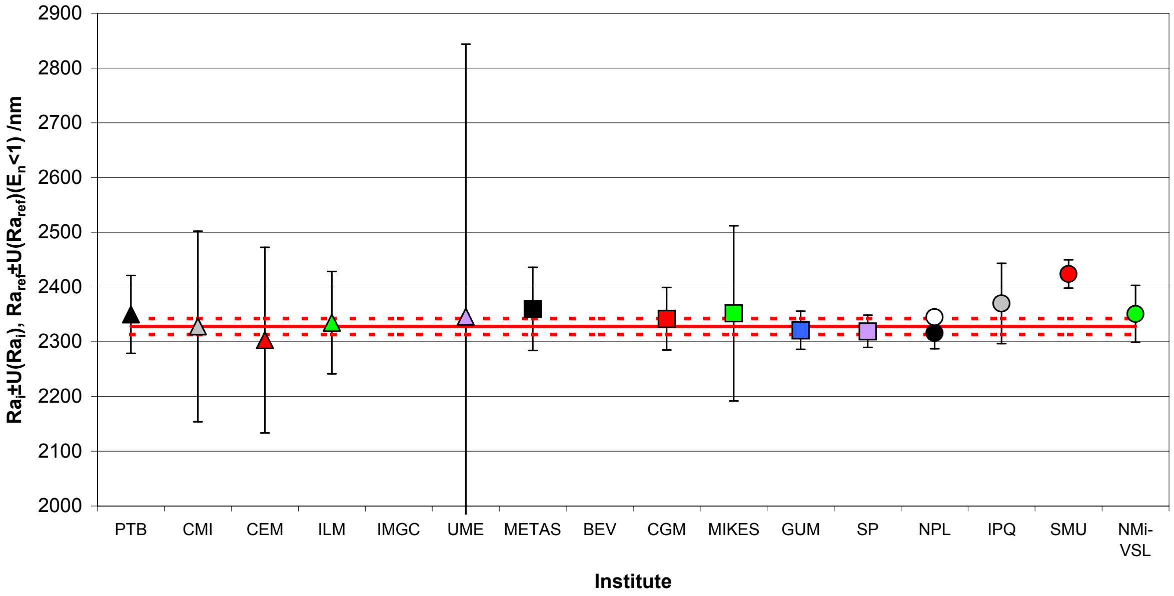
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

Roughness standard 686sg
$Ra_i \pm U(Ra_i)$, $Ra_{ref} \pm U(Ra_{ref})(E_n<1)$



 # open symbol shows corrected value of

NPL *Ra* = (2345 +/- 12,1) nm

Results of *Rz*

Institute	Rz	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	14300	290	429	214,5	0,15	63,30	422,64
CMI	n	CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	13597	438	354			639,70	346,26
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	14046	195	189,75	94,875	0,94	190,70	174,89
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	14308	25	715,43	357,71712	0,10	71,30	711,64
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	14300	258,1	497,6	248,8	0,13	63,30	492,13
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		14450	297	895	447,5	0,24	213,30	891,97
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	14257	326	200	100	0,10	20,30	185,97
MIKES		FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250	14341	274,76	500	250	0,21	104,30	494,55
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	14220	291,8	160	80	0,09	16,70	142,07
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	14190	164	162,7	81,349766	0,26	46,70	145,10
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	14353	305,1	176,2	88,1	0,61	116,30	160,09
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	14750	270	544,67	272,335	0,93	513,30	539,67
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		13559	123,7	247,6			677,70	236,41
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	14330	272	556	278	0,17	93,30	551,11
									Mean	14214,36	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	310,82	nm	14236,7	36,8	73,6	1,0	12

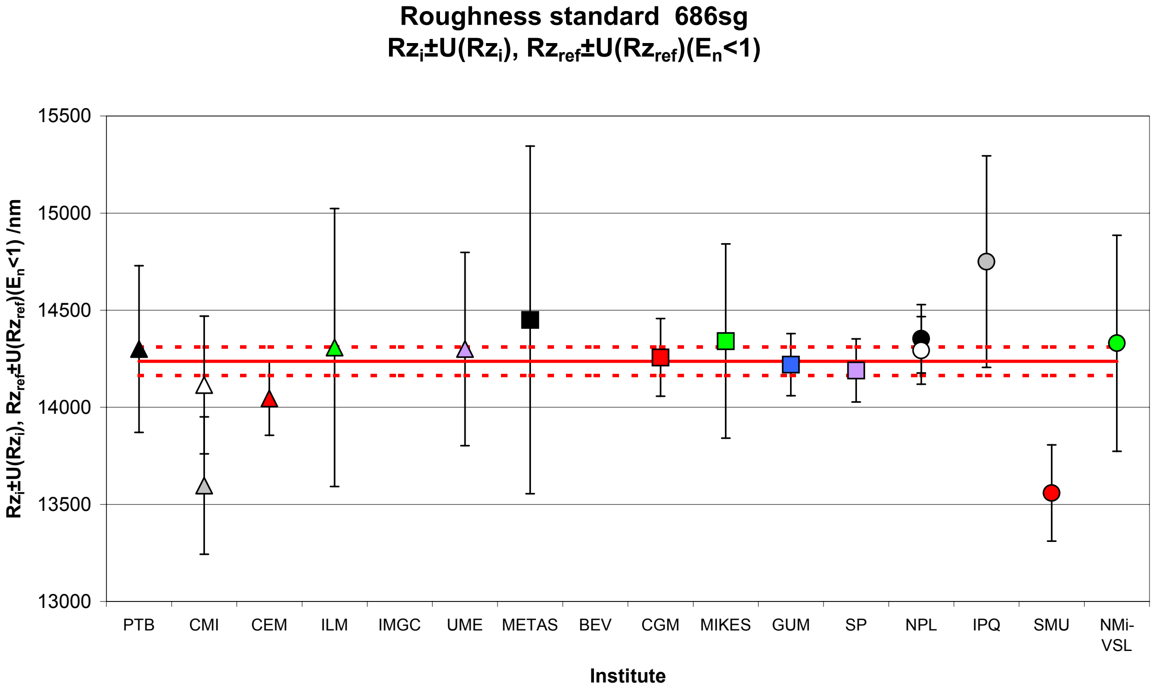
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. CMI En = 1,7



 # open symbol shows corrected value of

CMI *Rz* = (14115 +/- 354) nm
NPL *Rz* = (14293 +/- 174,1) nm

Results of *Rmax*

Institute	Rmax	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	15600	70	468	234	0,39	183,40	465,43
CMI	n	CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	15328	62	310			455,40	306,10
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	15297	47	1128,7	564,325	0,43	486,40	1127,59
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	15568	40	778,43	389,21574	0,28	215,40	776,89
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	15534	28,9	497,6	248,8	0,50	249,40	495,18
METAS	0	CH	FTS	Oct 01	2,5	8	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	15755	91	86	43	0,29	28,40	70,68
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	15380	30	140			403,40	131,14
SP	n	SE	FTS	May 02	2,5	8	0,5	0,7	0,25	15466	53	145,83			317,40	137,35
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	15791	120,7	69,7	34,85	0,09	7,60	49,57
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	15860	30	125,57	62,785	0,57	76,60	115,61
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		14675	189,3	378,7			1108,40	375,52
NMi-VSL	n	NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	15567	36	148			216,40	139,65
									Mean	15485,08	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	310,99	nm	15783,4	24,5	49,0	0,9	7

0=not measured

i=incomplete

n=excluded (En>1)

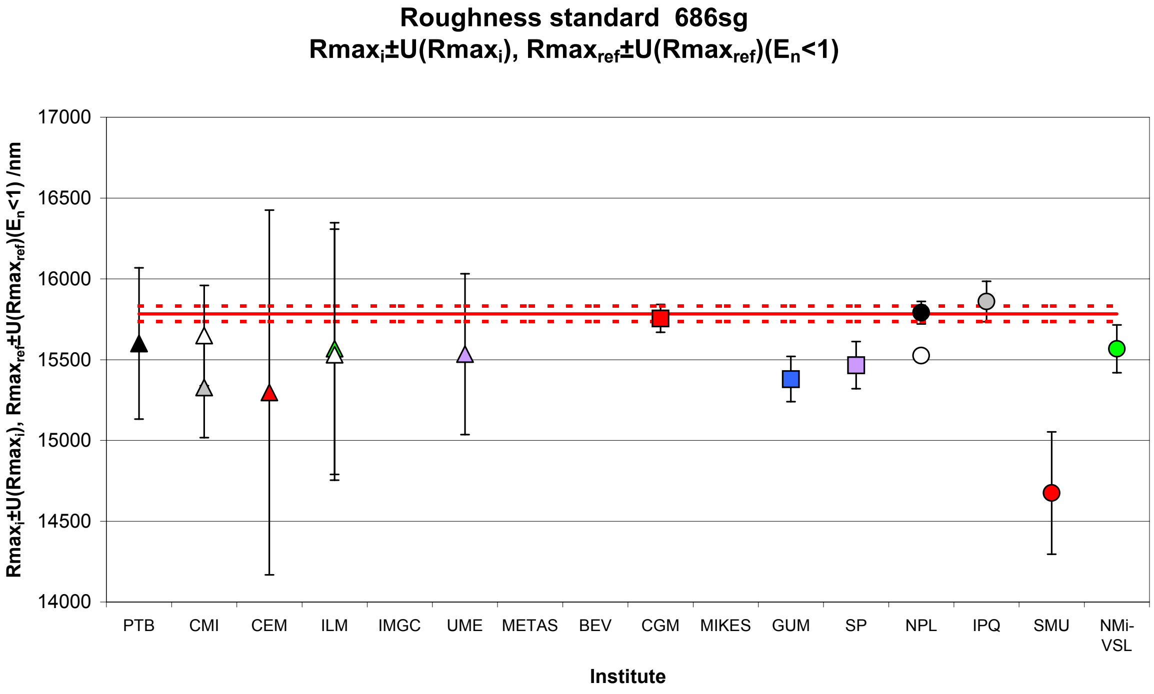
SMU excluded see Main ch 8.1

1. GUM En = 2,16

2. SP En = 1,71

3. CMI En = 1,35

4. Nmi-VSL En = 1,26



 # open symbol shows corrected value of

CMI *Rmax* = (15649 +/- 310) nm

ILM *Rmax* = (15531 +/- 777) nm

NPL *Rmax* = (15525 +/- 27,1) nm

Results of *Rk*

Institute	Rk	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Rk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	8180	210	327	163,5	0,16	54,40	323,31
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	8027	242	1698	849	0,06	98,60	1697,29
CEM	n	ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	7930	237	70			195,60	49,99
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	8230	218	411,56	205,77977	0,25	104,40	408,63
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	8137	297,5	634,4	317,2	0,02	11,40	632,50
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		8040	186	275	137,5	0,31	85,60	270,60
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	8203	109	86	43	0,78	77,40	70,68
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	8051	56,2	72	36	0,86	74,60	52,75
SP	n	SE	FTS	May 02	2,5	8	0,5	0,7	0,25	8361	216	150,36			235,40	142,15
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	8215	289,2	167	83,5	0,51	89,40	159,65
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	8250	150	304,41	152,205	0,40	124,40	300,44
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		8278	27,4	54,7			152,40	24,31
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	8075	143	293	146,5	0,17	50,60	288,87
									Mean	8152,08	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	121,25	nm	8125,6	24,5	49,0	1,1	10

0=not measured

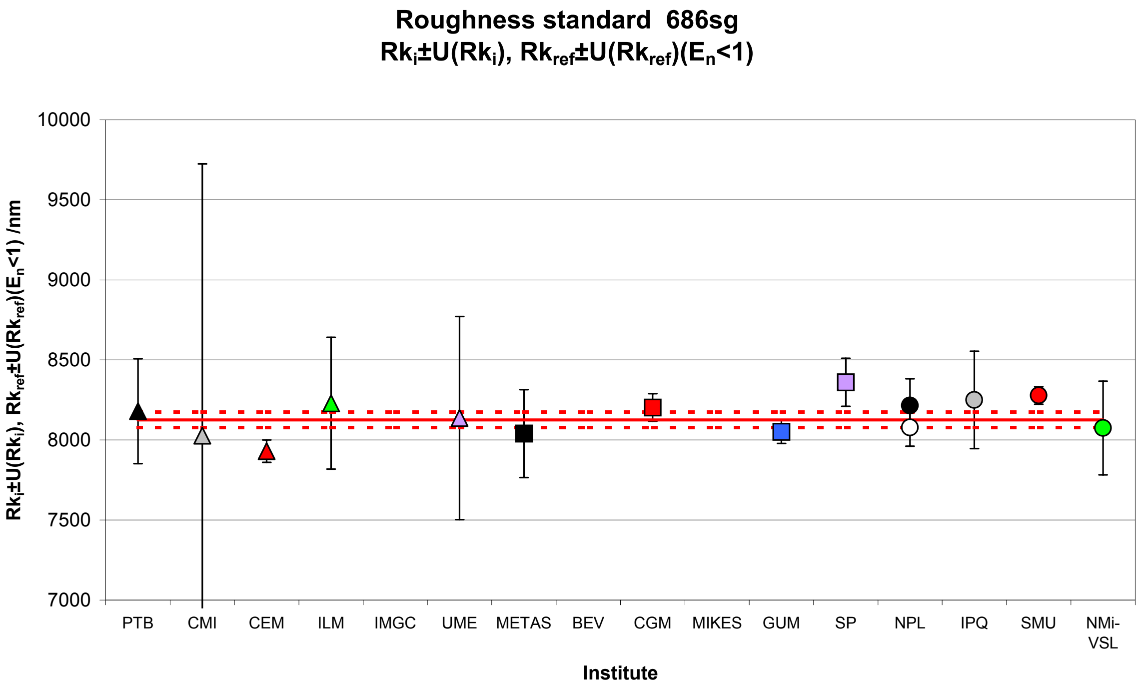
i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. CEM En = 1,89

2. SP En = 1,35



 # open symbol shows corrected value of

NPL *Rk* = (8078+/- 116,9) nm

Results of *R*pk

Institute	Rpk	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Rpk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB	n	DE	NS	May 01	2,5	8	0,1	1	0,2	1200	100	24			58,60	13,56
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	1226	59	212	106	0,15	32,60	211,07
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	1275	95	30	15	0,46	16,40	22,54
ILM	n	IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	1381	94	69,404			122,40	66,52
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	1231	125,8	634,4	317,2	0,04	27,60	634,09
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		1260	52	83	41,5	0,02	1,40	80,60
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	1206	53	64	32	0,79	52,60	60,86
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	1390	51,7	35			131,40	28,86
SP	n	SE	FTS	May 02	2,5	8	0,5	0,7	0,25	1372	87	60,648			113,40	57,32
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	1251	56,9	32,9	16,45	0,20	7,60	26,27
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	1290	80	166,23	83,115	0,19	31,40	165,05
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		1203	10,6	21,9			55,60	9,36
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	1276	66	132	66	0,13	17,40	130,51
									Mean	1273,92	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	67,57	nm	1258,6	9,9	19,8	0,8	8

0=not measured

i=incomplete

n=excluded (En>1)

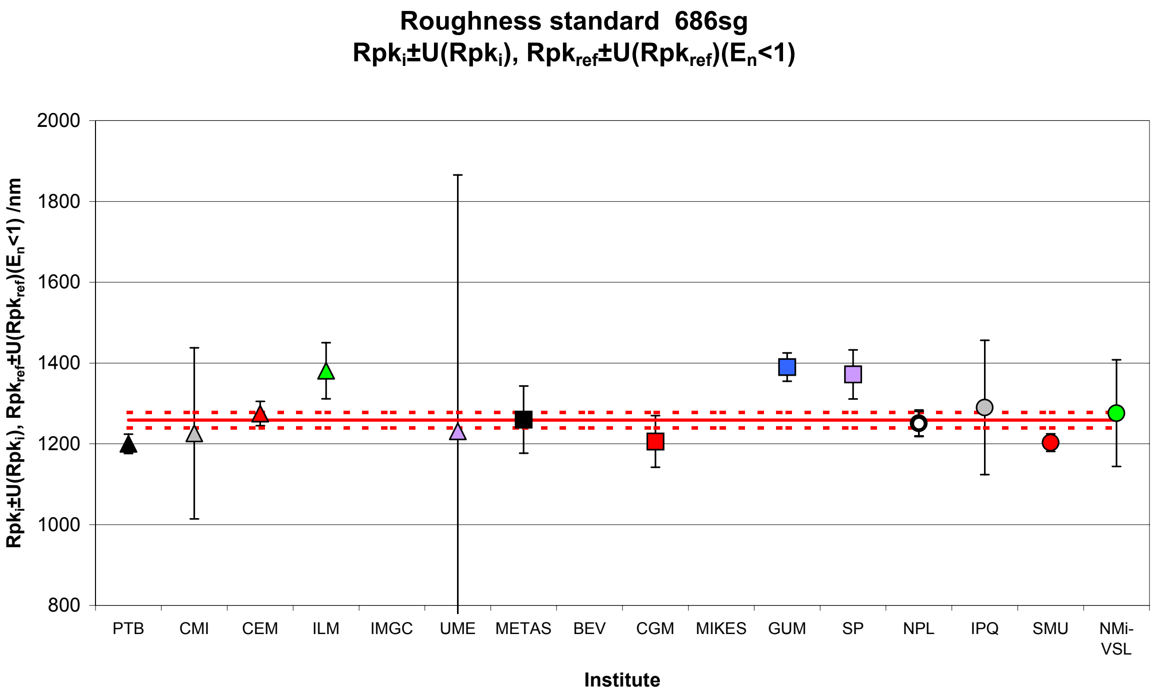
SMU excluded see Main ch 8.1

1. GUM En = 3,21

2. SP En = 1,97

3. ILM En = 1,96

4. PTB En = 1,22



 # open symbol shows corrected value of

NPL *Rpk* = (1250 +/- 30,3) nm

Results of *R*vk

Institute	Rvk	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Rvk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	3110	210	93	46,5	0,25	25,00	83,67
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	3214	362	260	130	0,30	79,00	256,81
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	3110	193	57	28,5	0,36	25,00	40,01
ILM	n	IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	3514	297	175,84			379,00	171,09
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	3110	130,3	634,4	317,2	0,04	25,00	633,10
METAS		CH	FTS	Oct 01	2,5	8	0,5	<1		3020	352	274	137	0,42	115,00	270,98
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	3251	250	155	77,5	0,72	116,00	149,59
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	3210	339,2	120	60	0,59	75,00	112,92
SP	n	SE	FTS	May 02	2,5	8	0,5	0,7	0,25	3701	98	73,033			566,00	60,71
NPL	n	UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	3326	299,6	173			191,00	168,17
IPQ		PT	S8P	Sep 02	2,5	8	0,5		1,5	3300	170	343,75	171,875	0,48	165,00	341,34
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		2939	66,1	132,3			196,00	125,92
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	3121	89	181	90,5	0,08	14,00	176,39
									Mean	3225,08	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	204,38	nm	3135,0	20,3	40,6	0,9	9

0=not measured

i=incomplete

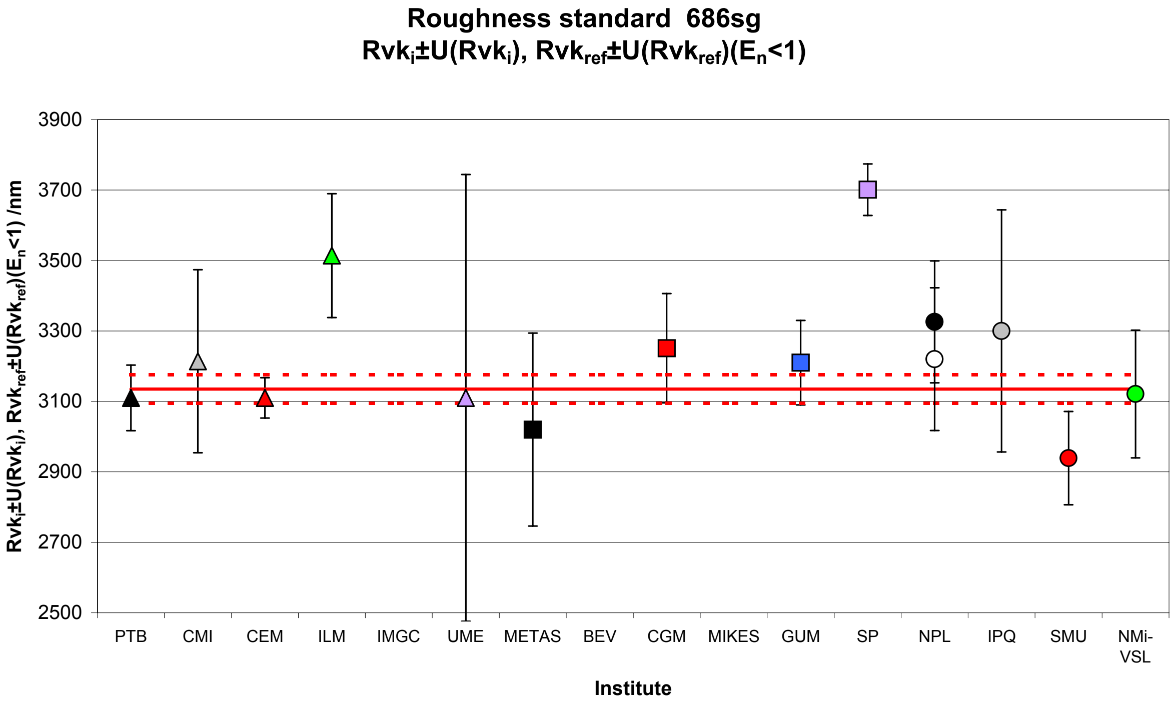
n=excluded (En>1)

SMU excluded see Main ch 8.1

1. SP En = 5,21

2. ILM En = 1,95

3. NPL En = 1,02



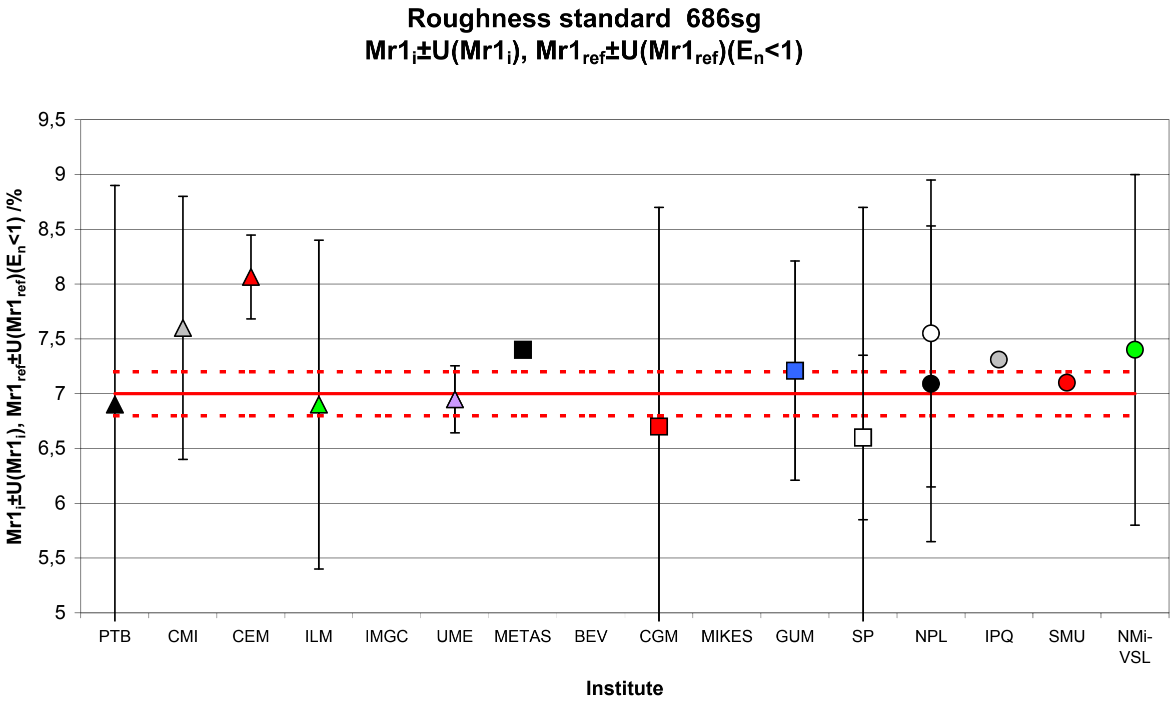
 # open symbol shows corrected value of

NPL *Rvk* = (3220+/- 202,6) nm

Results of *Mr1*

Institute	Mr1	Country	Instrument	Measured Date	λc	λs	Speed	Force	Sampl-dist	Mr1	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
										686sg	686sg	686sg	686sg	686sg	686sg	686sg
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	6,9	1,1	2	1	0,05	0,10	1,99
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	7,6	0,8	1,2	0,6	0,49	0,60	1,18
CEM	n	ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	8,065	1,011	0,382			1,07	0,33
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	6,9	0,9	1,5	0,75	0,07	0,10	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	6,948	1,235	0,306	0,153	0,14	0,05	0,23
METAS	i	CH	FTS	Oct 01	2,5	8	0,5	<1		7,4	0,5					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	6,7	0,6	2	1	0,15	0,30	1,99
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	7,21	0,37	1	0,5	0,21	0,21	0,98
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	6,6	1,3	0,751	0,375278	0,51	0,40	0,72
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	7,09	1	1,44	0,72	0,06	0,09	1,43
IPQ	i	PT	S8P	Sep 02	2,5	8	0,5		1,5	7,31	0,67					
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		7,1	125,1					
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	7,4	0,6	1,6	0,8	0,25	0,40	1,59
									Mean	7,17	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	0,39	%	7,0	0,1	0,2	0,6	9

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. CEM En = 1,77


Roughness standard 686sg
$Mr1_i \pm U(Mr1_i)$, $Mr1_{ref} \pm U(Mr1_{ref})(E_n<1)$

 # open symbol shows corrected value of

NPL	*Mr1* = (7,55 +/- 1,4) %
CGM	*Mr1* = (6,6 +/- 2,1 %

Results of *Mr2*

Institute	Mr2	Country	Instrument	Measured Date						686sg	686sg	686sg	686sg	686sg	686sg	686sg
					λc	λs	Speed	Force	Sampl-dist	Mr2	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	μm	mm/s	mN	μm	%	%	%	%		%	%
PTB		DE	NS	May 01	2,5	8	0,1	1	0,2	92,5	0,5	4	2	0,20	0,80	3,99
CMI		CZ	HT	Jun 01	2,5	8	0,5	0,75	1,3	92,7	0,9	2,2	1,1	0,27	0,60	2,19
CEM		ES	MPC	Jul 01	2,5	8	0,5	0,4	1,5	92,839	0,665	0,461	0,2305	0,92	0,46	0,42
ILM		IT	FTS	Aug 01	2,5	8	0,5	0,75	0,25	93,2	0,8	1,5	0,75	0,07	0,10	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	2,5	8,33	0,5	0,9	0,5	92,85	0,807	4,085	2,0425	0,11	0,45	4,08
METAS	i	CH	FTS	Oct 01	2,5	8	0,5	<1		92,2	0,7					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	2,5	8	0,1	1	1,5	92,8	0,3	2	1	0,25	0,50	1,99
MIKES	0	FI	FTS	Feb 02	2,500	8,000	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	2,5	8	0,5	<1	0,25	91,7	0,54	1			1,60	0,98
SP		SE	FTS	May 02	2,5	8	0,5	0,7	0,25	93,6	0,5	0,289	0,144338	0,85	0,30	0,21
NPL		UK	NS4	Jul 02	2,5	8,0	0,1	<0.1	1,5	93,08	0,94	1,43	0,715	0,15	0,22	1,42
IPQ	i	PT	S8P	Sep 02	2,5	8	0,5		1,5	93,04	0,31					
SMU	n	CS	FTS	Nov 02	2,5	8	1	1		92,7	82,4					
NMi-VSL		NL	FTS	Mrz 03	2,5	8	0,5	0,55	0,25	92,5	0,5	1,3	0,65	0,61	0,80	1,28
									Mean	92,75	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	0,47	%	93,3	0,1	0,2	1,2	9

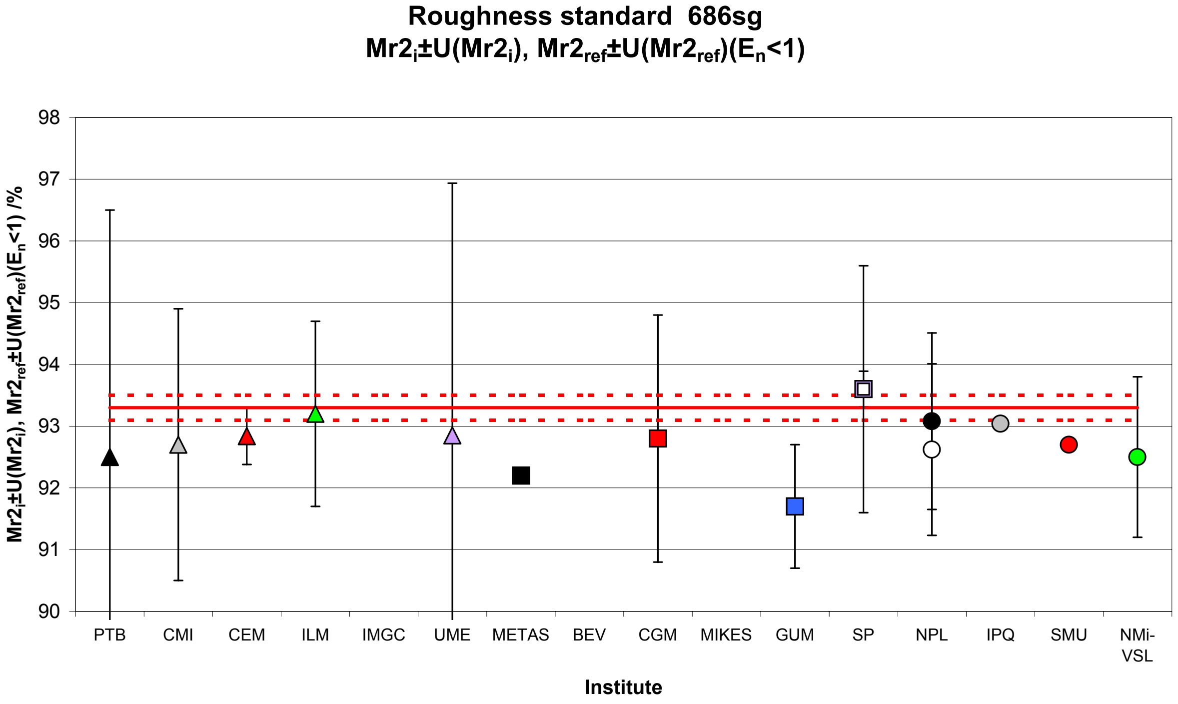
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. GUM En = 1,47



 # open symbol shows corrected value of

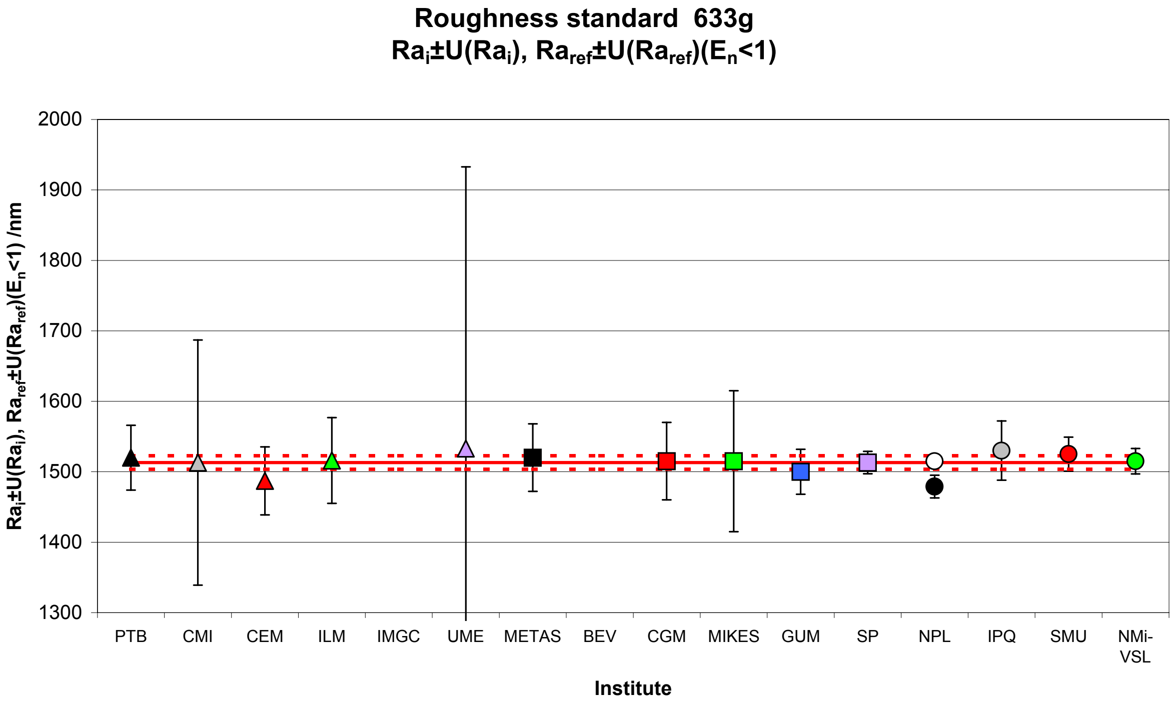
NPL	*Mr2* = (92,62 +/- 1,39) %
SP	*Mr2* = (93,6 +/- 2,0) %

2 ROUGHNESS STANDARD 633G

Results of *Ra*

Institute	Ra	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	1520	10	46	23	0,15	7,00	44,99
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	1513	23	174	87	0,00	0,00	173,73
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	1487	9,4	48,17	24,085	0,53	26,00	47,20
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	1516	2	60,846	30,422893	0,05	3,00	60,08
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	1533	8,2	399,7	199,85	0,05	20,00	399,58
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		1520	3	48	24	0,14	7,00	47,03
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	1515	4	55	27,5	0,04	2,00	54,16
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	1515	2,563	100	50	0,02	2,00	99,54
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	1500	2,1	32	16	0,39	13,00	30,53
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	1513	2	15,897	7,9485222	0,00	0,00	12,67
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	1479	27,8	16,1			34,00	12,92
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	1530	0	42,03	21,015	0,39	17,00	40,92
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		1525	4,9	24,2			12,00	22,21
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	1515	1	18	9	0,10	2,00	15,23
									Mean	1512,93	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	15,07	nm	1513,0	4,8	9,6	0,5	12

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. NPL En = 1,38



 # open symbol shows corrected value of

NPL *Ra* = (1515 +/- 1,8) nm

Results of *Rz*

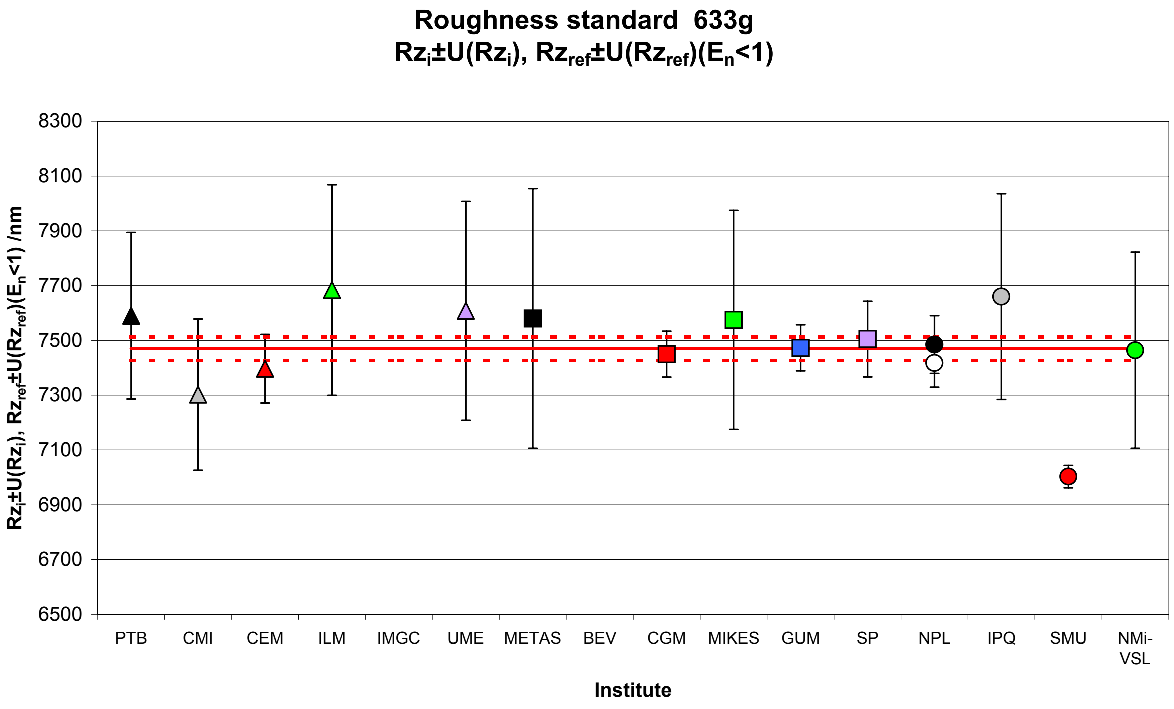
Institute	Rz	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	7590	240	304	152	0,39	120,10	301,00
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	7302	208	276	138	0,60	167,90	272,69
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	7397	195	125,28	62,64	0,55	72,90	117,81
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	7684	113	384,26	192,13188	0,55	214,10	381,90
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	7608	197,8	399,7	199,85	0,34	138,10	397,42
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		7580	188	474	237	0,23	110,10	472,08
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	7450	88	84	42	0,21	19,90	72,40
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	7575	177,25	400	200	0,26	105,10	397,73
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	7473	146,7	84	42	0,03	3,10	72,40
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	7505	203	138,29	69,142517	0,24	35,10	131,56
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	7485	182,9	105,6	52,8	0,13	15,10	96,63
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	7660	180	375,59	187,795	0,50	190,10	373,17
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		7003	26,2	40,9				
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	7464	174	358	179	0,02	5,90	355,46
									Mean	7484,00	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	173,04	nm	7469,9	21,3	42,6	0,8	13

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Rz* = (7418 +/- 88,6) nm

Results of *Rmax*

Institute	Rmax	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	8960	110	269	134,5	0,07	20,20	262,67
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	8941	133	316	158	0,00	1,20	310,63
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	8743	128	667,3	333,65	0,29	196,80	664,77
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	8842	91	442,16	221,07771	0,22	97,80	438,33
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	9041	123	399,7	199,85	0,25	101,20	395,47
METAS	0	CH	FTS	Oct 01	0,8	2,5	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	8883	259	164	82	0,33	56,80	153,40
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	8752	89,1	86			187,80	63,50
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	8868	90	97,79	48,895182	0,63	71,80	78,73
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	9027	189,5	109,4	54,7	0,70	87,20	92,76
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	9080	100	221,28	110,64	0,61	140,20	213,54
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		7913	53,5	107,4			1026,80	90,39
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	8905	121	261	130,5	0,13	34,80	254,47
									Mean	8829,58	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	307,43	nm	8939,8	29,0	58,0	0,9	10

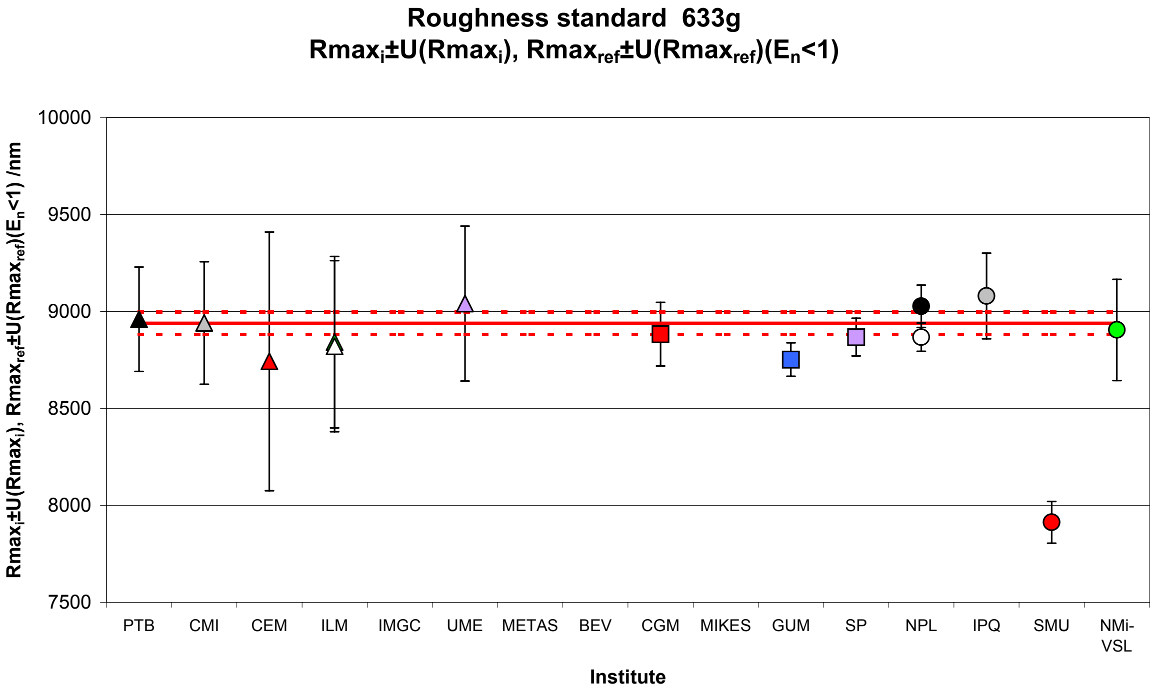
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. GUM En = 1,31



 # open symbol shows corrected value of

ILM	*Rmax* = (8821 +/-441) nm
NPL	*Rmax* = (8868 +/- 73) nm

Results of *Rk*

Institute	Rk	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Rk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	4480	50	179	89,5	0,27	48,30	176,60
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	4359	125	1694	847	0,04	72,70	1693,75
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	4320	66	115	57,5	0,94	111,70	111,23
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	4416	113	220,91	110,45547	0,07	15,70	218,97
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	4464	99,8	523	261,5	0,06	32,30	522,18
METAS	n	CH	FTS	Oct 01	0,8	2,5	0,5	<1		4240	159	163			191,70	160,36
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	4466	19	59	29,5	0,52	34,30	51,27
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	4371	136,2	64	32	0,86	60,70	56,95
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	4382	124	83,068	41,53423	0,56	49,70	77,77
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	4688	178,2	102,9			256,30	98,67
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	4480	30	83,27	41,635	0,55	48,30	77,98
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		4161	24,2	40,9			270,70	28,64
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	4487	26	67	33,5	0,76	55,30	60,30
									Mean	4408,77	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	130,06	nm	4431,7	14,6	29,2	1,3	10

0=not measured

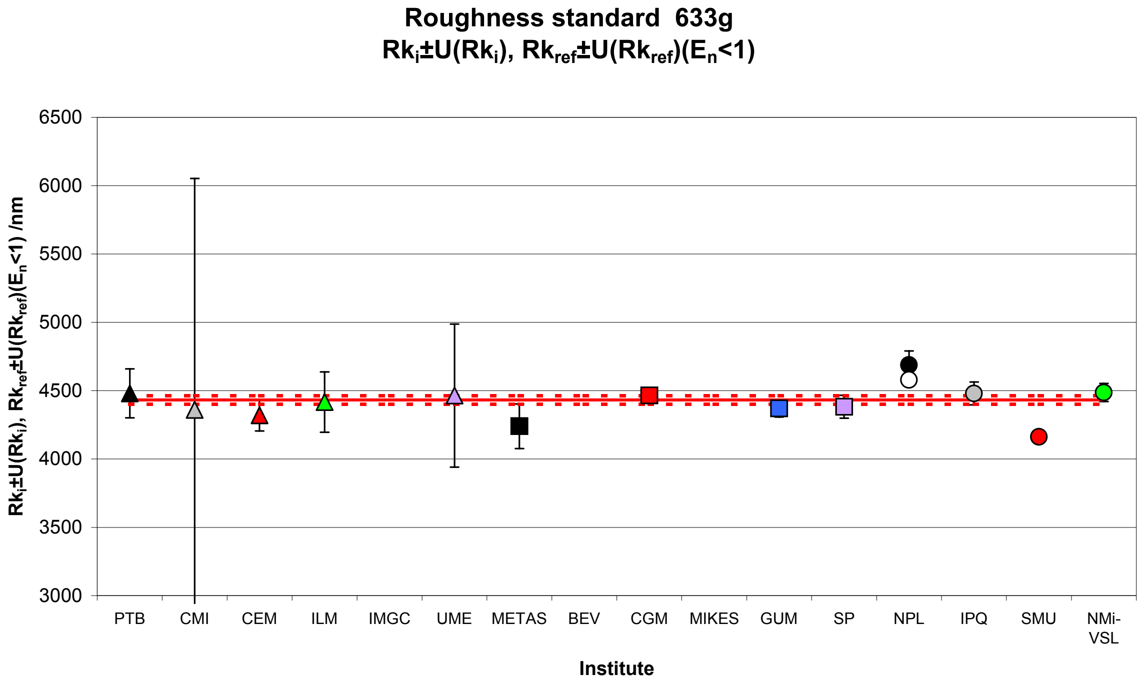
i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. NPL En = 2,28

2. METAS En = 1,12



 # open symbol shows corrected value of

NPL *Rk* = (4579 +/- 41,9) nm

Results of *R*pk

Institute	Rpk	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Rpk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	700	20	14	7	0,41	7,60	6,87
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	863	65	212	106	0,73	155,40	211,65
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	733	34	112	56	0,23	25,40	111,33
ILM	n	IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	906	77	45,838			198,40	44,18
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	739	52,1	523	261,5	0,06	31,40	522,86
METAS	n	CH	FTS	Oct 01	0,8	2,5	0,5	<1		880	144	99			172,40	98,25
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	702	15	56	28	0,10	5,60	54,65
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	833	52,1	35			125,40	32,80
SP	n	SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	896	76	49,6			188,40	48,08
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	869	94,7	54,7			161,40	53,32
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	750	20	58,88	29,44	0,71	42,40	57,60
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		764	15,5	21,9			56,40	18,19
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	732	14	33	16,5	0,69	24,40	30,66
									Mean	797,46	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	77,90	nm	707,6	6,1	12,2	1,1	7

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. ILM En = 3,39

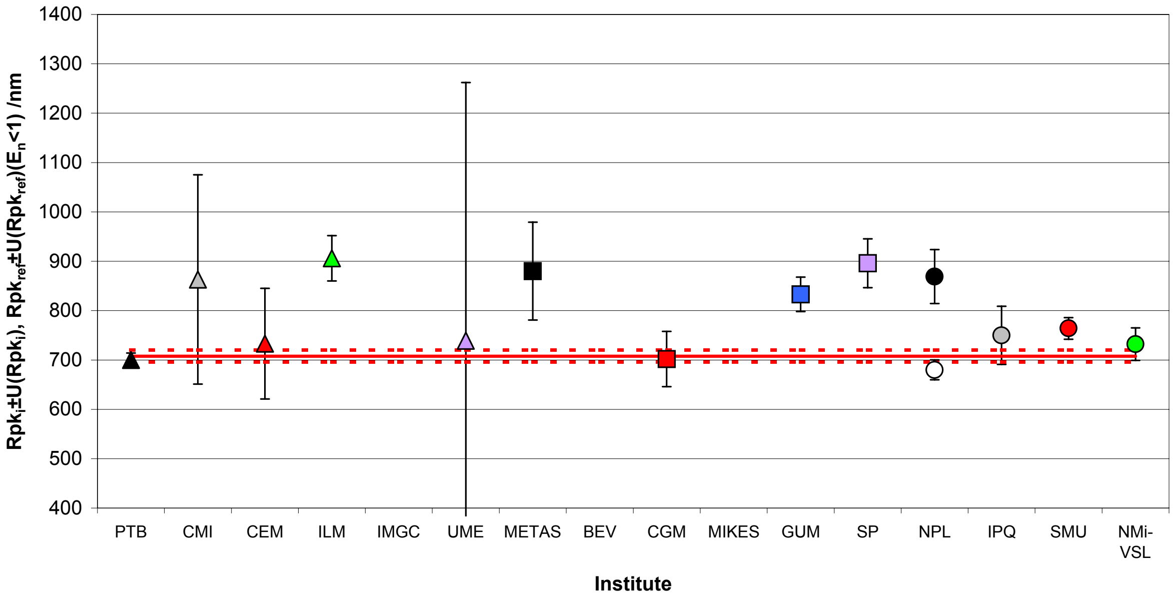
2. SP En = 3,12

3. GUM En = 2,82

4. NPL En = 2,71

5. METAS En = 1,70

Roughness standard 633g
$Rpk_i \pm U(Rpk_i)$, $Rpk_{ref} \pm U(Rpk_{ref})(E_n<1)$



 # open symbol shows corrected value of

NPL *Rpk* = (680+/- 20,1) nm

Results of *R*vk

Institute	Rvk	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Rvk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	2480	40	74	37	0,03	2,60	68,25
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	2619	152	176	88	0,76	136,40	173,66
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	2433	46	113	56,5	0,43	49,60	109,32
ILM	n	IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	2794	135	139,88			311,40	136,92
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	2529	53,2	523	261,5	0,09	46,40	522,22
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		2570	324	244	122	0,36	87,40	242,32
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	2462	19	57	28,5	0,32	20,60	49,31
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	2735	113	52			252,40	43,43
SP	n	SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	2672	123	78,642			189,40	73,26
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	2191	176,1	101,7			291,60	97,60
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	2500	20	62,18	31,09	0,25	17,40	55,21
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		2237	47,7	95,9			245,60	91,54
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	2483	25	54	27	0,01	0,40	45,80
									Mean	2515,77	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	173,01	nm	2482,6	14,3	28,6	0,8	8

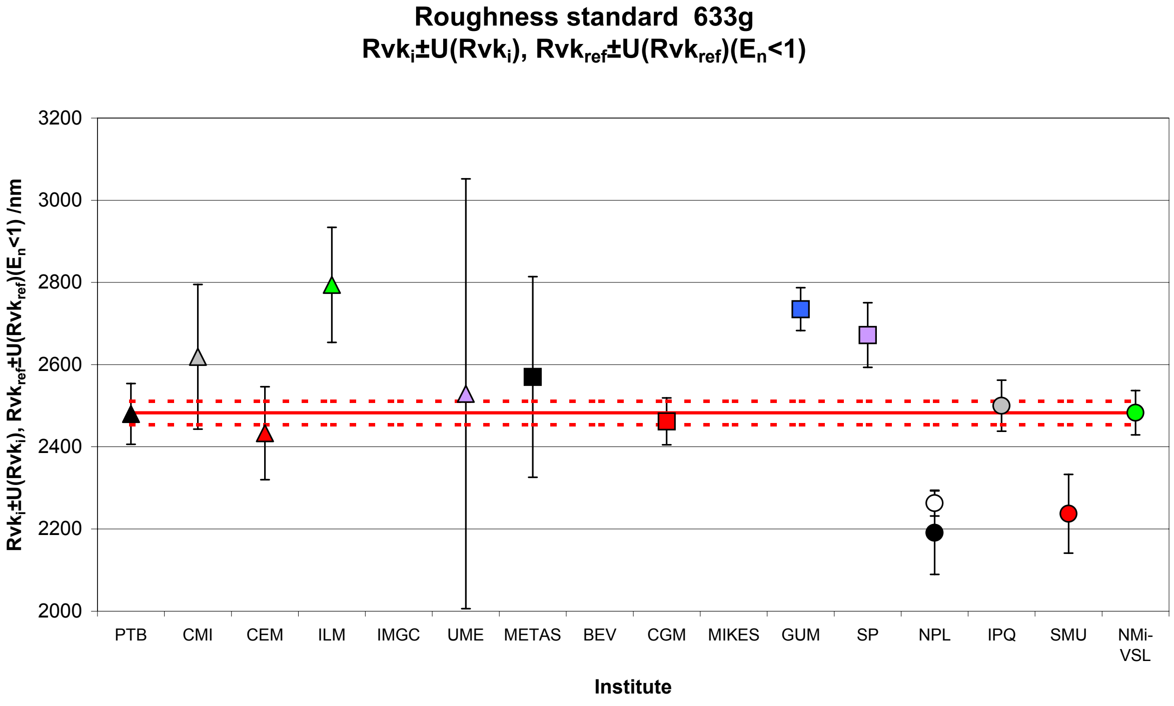
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. GUM En = 3,41
2. NPL En = 2,89
3. ILM En = 1,96
4. SP En = 2,01



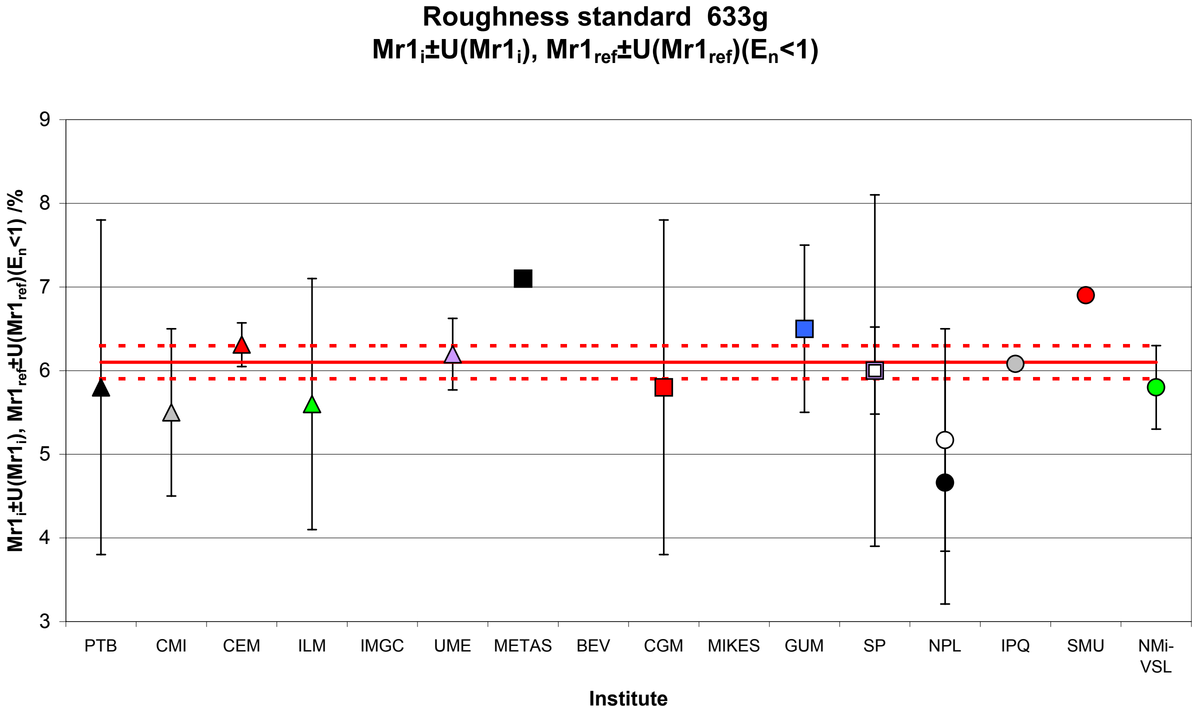
 # open symbol shows corrected value of

NPL *Rvk* = (2263 +/- 31,3) nm

Results of *Mr1*

Institute	Mr1	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Mr1	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	5,8	0,3	2	1	0,15	0,30	1,99
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	5,5	0,3	1	0,5	0,59	0,60	0,98
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	6,31	0,221	0,261	0,1305	0,64	0,21	0,17
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	5,6	0,5	1,5	0,75	0,33	0,50	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	6,196	0,413	0,428	0,214	0,20	0,10	0,38
METAS	i	CH	FTS	Oct 01	0,8	2,5	0,5	<1		7,1	0,7					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	5,8	0,1	2	1	0,15	0,30	1,99
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	6,5	0,5	1	0,5	0,39	0,40	0,98
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	6	0,9	0,52	0,259808	0,18	0,10	0,48
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	4,66	1,06	1,45	0,725	0,98	1,44	1,44
IPQ	i	PT	S8P	Sep 02	0,8	2,5	0,5		0,5	6,08	0,13					
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		6,9	89,6					
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	5,8	0,1	0,5	0,25	0,56	0,30	0,46
									Mean	6,02	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	0,63	%	6,1	0,1	0,2	1,1	10

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1


Roughness standard 633g
$Mr1_i \pm U(Mr1_i)$, $Mr1_{ref} \pm U(Mr1_{ref})(E_n<1)$

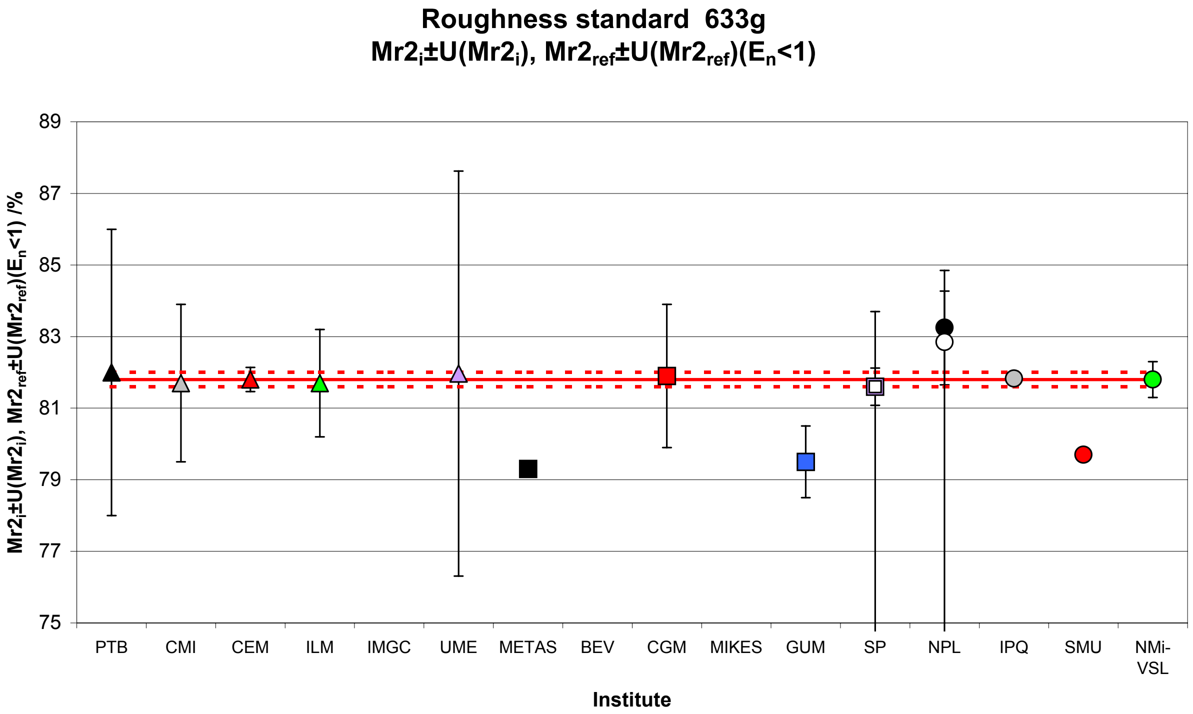
 # open symbol shows corrected value of

NPL *Mr1* = (5,17 +/- 1,33) %
SP *Mr1* = (6,0 +/- 2,1) %

Results of *Mr2*

Institute	Mr2	Country	Instrument	Measured Date						633g	633g	633g	633g	633g	633g	633g
					λc	λs	Speed	Force	Sampl-dist	Mr2	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	82	0,3	4	2	0,05	0,20	3,99
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	81,7	0,6	2,2	1,1	0,05	0,10	2,19
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	81,8	0,347	0,339	0,1695	0,00	0,00	0,27
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	81,7	0,5	1,5	0,75	0,07	0,10	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	81,968	0,469	5,656	2,828	0,03	0,17	5,65
METAS	i	CH	FTS	Oct 01	0,8	2,5	0,5	<1		79,3	1,2					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	81,9	0,2	2	1	0,05	0,10	1,99
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	79,5	0,4	1			2,30	0,98
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	81,6	0,9	0,52	0,259808	0,36	0,20	0,48
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	83,25	1,56	1,6	0,8	0,90	1,45	1,59
IPQ	i	PT	S8P	Sep 02	0,8	2,5	0,5		0,5	81,83	0,18					
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		79,7	211,9					
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	81,8	0,1	0,5	0,25	0,00	0,00	0,46
0=not measured									Mean	81,39	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
i=incomplete									Stdev	1,15	%	81,8	0,1	0,2	0,7	9

n=excluded (En>1)
SMU excluded see Main ch 8.1
1. GUM En = 2,16



 # open symbol shows corrected value of

NPL *Mr2* = (82,85 +/- 1,42) nm
SP *Mr2* = (81,6 +/- 2,1) nm

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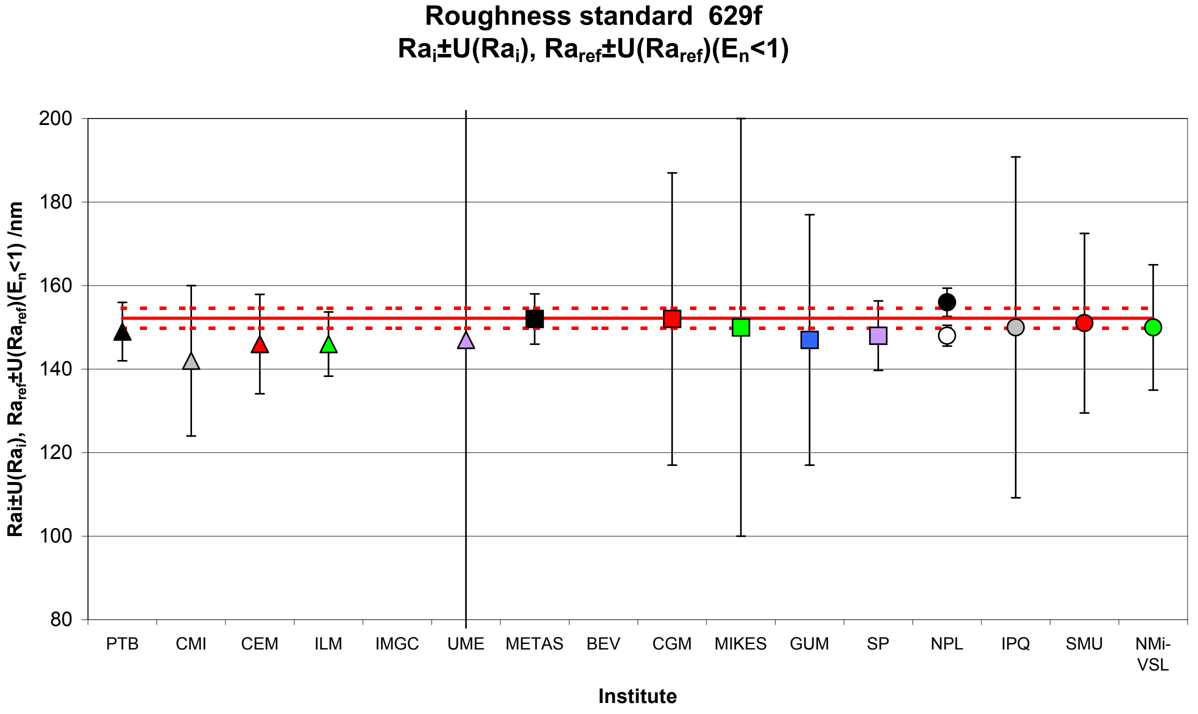
Results of *Ra*

Institute	Ra	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	149	4	7	3,5	0,43	3,20	6,58
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	142	3	18	9	0,56	10,20	17,84
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	146	3	11,89	5,945	0,51	6,20	11,65
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	146	3	7,688	3,8440083	0,77	6,20	7,30
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	147	2,9	98,1	49,05	0,05	5,20	98,07
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		152	3	6	3	0,03	0,20	5,50
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	152	4	35	17,5	0,01	0,20	34,92
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	150	2,446	50	25	0,04	2,20	49,94
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	147	2,1	30	15	0,17	5,20	29,90
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	148	2	8,3107	4,1553447	0,49	4,20	7,96
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	156	5,5	3,4	1,7	0,91	3,80	2,41
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	150	0	40,82	20,41	0,05	2,20	40,75
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		151	0,5	21,5			1,20	21,37
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	150	2	15	7,5	0,14	2,20	14,81
									Mean	149,00	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	3,40	nm	152,2	1,2	2,4	1,0	13

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Ra* = (148 +/- 2,5) nm

Results of *Rz*

Institute	Rz	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	1260	70	88	44	0,09	7,80	86,61
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	1172	55	132	66	0,60	80,20	131,07
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	1248	45	102,85	51,425	0,04	4,20	101,66
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	1299	34	65,326	32,663062	0,70	46,80	63,44
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	1255	40,7	98,1	49,05	0,03	2,80	96,85
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		1270	47	85	42,5	0,21	17,80	83,56
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	1235	41	51	25,5	0,32	17,20	48,56
MIKES		FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250	1277	45,546	100	50	0,25	24,80	98,78
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	1252	34,2	33	16,5	0,01	0,20	29,08
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	1257	43	34,275	17,137731	0,13	4,80	30,52
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	1236	57,1	33	16,5	0,44	16,20	29,08
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	1320	50	122,2	61,1	0,55	67,80	121,20
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		1191	6,6	15,3				
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	1258	26	85	42,5	0,07	5,80	83,56
									Mean	1252,14	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	37,82	nm	1252,2	7,8	15,6	0,7	13

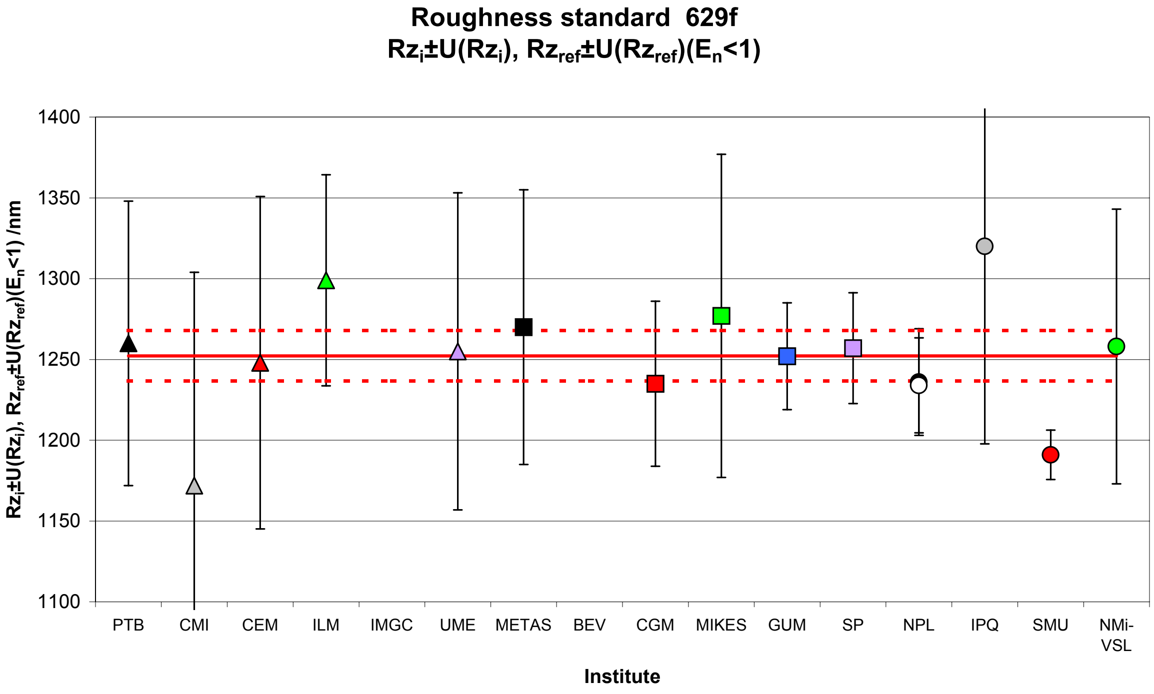
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$



 # open symbol shows corrected value of

NPL *Rz* = (1234 +/- 29,4) nm

Results of *Rmax*

Institute	Rmax	Country	Instrument	Measured						629f	629f	629f	629f	629f	629f	629f
				Date	λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	1420	90	85	42,5	0,00	0,20	81,54
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	1342	91	202	101	0,38	77,80	200,57
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	1428	99	224,6	112,3	0,04	8,20	223,31
ILM	n	IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	1512	49	75,923			92,20	72,03
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	1421	51,5	98,1	49,05	0,01	1,20	95,12
METAS	0	CH	FTS	Oct 01	0,8	2,5	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	1398	91	69	34,5	0,30	21,80	64,69
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	1423	75	40	20	0,07	3,20	32,00
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	1421	63	44,026	22,012772	0,02	1,20	36,91
NPL	n	UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	1545	83,9	48,5			125,20	42,15
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	1510	110	232,74	116,37	0,39	90,20	231,50
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		1352	19,2	39,2			67,80	30,99
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	1440	33	103	51,5	0,19	20,20	100,16
									Mean	1434,33	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	61,34	nm	1419,8	12,0	24,0	0,5	9

0=not measured

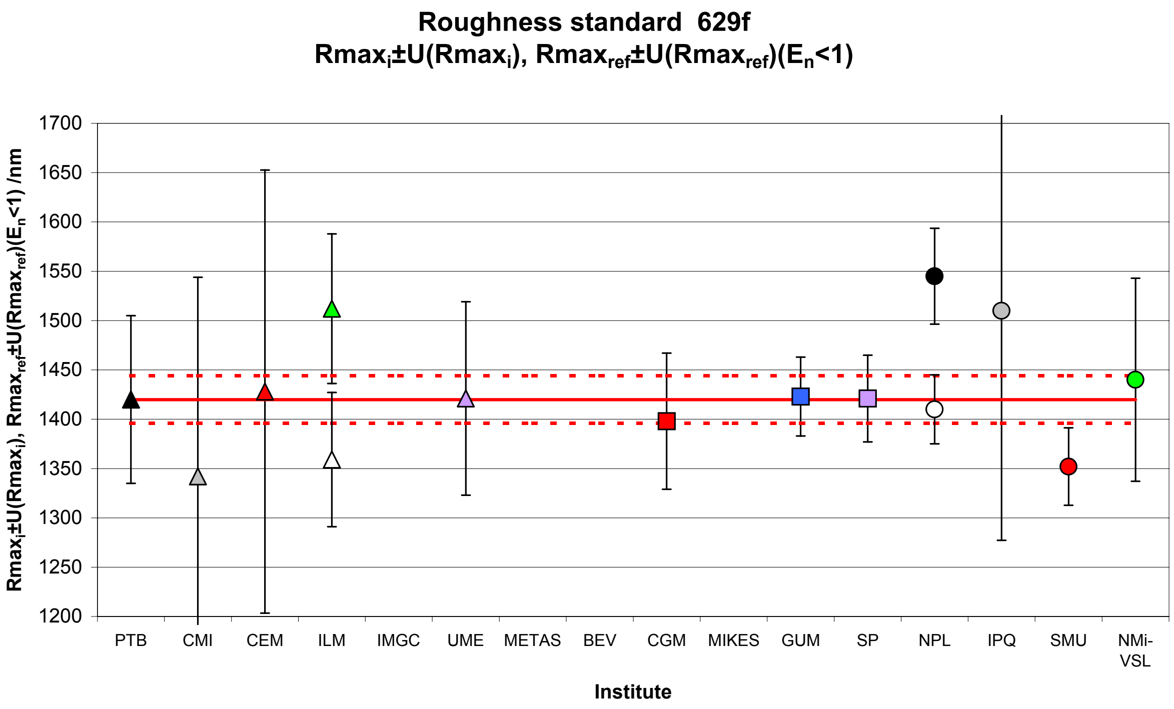
i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. NPL En = 1,82

2. ILM En = 1,06



 # open symbol shows corrected value of

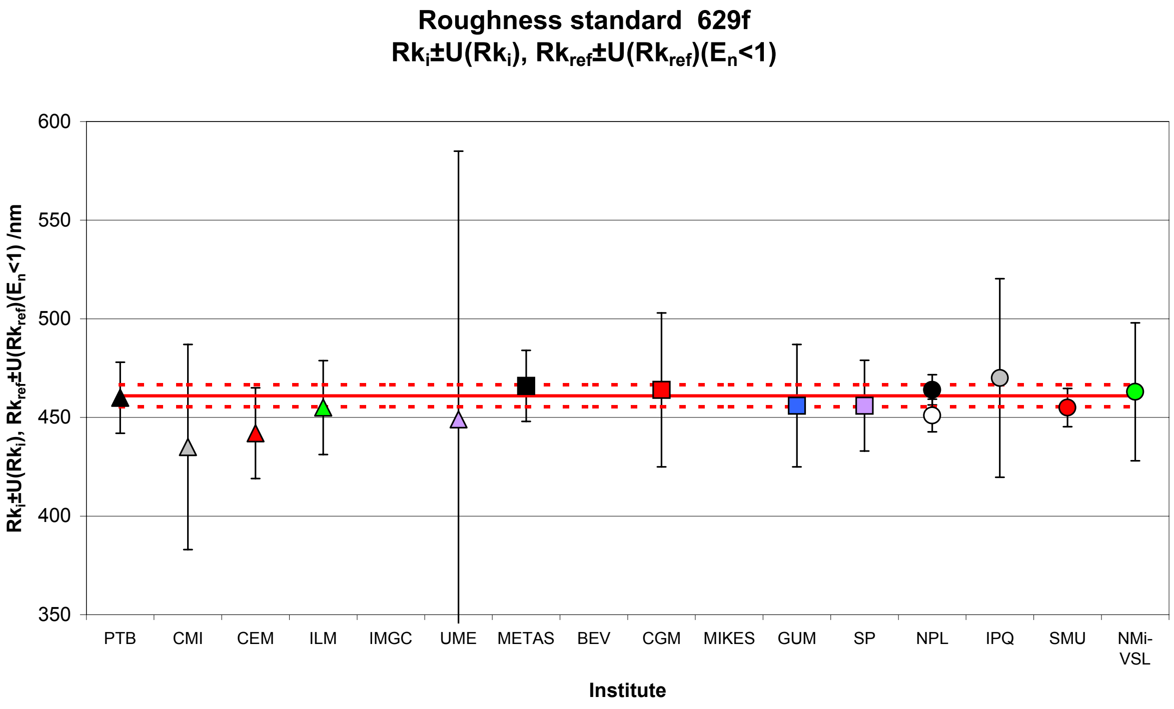
ILM *Rmax* = (1359 +/- 68) nm

NPL *Rmax* = (1410 +/- 34,9) nm

Results of *Rk*

Institute	Rk	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Rk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	460	10	18	9	0,05	1,00	17,11
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	435	9	52	26	0,50	26,00	51,70
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	442	8	23	11,5	0,80	19,00	22,31
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	455	15	23,803	11,901287	0,25	6,00	23,13
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	449	11,8	136	68	0,09	12,00	135,88
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		466	16	18	9	0,27	5,00	17,11
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	464	12	39	19,5	0,08	3,00	38,60
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	456	15,9	31	15,5	0,16	5,00	30,49
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	456	17	22,98	11,489845	0,21	5,00	22,29
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	464	13,1	7,7	3,85	0,32	3,00	5,28
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	470	10	50,33	25,165	0,18	9,00	50,02
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		455	1,8	9,7			6,00	7,92
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	463	8	35	17,5	0,06	2,00	34,55
									Mean	456,54	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	9,89	nm	461,0	2,8	5,6	0,7	12

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Rk* = (451 +/- 8,3) nm

Results of *R*pk

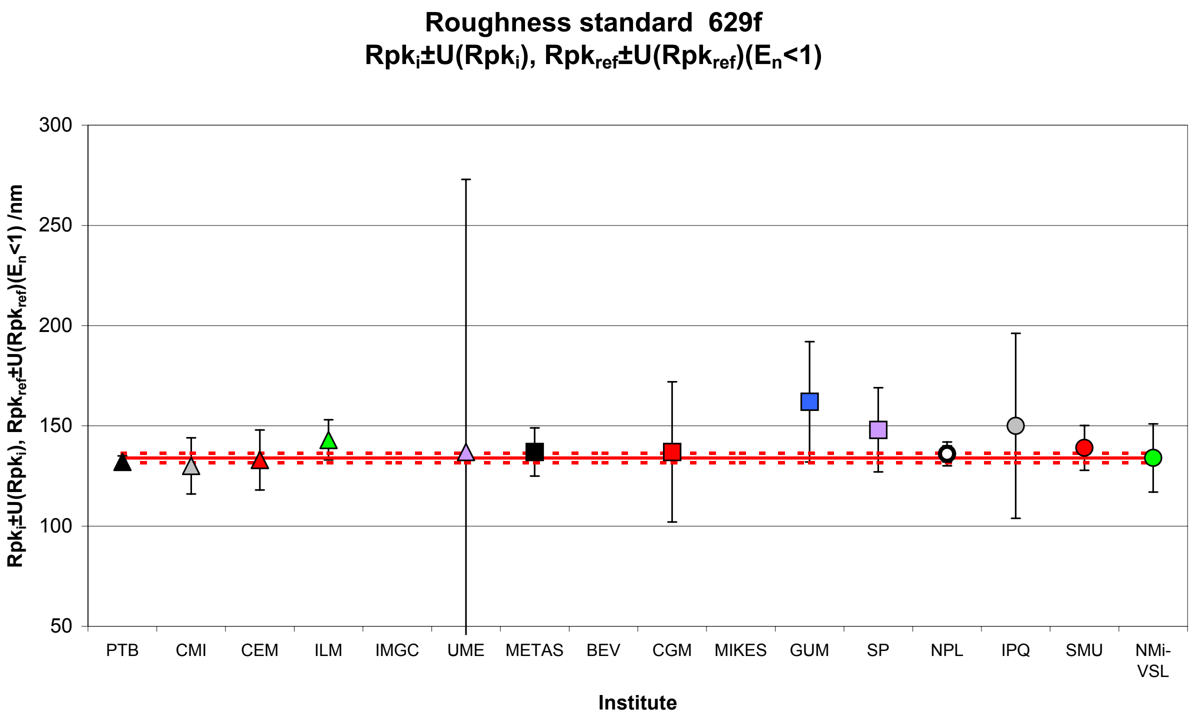
Institute	**Rpk**	Country	Instrument	Measured Date						**629f**	**629f**	**629f**	**629f**	**629f**	**629f**	**629f**
					λc	λs	Speed	Force	Sampl-dist	Rpk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	132	6	3	1,5	0,52	2,00	1,80
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	130	7	14	7	0,28	4,00	13,79
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	133	6	15	7,5	0,07	1,00	14,81
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	143	15	10,006	5,0030616	0,87	9,00	9,71
IMGC	**0**	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	137	5,7	136	68	0,02	3,00	135,98
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		137	12	12	6	0,25	3,00	11,76
BEV	**0**	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	137	7	35	17,5	0,09	3,00	34,92
MIKES	**0**	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	162	9,2	30	15	0,93	28,00	29,90
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	148	9	21,014	10,506953	0,66	14,00	20,88
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	136	10,2	6	3	0,31	2,00	5,50
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	150	10	46,16	23,08	0,35	16,00	46,10
SMU	**n**	CS	FTS	Nov 02	0,8	2,5	1	1		139	2,9	11,2			5,00	10,94
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	134	4	17	8,5	0,00	0,00	16,83
									Mean	139,85	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	8,90	nm	134,0	1,2	2,4	1,0	12

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1



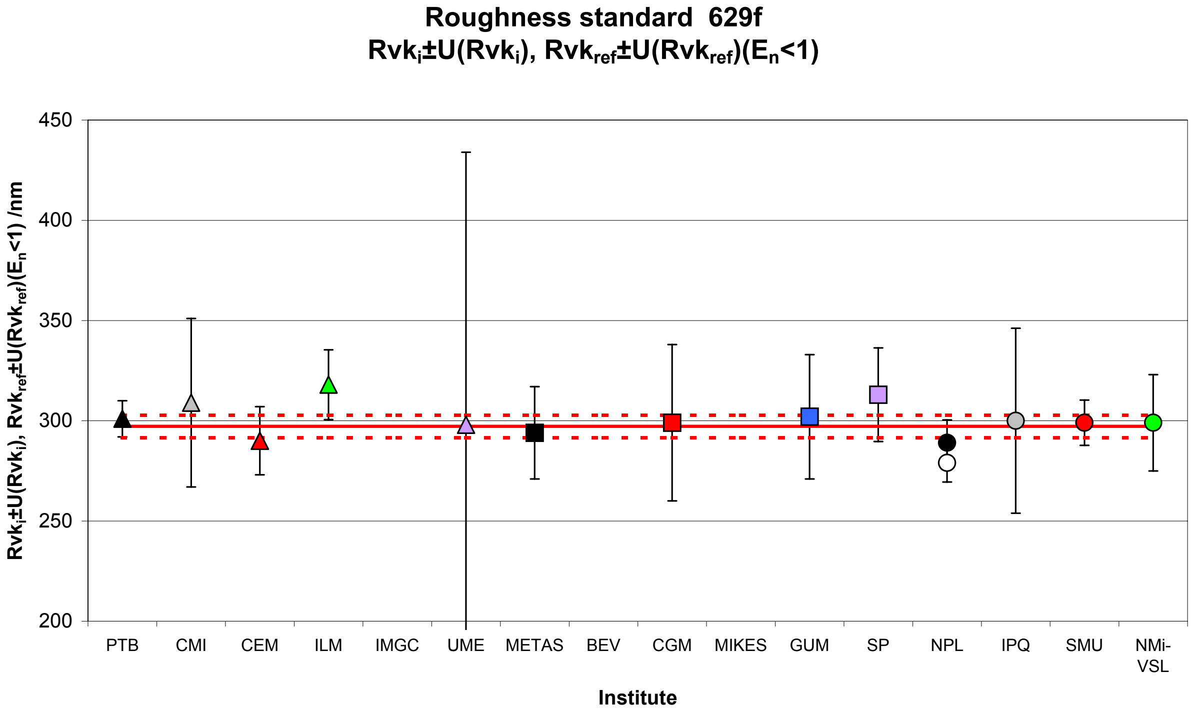
 # open symbol shows corrected value of

NPL *Rpk* = (136 +/- 4) nm

Results of *R*vk

Institute	Rvk	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Rvk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	301	20	9	4,5	0,36	3,80	7,05
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	309	18	42	21	0,28	11,80	41,62
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	290	10	17	8,5	0,40	7,20	16,05
ILM	n	IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	318	12	17,373			20,80	16,45
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	298	7,6	136	68	0,01	0,80	135,88
METAS		CH	FTS	Oct 01	0,8	2,5	0,5	<1		294	23	23	11,5	0,14	3,20	22,31
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	299	12	39	19,5	0,05	1,80	38,60
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	302	18,2	31	15,5	0,15	4,80	30,49
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	313	19	23,321	11,660605	0,66	15,80	22,64
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	289	19,7	11,4	5,7	0,65	8,20	9,93
IPQ		PT	S8P	Sep 02	0,8	2,5	0,5		0,5	300	10	46,19	23,095	0,06	2,80	45,85
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		299	3,5	11,3			1,80	9,81
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	299	9	24	12	0,07	1,80	23,34
									Mean	300,85	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	8,34	nm	297,2	2,8	5,6	0,8	11

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. ILM En = 1,04



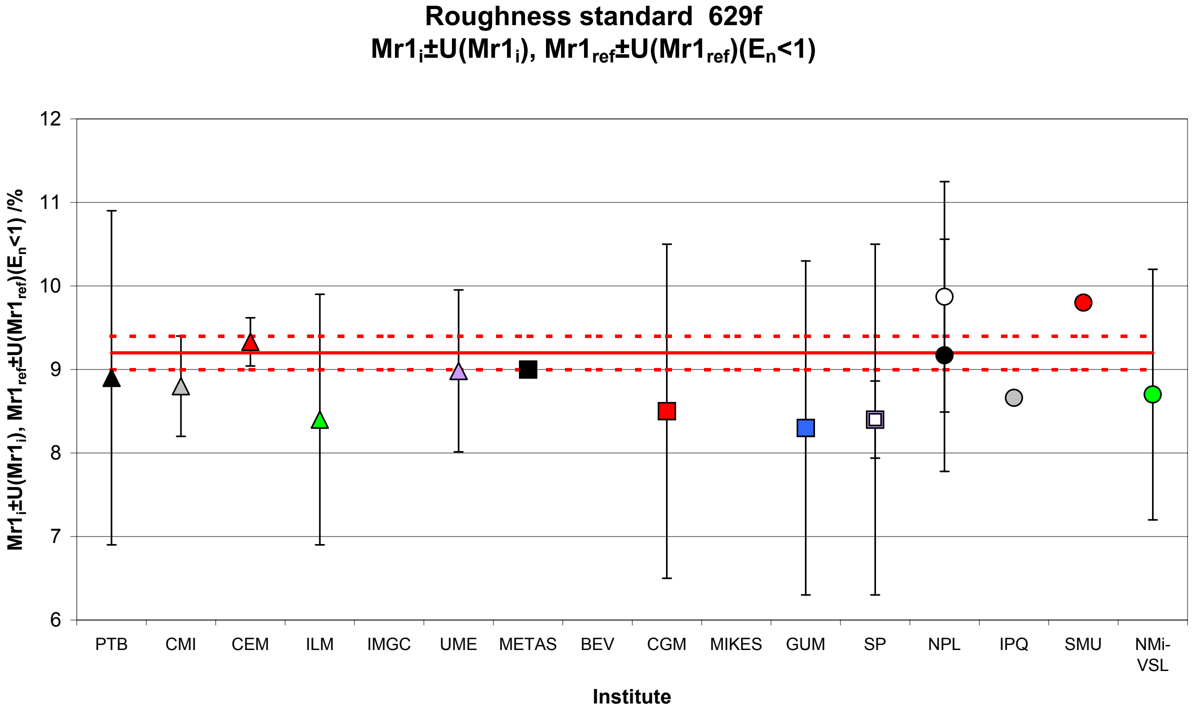
 # open symbol shows corrected value of

NPL *Rvk* = (297 +/- 9,6) nm

Results of *Mr1*

Institute	Mr1	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Mr1	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	8,9	0,8	2	1	0,15	0,30	1,99
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	8,8	0,6	0,6	0,3	0,63	0,40	0,57
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	9,33	0,494	0,288	0,144	0,37	0,13	0,21
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	8,4	1	1,5	0,75	0,53	0,80	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	8,982	0,86	0,97	0,485	0,22	0,22	0,95
METAS	i	CH	FTS	Oct 01	0,8	2,5	0,5	<1		9	0,8					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	8,5	0,7	2	1	0,35	0,70	1,99
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	8,3	0,49	2	1	0,45	0,90	1,99
SP	n	SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	8,4	0,8	0,462			0,80	0,42
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	9,17	0,74	1,39	0,695	0,02	0,03	1,38
IPQ	i	PT	S8P	Sep 02	0,8	2,5	0,5		0,5	8,66	0,46					
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		9,8	136,2					
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	8,7	0,4	1,5	0,75	0,33	0,50	1,49
									Mean	8,84	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	0,43	%	9,2	0,1	0,2	0,8	9

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. SP En = 1,19



 # open symbol shows corrected value of

NPL *Mr1* = (9,87 +/- 1,38) %
SP *Mr1* = (8,4 +/- 2,1) %

Results of *Mr2*

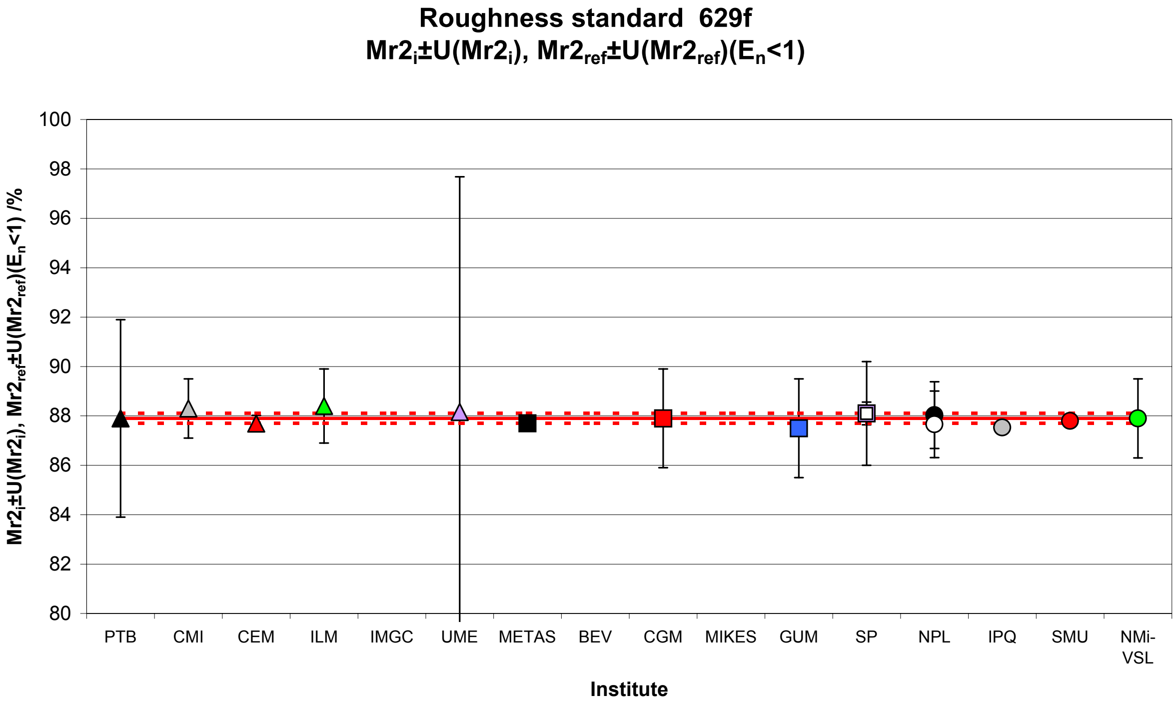
Institute	Mr2	Country	Instrument	Measured Date						629f	629f	629f	629f	629f	629f	629f
					λc	λs	Speed	Force	Sampl-dist	Mr2	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,8	2,5	0,1	1	0,2	87,9	0,7	4	2	0,00	0,00	3,99
CMI		CZ	HT	Jun 01	0,8	2,5	0,5	0,75	0,42	88,3	0,7	1,2	0,6	0,33	0,40	1,18
CEM		ES	MPC	Jul 01	0,8	2,5	0,5	0,4	0,5	87,69	0,461	0,332	0,166	0,54	0,21	0,26
ILM		IT	FTS	Aug 01	0,8	2,5	0,5	0,75	0,25	88,4	0,9	1,5	0,75	0,33	0,50	1,49
IMGC	0	IT	TS	Aug 01												
UME		TR	MPC	Sep 01	0,8	2,67	0,5	0,9	0,35	88,158	0,654	9,521	4,7605	0,03	0,26	9,52
METAS	i	CH	FTS	Oct 01	0,8	2,5	0,5	<1		87,7	0,8					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,8	2,5	0,05	1	0,5	87,9	0,4	2	1	0,00	0,00	1,99
MIKES	0	FI	FTS	Feb 02	0,800	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,8	2,5	0,5	<1	0,25	87,5	0,61	2	1	0,20	0,40	1,99
SP		SE	FTS	May 02	0,8	2,5	0,5	0,7	0,25	88,1	0,8	0,462	0,23094	0,40	0,20	0,42
NPL		UK	NS4	Jul 02	0,8	2,5	0,1	<0.1	0,5	88,03	0,51	1,35	0,675	0,10	0,13	1,34
IPQ	i	PT	S8P	Sep 02	0,8	2,5	0,5		0,5	87,53	0,4					
SMU	n	CS	FTS	Nov 02	0,8	2,5	1	1		87,8	121,4					
NMi-VSL		NL	FTS	Mrz 03	0,8	2,5	0,5	0,55	0,25	87,9	0,5	1,6	0,8	0,00	0,00	1,59
									Mean	87,92	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	0,28	%	87,9	0,1	0,2	0,6	10

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Mr2* = (87,66 +/- 1,35) nm
SP *Mr2* = (88,1 +/- 2,1) nm

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Results of *Ra*

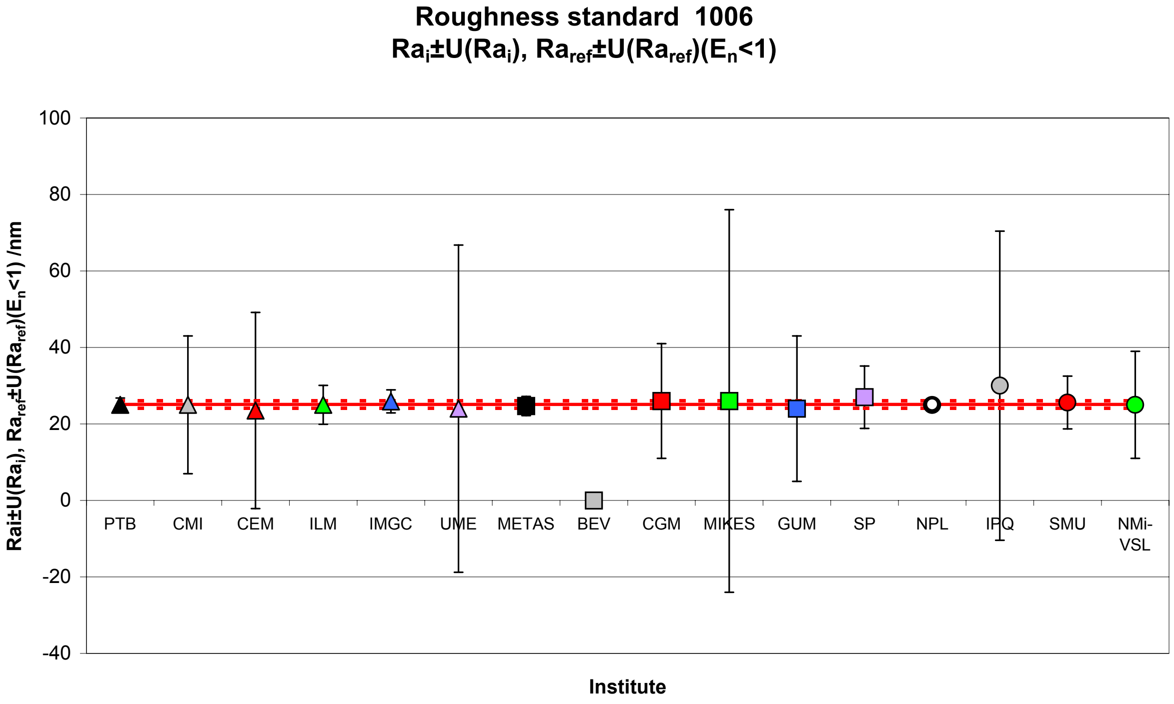
Institute	Ra	Country	Instrument	Measured						1006	1006	1006	1006	1006	1006	1006
				Date	λc	λs	Speed	Force	Sampl-dist	Ra	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	25	0,9	1,8	0,9	0,05	0,10	1,50
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	25	1	18	9	0,01	0,10	17,97
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	23,52	0,55	25,66	12,83	0,06	1,58	25,64
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	25	1	5,099	2,5495098	0,02	0,10	5,00
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,025	1	25,9	0,8	3	1,5	0,25	0,80	2,83
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	24	1,6	42,8	21,4	0,03	1,10	42,79
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		24,7	0,7	2,5	1,25	0,15	0,40	2,29
BEV	**0**	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	26	1	15	7,5	0,06	0,90	14,97
MIKES		FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	26	0,603	50	25	0,02	0,90	49,99
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	24	0,6	19	9,5	0,06	1,10	18,97
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	27	1,4	8,1641	4,0820333	0,23	1,90	8,10
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	24,98	0,74	1,39	0,695	0,07	0,12	0,97
IPQ		PT	S8P	Sep 02						30	0	40,41	20,205	0,12	4,90	40,40
SMU	**n**	CS	FTS	Nov 02	0,25	2,5	1	1		25,6	0,1	6,9			0,50	6,83
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	25	1	14	7	0,01	0,10	13,96
									Mean	25,45	nm	X_{ref} /nm	u(X_{ref}) /nm	U(X_{ref}) /nm	R_B	n
									Stdev	1,55	nm	25,1	0,5	1,0	0,2	14

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1



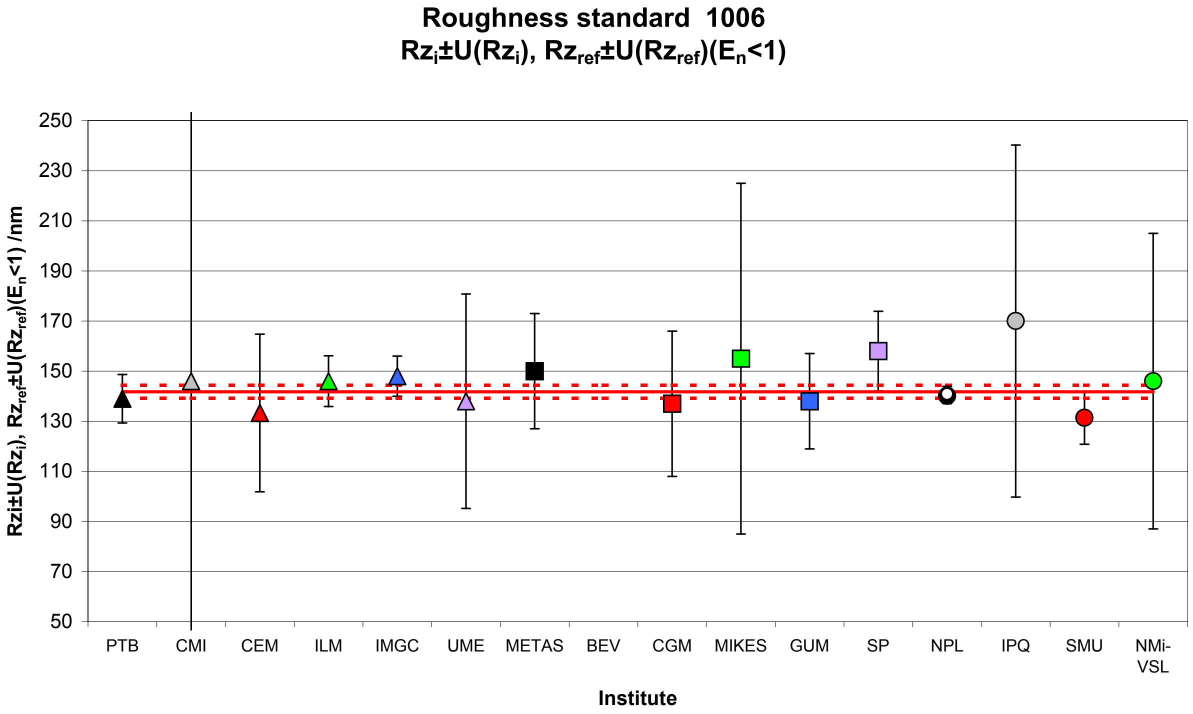
 # open symbol shows corrected value of

NPL *Ra* = (25,1 +/- 1,37) nm

Results of *Rz*

Institute	Rz	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Rz	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	139	2	9,7	4,85	0,28	2,80	9,35
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	146	9	128	64	0,03	4,20	127,97
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	133,29	4,5	31,45	15,725	0,27	8,51	31,34
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	146	4	10,114	5,0569259	0,40	4,20	9,77
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,025	1	148	3,7	8	4	0,74	6,20	7,57
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	138	6,1	42,8	21,4	0,09	3,80	42,72
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		150	6	23	11,5	0,35	8,20	22,85
BEV	**0**	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	137	6	29	14,5	0,16	4,80	28,88
MIKES		FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	155	8,521	70	35	0,19	13,20	69,95
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	138	3,2	19	9,5	0,20	3,80	18,82
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	158	12	15,917	7,9583617	1,00	16,20	15,70
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	140,14	4,57	3,06	1,53	0,41	1,66	1,61
IPQ		PT	S8P	Sep 02						170	0	70,24	35,12	0,40	28,20	70,19
SMU	**n**	CS	FTS	Nov 02	0,25	2,5	1	1		131,4	3,1	10,6			10,40	10,28
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	146	9	59	29,5	0,07	4,20	58,94
									Mean	145,06	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	10,26	nm	141,8	1,3	2,6	0,9	14

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Rz* = (140,9 +/- 3,02) nm

Results of *Rmax*

Institute	Rmax	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Rmax	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	177	11	15,9	7,95	1,00	16,60	15,16
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	176	14	196	98	0,09	17,60	195,94
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	172,9	16,6	36,99	18,495	0,55	20,70	36,68
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	203	15	12,33	6,1648702	0,71	9,40	11,36
IMGC		IT	TS	Aug 01	0,25	1	0,025	0,025	1	203,7	4,4	10	5	0,91	10,10	8,77
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	175	13	42,8	21,4	0,43	18,60	42,53
METAS	0	CH	FTS	Oct 01	0,25	2,5	0,5	<1								
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	173	8	29	14,5	0,70	20,60	28,60
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM	n	PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	171	9,7	19			22,60	18,38
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	203	22	19,272	9,6357571	0,47	9,40	18,66
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	189,36	12,79	7,5	3,75	0,48	4,24	5,76
IPQ		PT	S8P	Sep 02						220	20	85,05	42,525	0,31	26,40	84,91
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		155,5	3,9	11,7			38,10	10,67
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	185	23	81	40,5	0,11	8,60	80,86
									Mean	184,96	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	17,90	nm	193,6	2,4	4,8	1,3	11

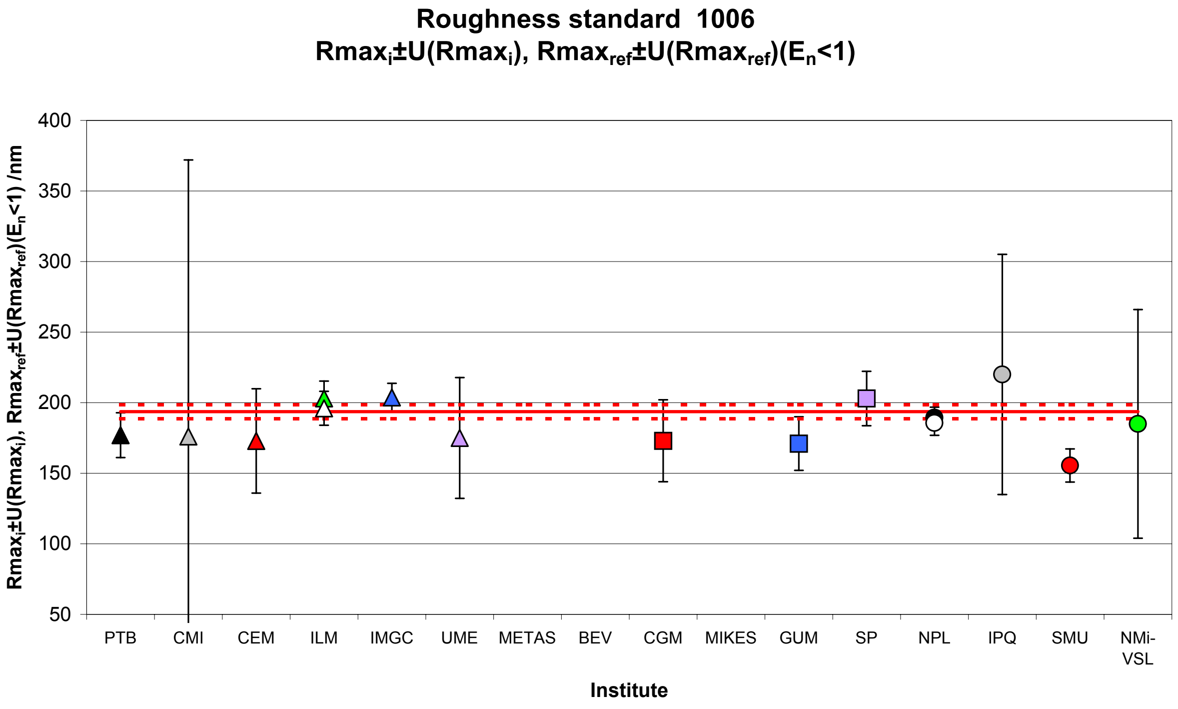
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. GUM En = 1,08



 # open symbol shows corrected value of

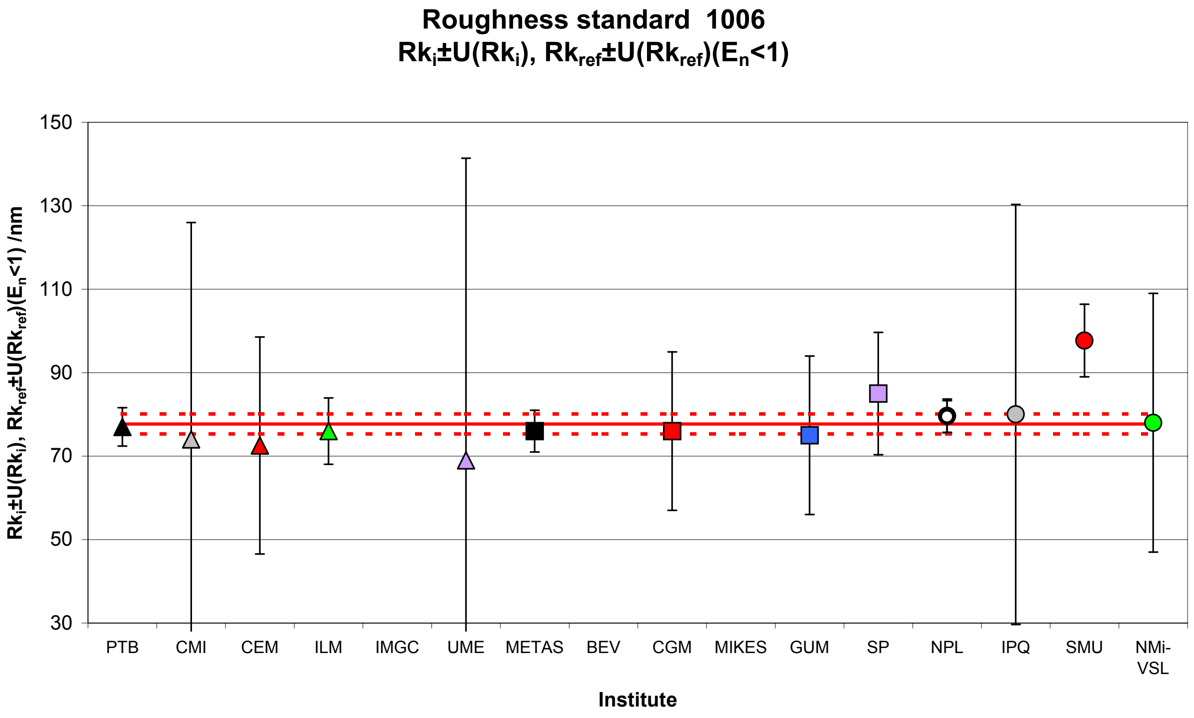
ILM *Rmax* = (196 +/- 12) nm

NPL *Rmax* = (185,7 +/- 8,74) nm

Results of *Rk*

Institute	Rk	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Rk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	77	3,9	4,6	2,3	0,13	0,70	3,92
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	74	5	52	26	0,07	3,70	51,94
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	72,56	3,25	26	13	0,20	5,14	25,89
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	76	6	7,9649	3,9824616	0,20	1,70	7,59
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,025	1							
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	69	12,6	72,4	36,2	0,12	8,70	72,36
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		76	6	5	2,5	0,31	1,70	4,39
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	76	6	19	9,5	0,09	1,70	18,85
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	75	3,2	19	9,5	0,14	2,70	18,85
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	85	6	14,657	7,3284587	0,49	7,30	14,46
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	79,63	6,62	4,04	2,02	0,41	1,93	3,25
IPQ		PT	S8P	Sep 02						80	10	50,33	25,165	0,05	2,30	50,27
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		97,7	0,3	8,7			20,00	8,36
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	78	4	31	15,5	0,01	0,30	30,91
									Mean	78,15	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	7,02	nm	77,7	1,2	2,4	0,5	12

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL *Rk* = (79,48 +/- 3,79) nm

Results of *R*pk

Institute	Rpk	Country	Instrument	Measured Date	λc	λs	Speed	Force	Sampl-dist	1006 Rpk	1006 s	1006 U(k=2)	1006 uc=U/2	1006 E_n	1006 DoE/|Xir|	1006 DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	27	1,3	1,4	0,7	0,22	0,40	0,72
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	31	5	14	7	0,26	3,60	13,95
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	26,1	1,17	27	13,5	0,05	1,30	26,97
ILM	n	IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	35	6	7,2154			7,60	7,11
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,025	1	0	0	0				
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	29	3,1	72,4	36,2	0,02	1,60	72,39
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		30	3	3,5	1,75	0,70	2,60	3,29
BEV	0	A	IM	Nov 01						0	0	0				
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	28	3	14	7	0,04	0,60	13,95
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	0	0	0				
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	28	2,9	19	9,5	0,03	0,60	18,96
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	31	4	14,403	7,2015827	0,25	3,60	14,35
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	27,24	4,77	3,05	1,525	0,05	0,16	2,80
IPQ		PT	S8P	Sep 02						30	0	41,63	20,815	0,06	2,60	41,61
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		19,4	0,8	8,8			8,00	8,72
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	28	2	15	7,5	0,04	0,60	14,95
									Mean	23,11	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	11,90	nm	27,4	0,6	1,2	0,6	11

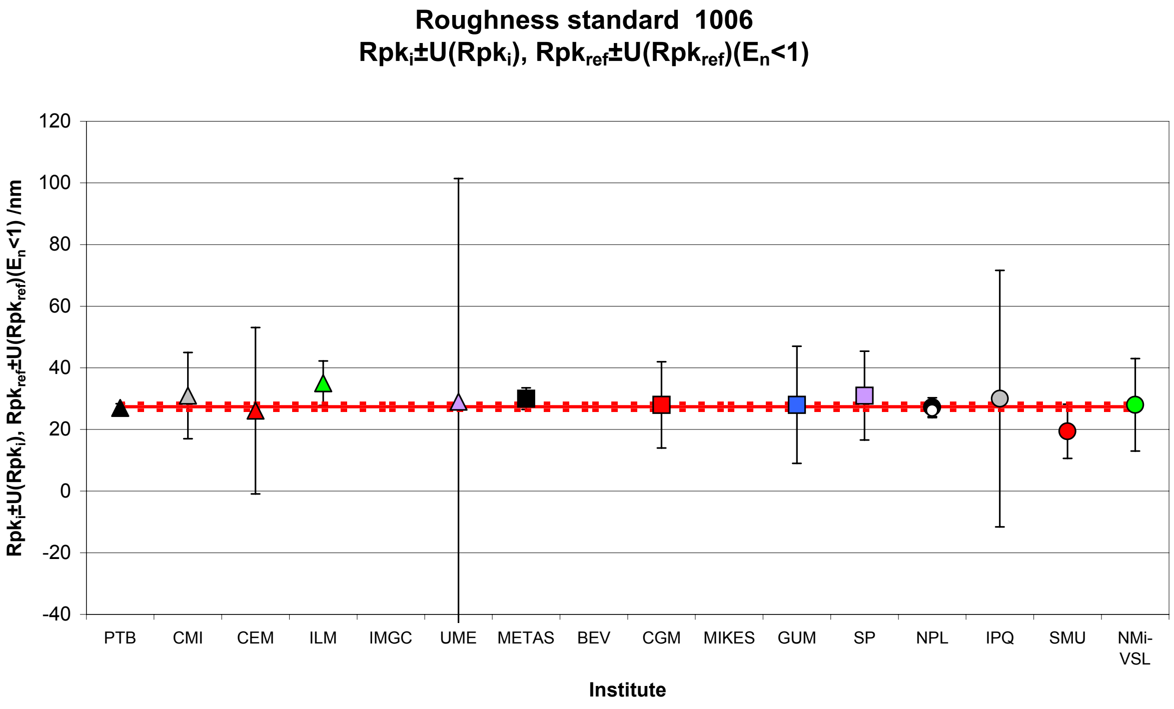
0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1

1. ILM En = 1,01



 # open symbol shows corrected value of

NPL *Rpk* = (26,2 +/- 2,35) nm

Results of *R*vk

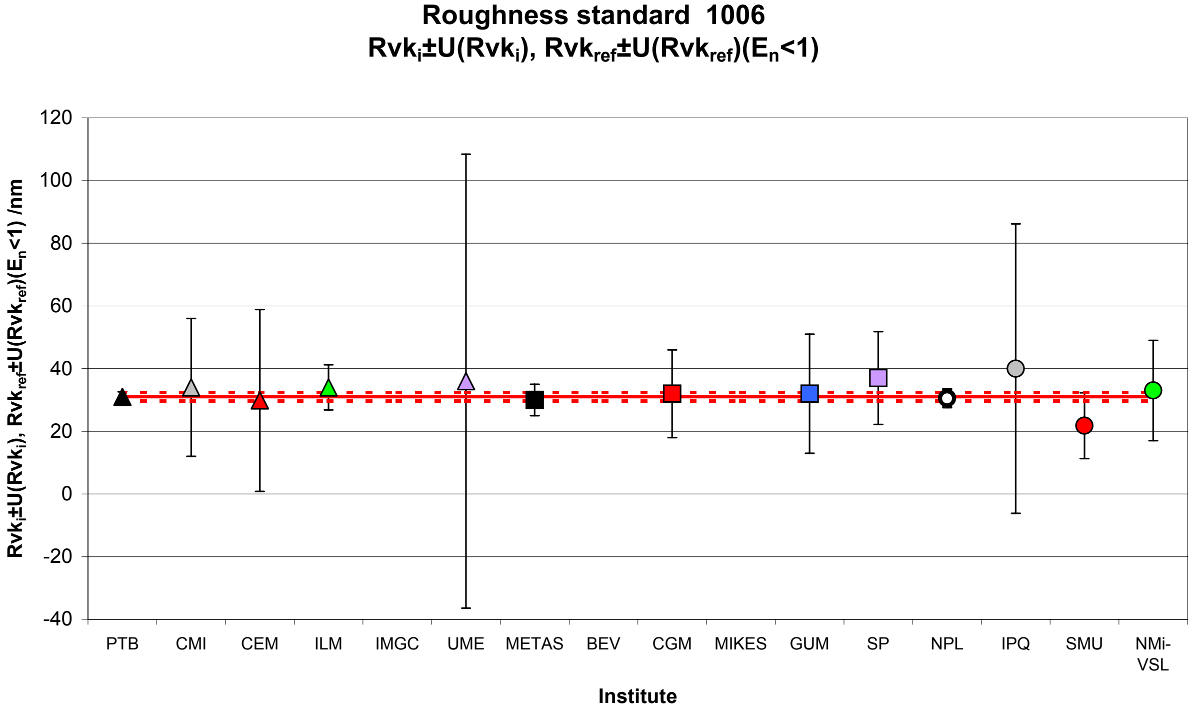
Institute	Rvk	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Rvk	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	nm	nm	nm	nm		nm	nm
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	31	1,9	1,6	0,8	0,00	0,00	0,77
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	34	6	22	11	0,14	3,00	21,96
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	29,83	2,07	29	14,5	0,04	1,17	28,97
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	34	4	7,2035	3,6017357	0,41	3,00	7,07
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,025	1	0	0	0				
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	36	6	72,4	36,2	0,07	5,00	72,39
METAS		CH	FTS	Oct 01	0,25	2,5	0,5	<1		30	7	5	2,5	0,19	1,00	4,80
BEV	0	A	IM	Nov 01						0	0	0				
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	32	2	14	7	0,07	1,00	13,93
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250	0	0	0				
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	32	4,4	19	9,5	0,05	1,00	18,95
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	37	7	14,792	7,3961852	0,40	6,00	14,73
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	30,57	4,69	3,01	1,505	0,13	0,43	2,66
IPQ		PT	S8P	Sep 02						40	10	46,19	23,095	0,19	9,00	46,17
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		21,8	2,9	10,5			9,20	10,41
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	33	2	16	8	0,12	2,00	15,94
									Mean	26,33	nm	X_{ref} /nm	$u(X_{ref})$ /nm	$U(X_{ref})$ /nm	R_B	n
									Stdev	13,63	nm	31,0	0,7	1,4	0,4	12

0=not measured

i=incomplete

n=excluded (En>1)

SMU excluded see Main ch 8.1


Roughness standard 1006
$Rvk_i \pm U(Rvk_i)$, $Rvk_{ref} \pm U(Rvk_{ref})(E_n<1)$

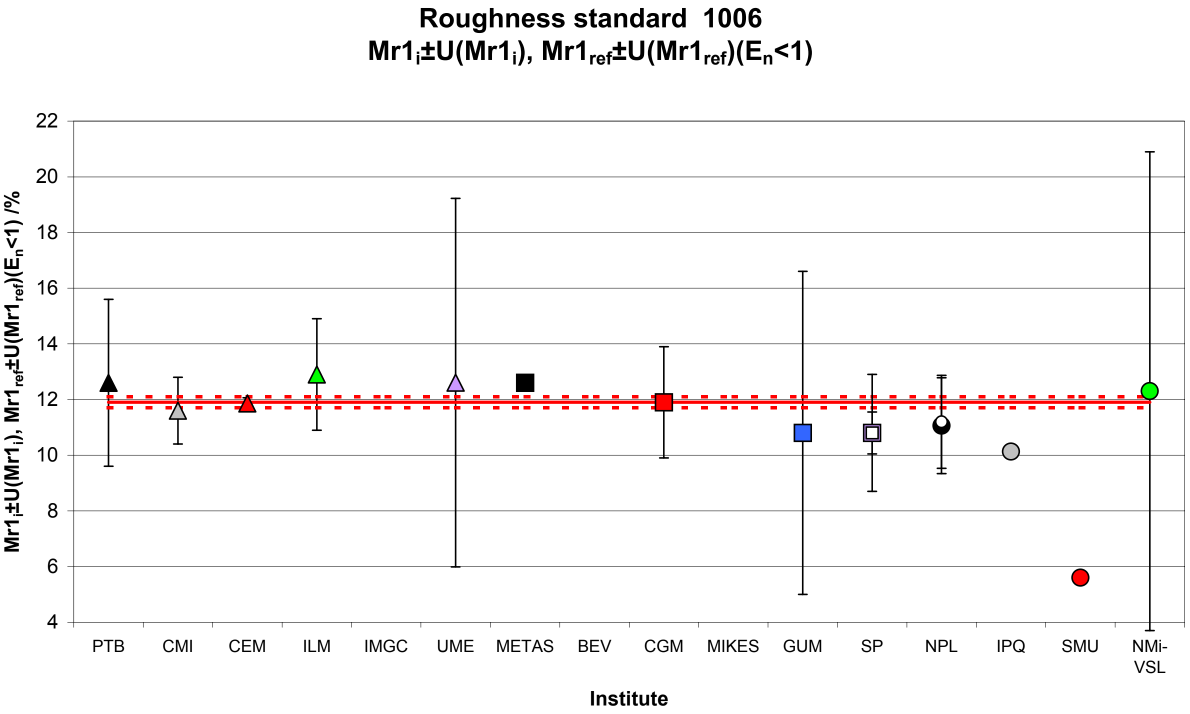
 # open symbol shows corrected value of

NPL *Rvk* = (30,5 +/- 2,72) nm

Results of *Mr1*

Institute	Mr1	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Mr1	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	12,6	0,7	3	1,5	0,23	0,70	2,99
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	11,6	1,9	1,2	0,6	0,25	0,30	1,18
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	11,86	0,683	0,2	0,1	0,14	0,04	0,00
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	12,9	1,8	2	1	0,50	1,00	1,99
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,025	1							
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	12,606	0,784	6,618	3,309	0,11	0,71	6,61
METAS	i	CH	FTS	Oct 01	0,25	2,5	0,5	<1		12,6	1					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	11,9	1,1	2	1	0,00	0,00	1,99
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	10,8	1,35	5,8	2,9	0,19	1,10	5,80
SP	n	SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	10,8	1,3	0,751			1,10	0,72
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	11,06	1,92	1,72	0,86	0,49	0,84	1,71
IPQ	i	PT	S8P	Sep 02						10,13	0,89					
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		5,6	290					
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	12,3	0,9	8,6	4,3	0,05	0,40	8,60
									Mean	11,29	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
									Stdev	1,91	%	11,9	0,1	0,2	0,6	9

0=not measured
i=incomplete
n=excluded (En>1)
SMU excluded see Main ch 8.1
1. SP En = 1,29


Roughness standard 1006
$Mr1_i \pm U(Mr1_i)$, $Mr1_{ref} \pm U(Mr1_{ref})(E_n<1)$

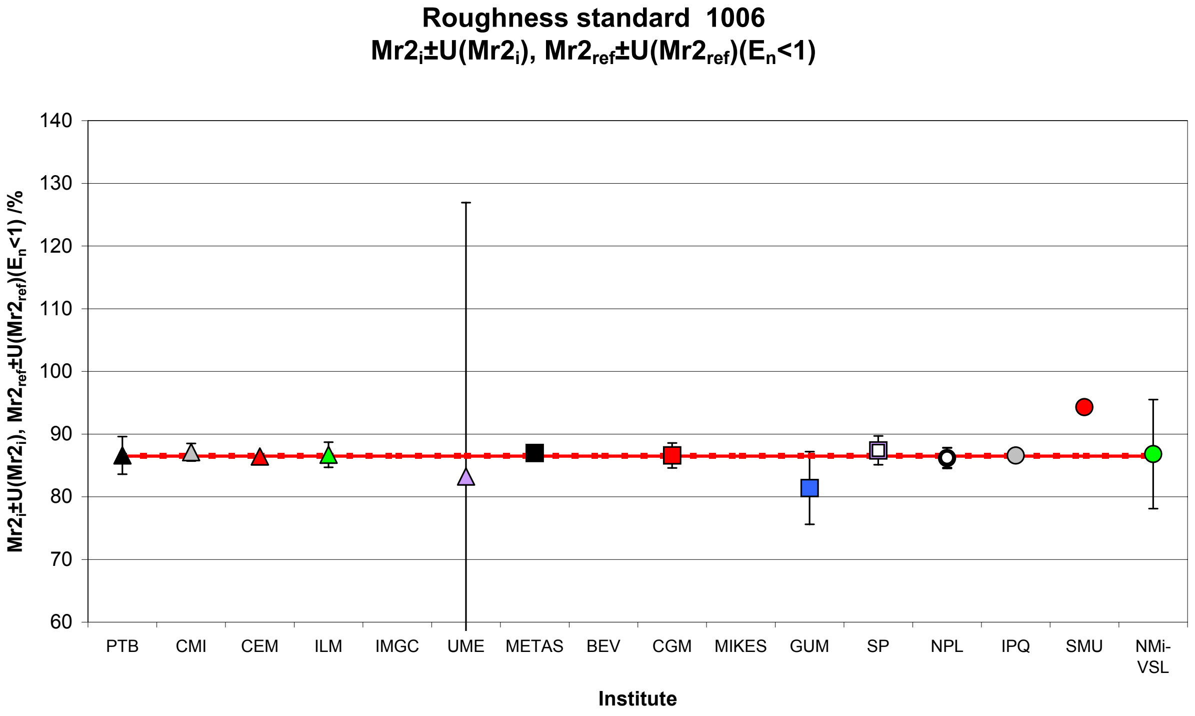
 # open symbol shows corrected value of

NPL *Mr1* = (11,2 +/- 1,67) %
SP *Mr1* = (10,8 +/- 2,1) %

Results of *Mr2*

Institute	Mr2	Country	Instrument	Measured Date						1006	1006	1006	1006	1006	1006	1006
					λc	λs	Speed	Force	Sampl-dist	Mr2	s	U(k=2)	uc=U/2	E_n	DoE/|Xir|	DoE/Uir
					mm	µm	mm/s	mN	µm	%	%	%	%		%	%
PTB		DE	NS	May 01	0,25	2,5	0,05	0,025	0,15	86,6	0,7	3	1,5	0,03	0,10	2,99
CMI		CZ	HT	Jun 01	0,25	2,5	0,5	0,75	0,13	87,1	1,7	1,4	0,7	0,42	0,60	1,39
CEM		ES	MPC	Jul 01	0,25	2,5	0,1	0,4	0,5	86,42	0,688	0,2	0,1	0,28	0,08	0,00
ILM		IT	FTS	Aug 01	0,25	2,5	0,5	0,75	0,25	86,7	1,2	2	1	0,10	0,20	1,99
IMGC	0	IT	TS	Aug 01	0,25	1	0,025	0,025	1							
UME		TR	MPC	Sep 01	0,25	2,5	0,1	0,9	0,1	83,232	4,394	43,7	21,8485	0,07	3,27	43,70
METAS	i	CH	FTS	Oct 01	0,25	2,5	0,5	<1		87	1,5					
BEV	0	A	IM	Nov 01												
CGM		DK	FTS	Jan 02	0,25	2,5	0,05	1	0,2	86,6	1	2	1	0,05	0,10	1,99
MIKES	0	FI	FTS	Feb 02	0,250	2,500	0,500	1,000	0,250							
GUM		PL	FTS	Apr 02	0,25	2,5	0,5	<1	0,25	81,4	1,25	5,8	2,9	0,88	5,10	5,80
SP		SE	FTS	May 02	0,25	2,5	0,5	0,7	0,25	87,4	1,9	1,097	0,548483	0,81	0,90	1,08
NPL		UK	NS4	Jul 02	0,3	2,5	0,0	<0.1	0,5	86,17	1,75	1,66	0,83	0,20	0,33	1,65
IPQ	i	PT	S8P	Sep 02						86,58	1,14					
SMU	n	CS	FTS	Nov 02	0,25	2,5	1	1		94,3	261,9					
NMi-VSL		NL	FTS	Mrz 03	0,25	2,5	0,5	0,55	0,25	86,8	1,1	8,7	4,35	0,03	0,30	8,70
0=not measured									Mean	86,64	%	X_{ref} /%	$u(X_{ref})$ /%	$U(X_{ref})$ /%	R_B	n
i=incomplete									Stdev	2,87	%	86,5	0,1	0,2	0,9	10

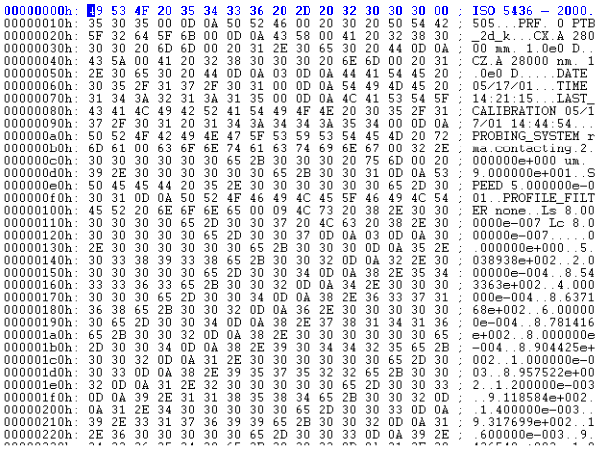
n=excluded (En>1)
SMU excluded see Main ch 8.1



 # open symbol shows corrected value of

NPL	*Mr2* = (86,22 +/- 1,56) %
SP	*Mr2* = (87,4 +/- 2,3) %

Appendix D4



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000001b0h: 2D 30 30 34 0D 0A 38 2E 39 30 34 34 32 35 65 2B ; -004..8.904425e+
000001c0h: 30 30 32 0D 0A 31 2E 30 30 30 30 30 30 65 2D 30 ; 002..1.000000e-0
000001d0h: 30 33 0D 0A 38 2E 39 35 37 35 32 32 65 2B 30 30 ; 03..8.957522e+00
000001e0h: 32 0D 0A 31 2E 32 30 30 30 30 30 65 2D 30 30 33 ; 2..1.200000e-003
000001f0h: 0D 0A 39 2E 31 31 38 35 38 34 65 2B 30 30 32 0D ; ..9.118584e+002.
00000200h: 0A 31 2E 34 30 30 30 30 30 65 2D 30 30 33 0D 0A ; .1.400000e-003..
00000210h: 39 2E 33 31 37 36 39 39 65 2B 30 30 32 0D 0A 31 ; 9.317699e+002..1
00000220h: 2E 36 30 30 30 30 30 65 2D 30 30 33 0D 0A 39 2E ; .600000e-003..9.
```

Software Gauges

Type F1

1. DATA FILE 1001.SMD

Institute	Country	Instrum	Measured Date			1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
				λc	λs	Ra	Ra-Ref.	Rq	Rq-Ref.	Rp	Rp-Ref.	Rv	Rv-Ref.	Rt	Rt-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
PTB	DE	NS	May 01	0,3	3	86,91		107,94		232,44		238,03		628,33	
UME	TR	MPC	Sep 01	0,3	0	90	3,09	110	2,06	240	7,56	240	1,97	630	1,67
METAS	CH	FTS	Oct 01	0,3	3	86,9	-0,01	107,9	-0,04	232,4	-0,04	238	-0,03	628,3	-0,03
CGM	DK	FTS	Jan 02			87	0,09	108	0,06	235	2,56	240	1,97	632	3,67
SP	SE	FTS	May 02	0,3	3	86,7	-0,21	107,7	-0,24	231,1	-1,34	329,3	91,27	560,5	-67,83
NPL	UK	NS4	Jul 02	0,3	2,5	87	0,09	107	-0,94	238	5,56	232	-6,03	625	-3,33
SMU	CS	FTS	Nov 02	0,8	3	54,7	-32,21	70,1	-37,84	159	-73,44	135	-103,03	572	-56,33
NMi-VSL	NL	FTS	Mrz 03	0,3	3	87	0,09	108	0,06	230	-2,44	239	0,97	610	-18,33
Mittelwert:						83,28	-4,15	103,33	-5,27	224,74	-8,80	236,42	-1,84	610,77	-20,07
STABW:						11,60	12,43	13,45	14,39	26,78	28,73	52,06	56,22	28,46	29,77

*)NPL value *(-1)

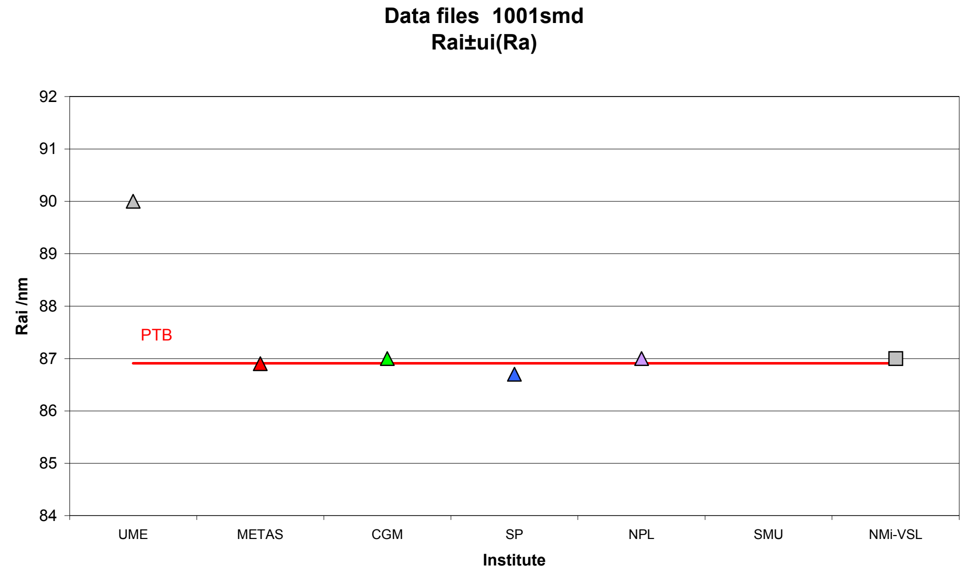
NPL corrected values	Ra	Ra-Ref.	Rq	Rq-Ref.	Rp	Rp-Ref.	Rv	Rv-Ref.	Rt	Rt-Ref.
NPL corrected values	87		107		232		238		628	

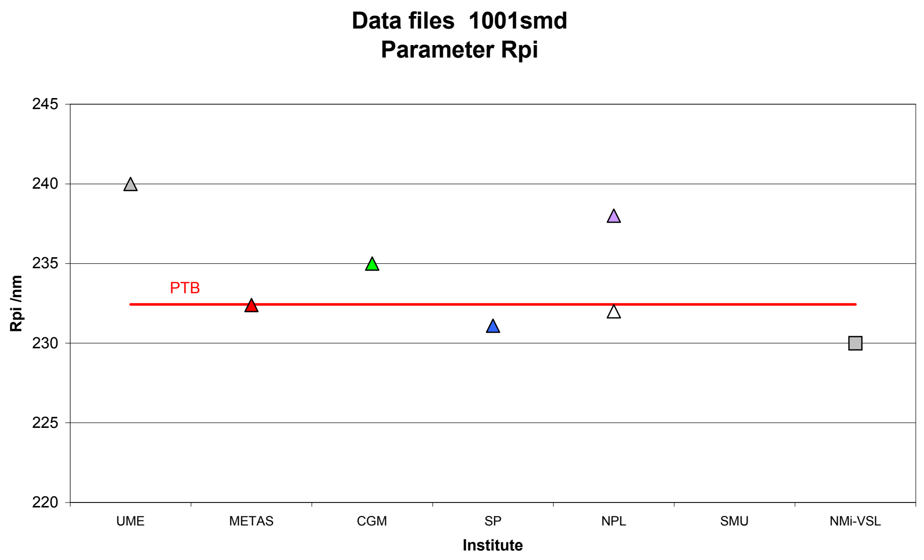
Institute	Country	Instrum	Measured Date			1001	1001	1001	1001	1001	1001	1001	1001
				λc	λs	Rz	Rz-Ref.	RSm	RSm-Ref.	Rmax	Rmax-Ref.	Rsk	Rsk-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm		
PTB	DE	NS	May 01	0,3	3	470,47		48880		561,37		-0,162	
UME	TR	MPC	Sep 01	0,3	0	480	9,53	63900	15020,00	570	8,63	0	0,16
METAS	CH	FTS	Oct 01	0,3	3	470,5	0,03					-0,009	0,15
CGM	DK	FTS	Jan 02			475	4,53			568	6,63	-0,008	0,15
SP	SE	FTS	May 02	0,3	3	460,1	-10,37			560,5	-0,87	-0,0074	0,15
NPL	UK	NS4	Jul 02	0,3	2,5	470	-0,47	65252	16372,00			0,16	0,32
SMU	CS	FTS	Nov 02	0,8	3	294	-176,47			470	-91,37	0,286	0,45
NMi-VSL	NL	FTS	Mrz 03	0,3	3	470	-0,47			610	48,63	-0,014	0,15
Mittelwert:						448,76	-24,81	59344,00	15696,00	556,65	-5,67	0,03	0,22
STABW:						62,78	67,15	9087,27	956,01	46,26	51,65	0,13	0,12

NPL corrected values	Rz	Rz-Ref.	RSm	RSm-Ref.	Rmax	Rmax-Ref.	Rsk	Rsk-Ref.
NPL corrected values	470		66135				-0,16	

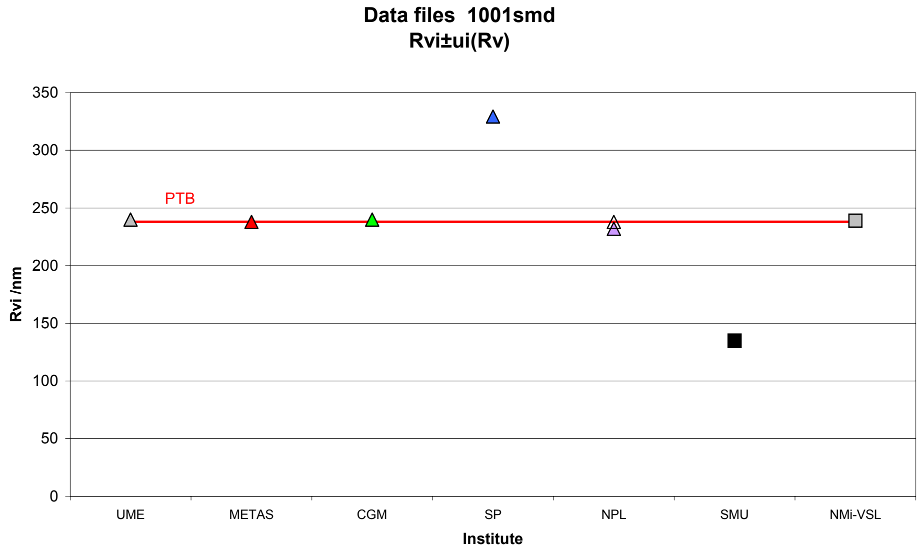
Institute	Country	Instrum	Measured Date			1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
				λc	λs	Rpk	Rpk-Ref.	Rk	Rk-Ref.	Rvk	Rvk-Ref.	Mr1%	Mr1%-Ref.	Mr2%	Mr2%-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	%	%	%	%
PTB	DE	NS	May 01	0,3	3	76,65		276,42		97,05		11,75		87,59	
UME	TR	MPC	Sep 01	0,3	0	70	-6,65	280	3,58	100	2,95	11,56	-0,19	87,81	0,22
METAS	CH	FTS	Oct 01	0,3	3										
CGM	DK	FTS	Jan 02			77	0,35	279	2,58	95	-2,05	11,8	0,05	87,6	0,01
SP	SE	FTS	May 02	0,3	3	76,1	-0,55	272,6	-3,82	91,1	-5,95	10	-1,75	88	0,41
NPL	UK	NS4	Jul 02	0,3	2,5										
SMU	CS	FTS	Nov 02	0,8	3	110	33,35	205	-71,42	84,6	-12,45	16	4,25	88,8	1,21
NMi-VSL	NL	FTS	Mrz 03	0,3	3	66	-10,65	264	-12,42	96	-1,05	10,4	-1,35	89,5	1,91
Mittelwert:						79,29	3,17	262,84	-16,30	93,96	-3,71	11,92	0,20	88,22	0,75
STABW:						15,67	17,46	28,92	31,47	5,42	5,82	2,14	2,39	0,77	0,79

Some selected diagrams

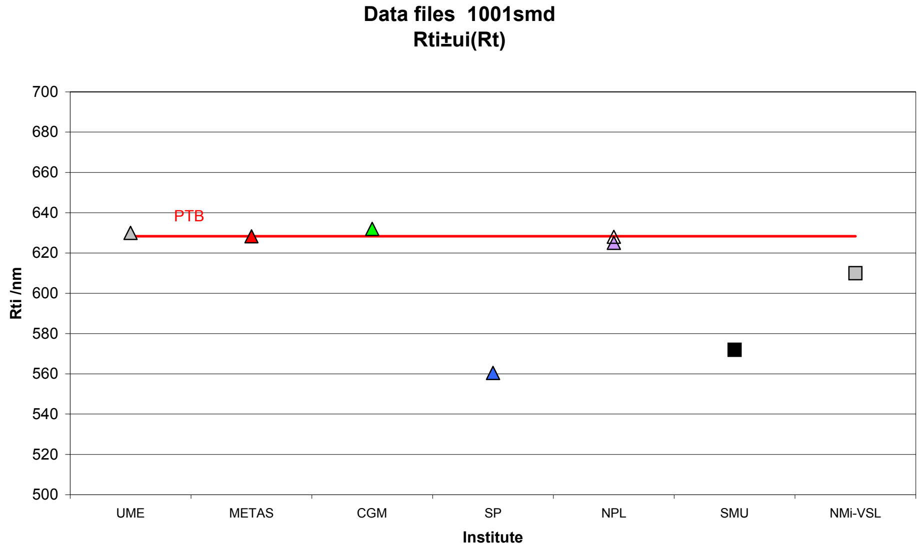




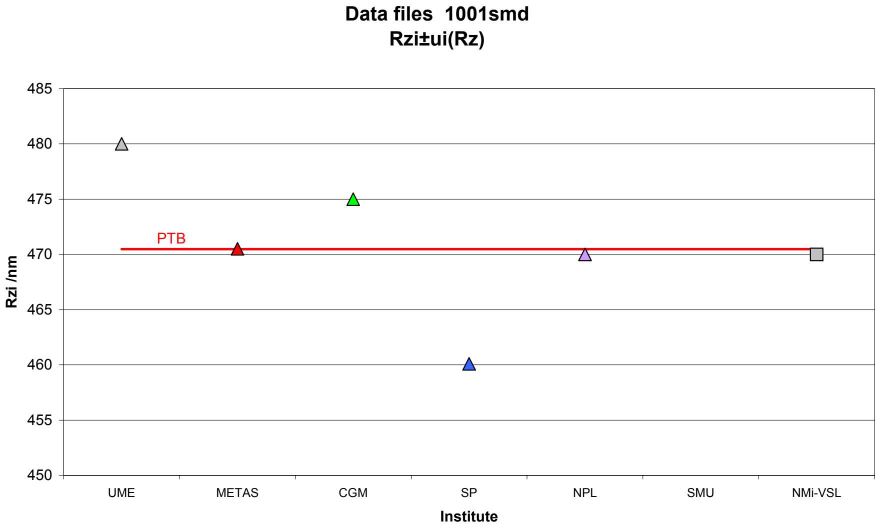
 # open symbol shows corrected value of NPL

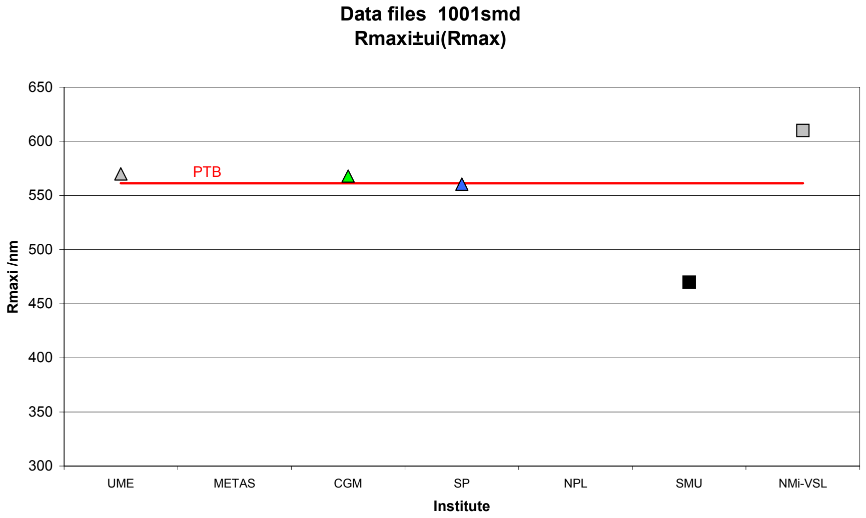


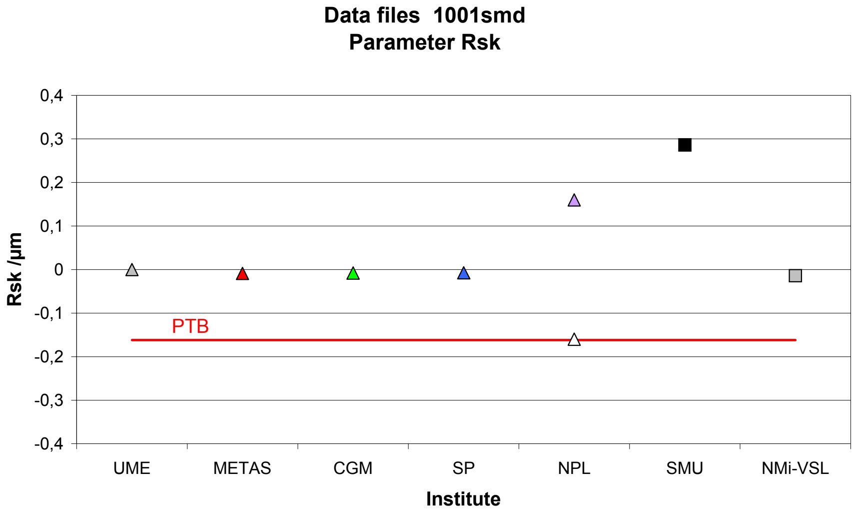
 # open symbol shows corrected value of NPL



 # open symbol shows corrected value of NPL

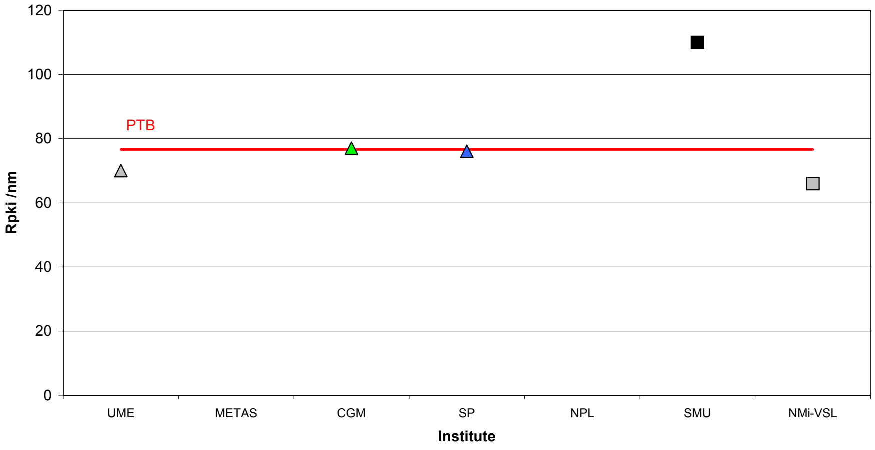




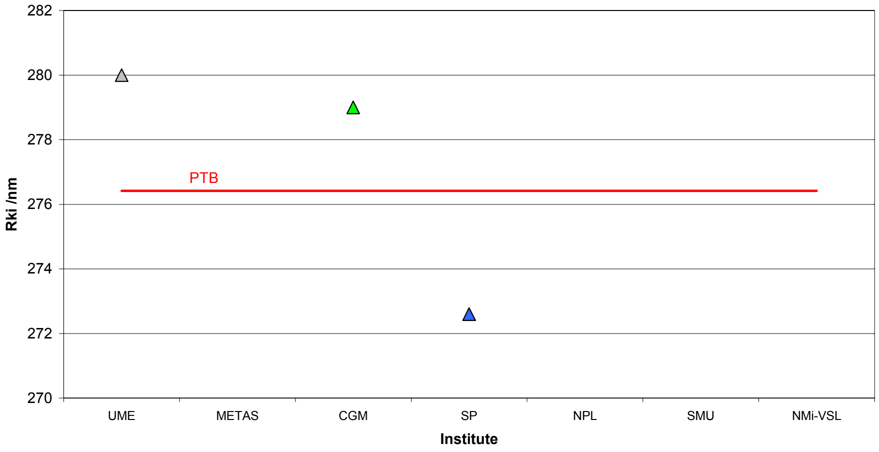


 # open symbol shows corrected value of NPL

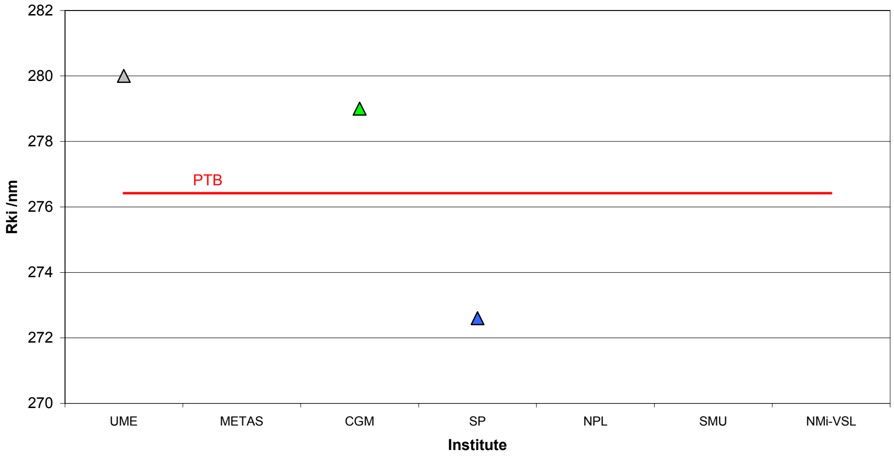
Data files 1001smd
Rpki±ui(Rpk)



Data files 1001smd
Rki±ui(Rk)



Data files 1001smd
Rki±ui(Rk)



2. DATA FILE 505.SMD

Institute	Country	Instrumen	Measured Date			505	505	505	505	505	505	505	505	505	505
				λc	λs	Ra	Ra-Ref.	Rq	Rq-Ref.	Rp	Rp-Ref.	Rv	Rv-Ref.	Rt	Rt-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
PTB	DE	NS	May 01	0,8	2,5	187,02		231,05		498,26		747,64		1424,69	
ILM	IT	FTS	Aug 01	unfilt	unfilte	176	-11,02	217	-14,05	492	-6,26	756	8,36	1248	-176,69
UME	TR	MPC	Sep 01	0,8	0	190	2,98	230	-1,05	520	21,74	780	32,36	1470	45,31
METAS	CH	FTS	Oct 01	0,8	2,5	186,5	-0,52	230,6	-0,45	510,7	12,44	725,7	-21,94	1456,4	31,71
CGM	DK	FTS	Jan 02			189	1,98	234	2,95	520	21,74	782	34,36	1472	47,31
SP	SE	FTS	May 02	0,8	2,5	186,8	-0,22	230,8	-0,25	523,7	25,44	888,8	141,16	1412,5	-12,19
NPL	UK	NS4	Jul 02	0,8	2,5	187	-0,02	230	-1,05	746	247,74	496	-251,64	1422	-2,69
SMU	CS	FTS	Nov 02	0,8	2,5	120	-67,02	150	-81,05	346	-152,26	389	-358,64	1430	5,31
NMi-VSL	NL	FTS	Mrz 03	0,8	2,5	186	-1,02	230	-1,05	509	10,74	724	-23,64	1452	27,31
Mittelwert:						178,70	-9,36	220,38	-12,00	518,41	22,67	698,79	-54,95	1420,84	-4,33
STABW:						22,37	23,68	26,82	28,35	101,74	108,46	155,62	165,21	68,29	72,99

*)NPL: Rv *-1

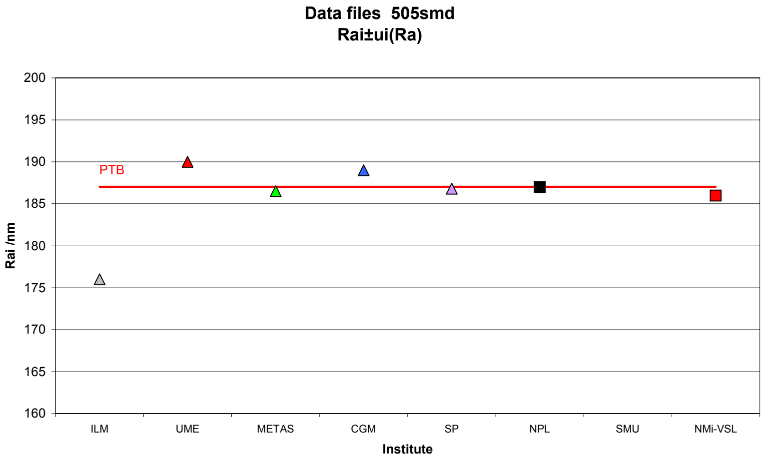
NPL corrected values	187	230	498	748	1425

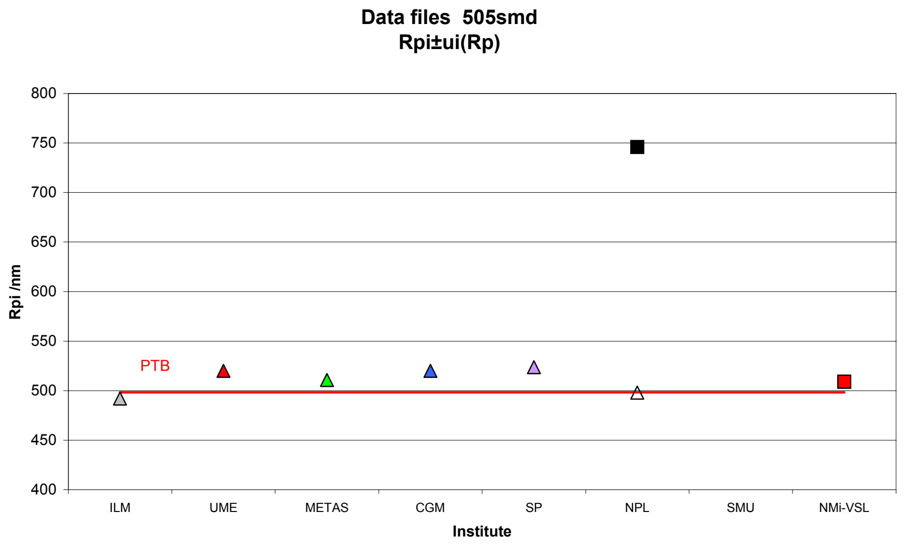
Institute	Country	Instrumen	Measured Date			505	505	505	505	505	505	505	505
				λc	λs	Rz	Rz-Ref.	RSm	RSm-Ref.	Rmax	Rmax-Ref	Rsk	Rsk-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm		
PTB	DE	NS	May 01	0,8	2,5	1245,91		30300		1421,99		-0,222	
ILM	IT	FTS	Aug 01	unfilt	unfilte	1112	-133,91			1248	-173,99	-0,261	-0,04
UME	TR	MPC	Sep 01	0,8	0	1300	54,09	45980	15680,00	1470	48,01	-0,28	-0,06
METAS	CH	FTS	Oct 01	0,8	2,5	1236,4	-9,51					-0,258	-0,04
CGM	DK	FTS	Jan 02			1302	56,09			1470	48,01	-0,284	-0,06
SP	SE	FTS	May 02	0,8	2,5	1198,3	-47,61			1412,5	-9,49	-0,285	-0,06
NPL	UK	NS4	Jul 02	0,8	2,5	1242	-3,91	99210	68910,00			0,24	0,46
SMU	CS	FTS	Nov 02	0,8	2,5	736	-509,91			1150	-271,99	-0,271	-0,05
NMi-VSL	NL	FTS	Mrz 03	0,8	2,5	1233	-12,91			1419	-2,99	-0,258	-0,04
Mittelwert:						1178,40	-75,95	58496,67	42295,00	1370,21	-60,41	-0,21	0,01
STABW:						175,19	185,32	36119,90	37639,29	122,61	131,96	0,17	0,18

NPL corrected values	1246	98808	-0,22

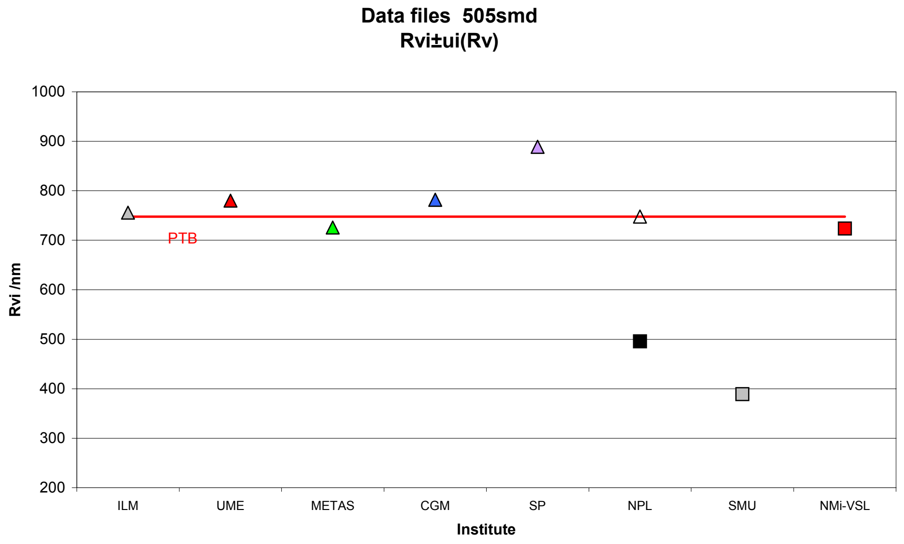
Institute	Country	Instrumen	Measured Date			505	505	505	505	505	505	505	505	505	505
				λc	λs	Rpk	Rpk-Ref.	Rk	Rk-Ref.	Rvk	Rvk-Ref.	Mr1%	Mr1%-Ref	Mr2%	Mr2%-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	%	%	%	%
PTB	DE	NS	May 01	0,8	2,5	134,68		636,93		254,13		7,72		89,86	
ILM	IT	FTS	Aug 01	unfilt	unfilte	129	-5,68	661	24,07	257	2,87	6	-1,72	91	1,14
UME	TR	MPC	Sep 01	0,8	0	140	5,32	650	13,07	250	-4,13	7,43	-0,29	89,92	0,06
METAS	CH	FTS	Oct 01	0,8	2,5										
CGM	DK	FTS	Jan 02			131	-3,68	661	24,07	252	-2,13	6,9	-0,82	90,1	0,24
SP	SE	FTS	May 02	0,8	2,5	152	17,32	657,1	20,17	251	-3,13	8	0,28	90	0,14
NPL	UK	NS4	Jul 02	0,8	2,5										
SMU	CS	FTS	Nov 02	0,8	2,5	184	49,32	448	-188,93	144	-110,13	13,2	5,48	89,6	-0,26
NMi-VSL	NL	FTS	Mrz 03	0,8	2,5	130	-4,68	640	3,07	244	-10,13	7,4	-0,32	90,3	0,44
Mittelwert:						142,95	9,65	622,00	-17,41	236,02	-21,13	8,09	0,44	90,11	0,29
STABW:						19,79	21,30	77,33	84,40	40,77	43,80	2,34	2,56	0,45	0,47

Some selected Diagrams

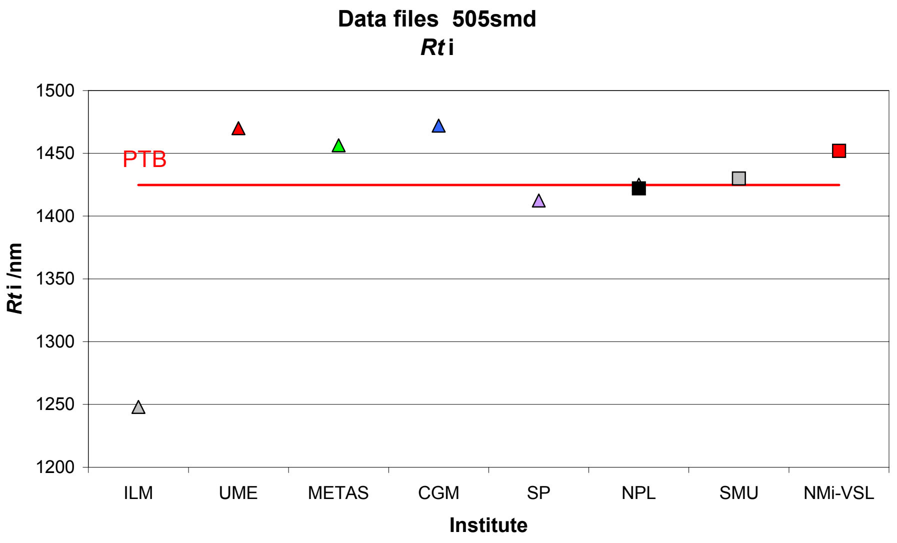




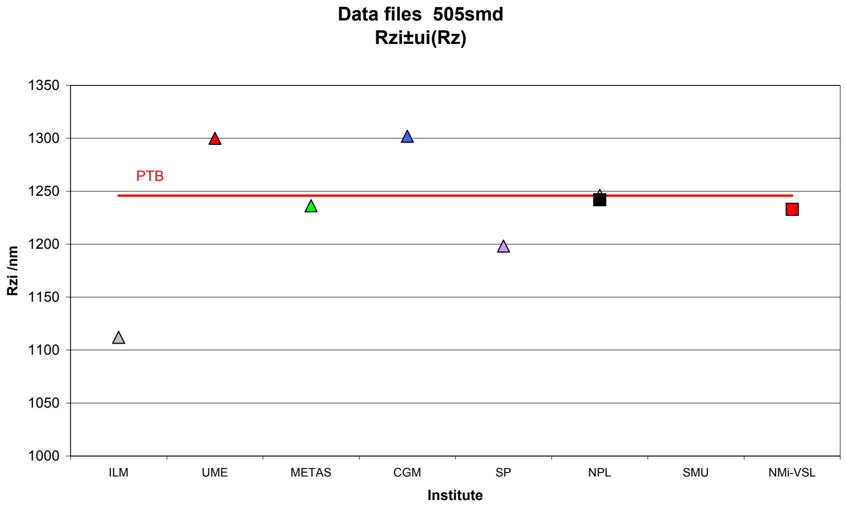
 # open symbol shows corrected value of NPL

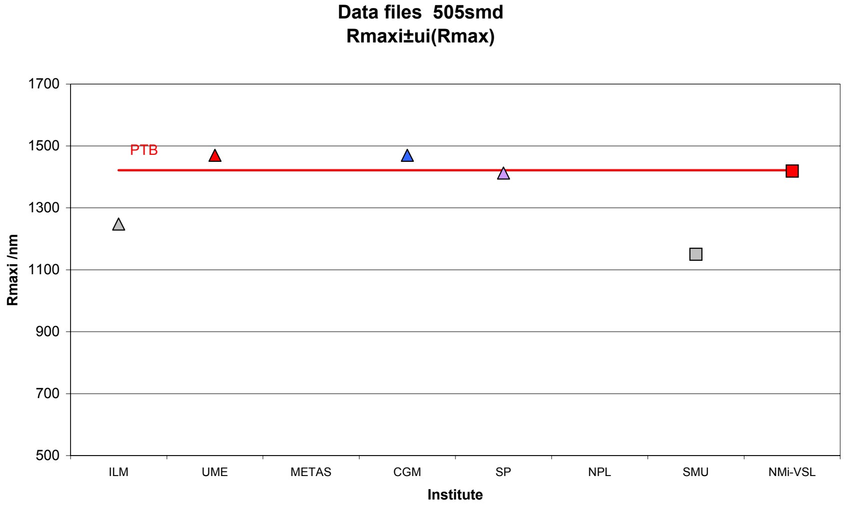


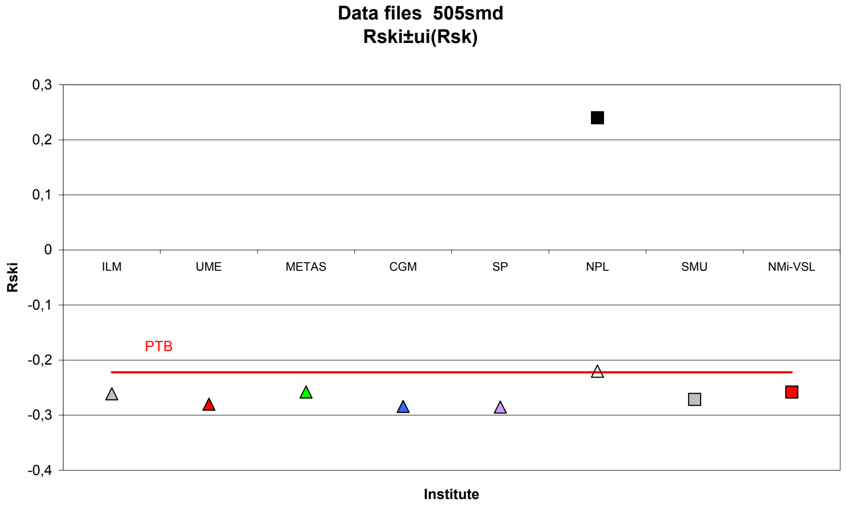
 # open symbol shows corrected value of NPL



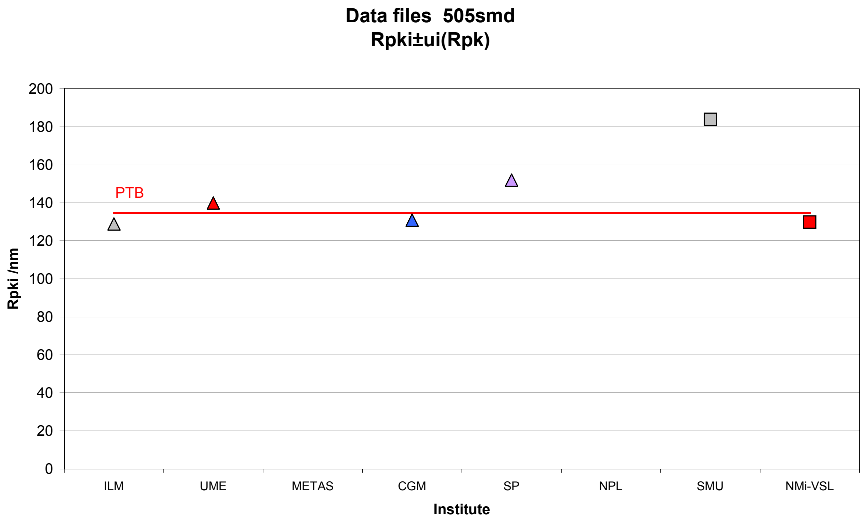
 # open symbol shows corrected value of NPL

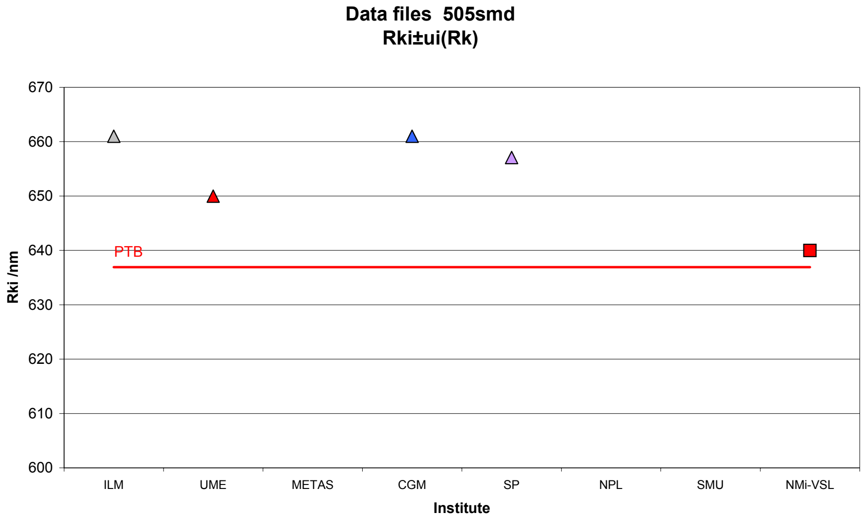


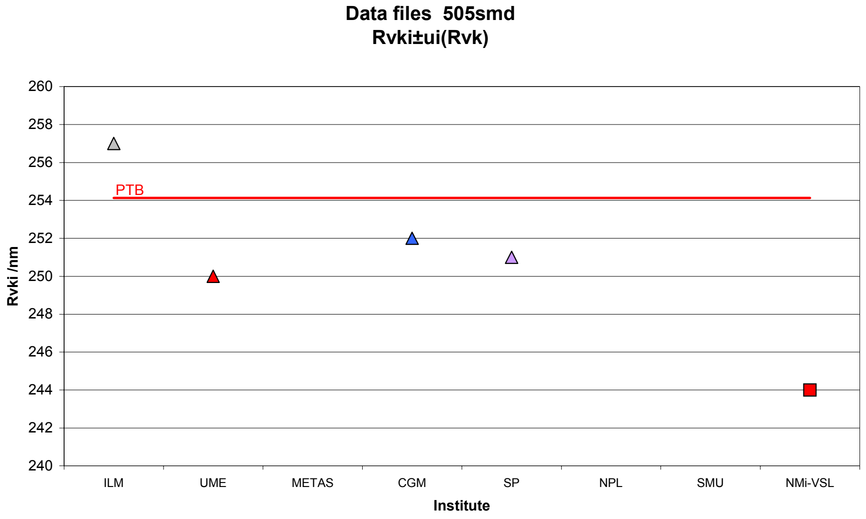




 # open symbol shows corrected value of NPL


Data files 505smd
Rpki±ui(Rpk)


Data files 505smd
Rki±ui(Rk)


Data files 505smd
Rvki±ui(Rvk)

3. DATA FILE 7080.SMD

Institute	Country	Instrumen	Measured			7080	7080	7080	7080	7080	7080	7080	7080	7080	7080
			Date	λc	λs	Ra	Ra-Ref.	Rq	Rq-Ref.	Rp	Rp-Ref	Rv	Rv-Ref.	Rt	Rt-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
PTB	DE	NS	Mai 01	0,3	3	423,65		484,11		754,08		721		1484,2	
UME	TY	MPC	Sep 01	0,3	0	430	6,35	490	5,89	760	5,92	740	19,01	1520	35,79
METAS	CH	FTS	Okt 01	0,3	3	423,8	0,15	484,2	0,09	753,8	-0,28	721	0,01	1482,8	-1,41
CGM	DK	FTS	Jan 02			422	-1,65	482	-2,11	755	0,92	730	9,01	1501	16,79
SP	SE	FTS	Mai 02	0,3	3	420,4	-3,25	480,5	-3,61	754,7	0,62	718,2	-2,79	1472,9	-11,31
NPL	UK	NS4	Jul 02	0,3	2,5	423	-0,65	483	-1,11	725	-29,08	754	-1474,99	1507	22,79
SMU	CS	FTS	Nov 02	0,8	3	216	-207,65	250	-234,11	401	#####	425	-295,99	947	-537,21
NMi-VSL	NL	FTS	Mrz 03	0,3	3	419	-4,65	479	-5,11	748	-6,08	713	-7,99	1474	-10,21
Mittelwert:						397,23		454,10		706,45		#####		######	
STABW:						73,30		82,53		123,89		#####		193,29	

)NPL Rp(-1)

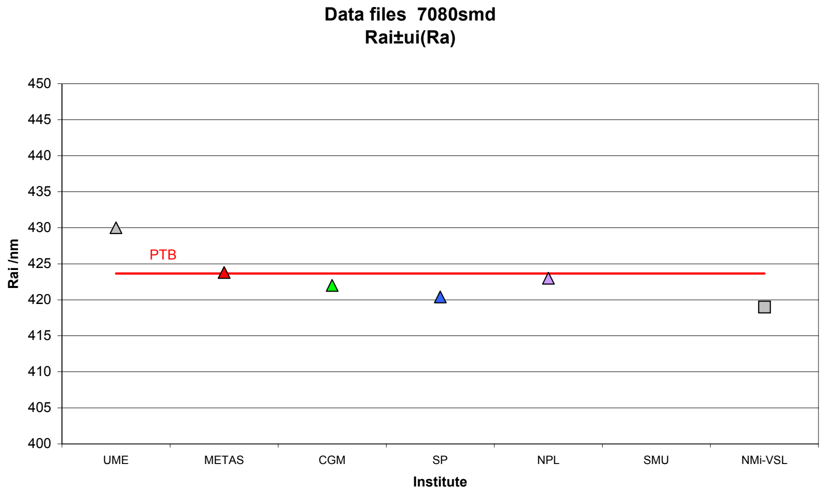
NPL corrected						424		484		754		721		1484	

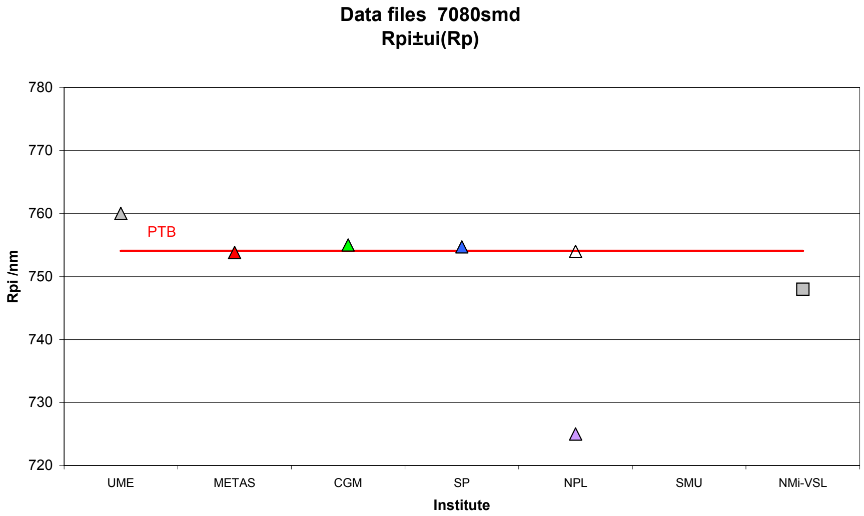
Institute	Country	Instrumen	Measured			7080	7080	7080	7080	7080	7080	7080	7080
			Date	λc	λs	Rz	Rz-Ref.	RSm	RSm-Ref.	Rmax	max-Re	Rsk	Rsk-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm		
PTB	DE	NS	Mai 01	0,3	3	1475,05		99790		1480,4		0,014	
UME	TY	MPC	Sep 01	0,3	0	1500	24,95	99920	130,00	1520	39,65	0,01	0,00
METAS	CH	FTS	Okt 01	0,3	3	1474,8	-0,25	99800	10,00			0,015	0,00
CGM	DK	FTS	Jan 02			1486	10,95			1501	20,65	0,012	0,00
SP	SE	FTS	Mai 02	0,3	3	1463,5	-11,55	99860	70,00	1467,2	-13,15	0,014	0,00
NPL	UK	NS4	Jul 02	0,3	2,5	1479	3,95	99661	-129,00			0	-0,01
SMU	CS	FTS	Nov 02	0,8	3	827	-648,05	10,6	#######	909	#####	-0,14	-0,15
NMi-VSL	NL	FTS	Mrz 03	0,3	3	1461	-14,05	99760	-30,00	1470	-10,35	0,052	0,04
Mittelwert:						1395,79		######		1391,26		0,00	
STABW:						230,16		######		237,11		0,06	

NPL corrected						1475		99825		./.		0,01	

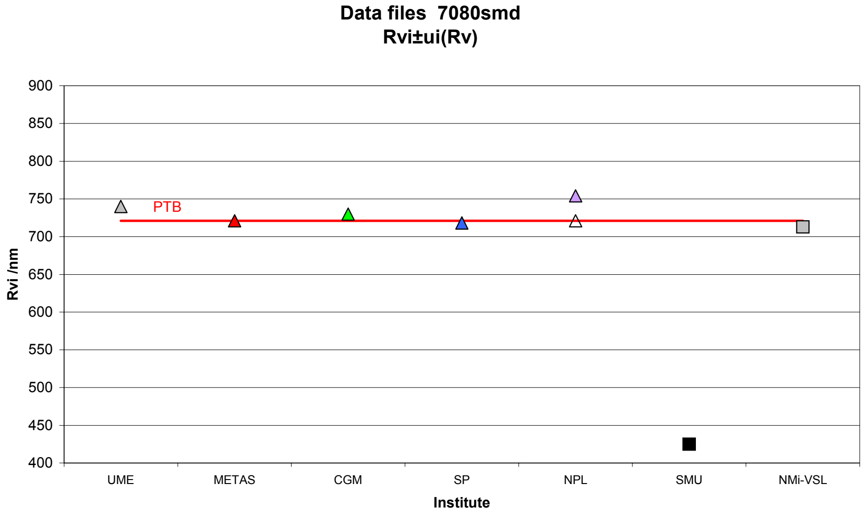
Institute	Country	Instrumen	Measured			7080	7080	7080	7080	7080	7080	7080	7080	7080	7080
			Date	λc	λs	Rpk	Rpk-Ref	Rk	Rk-Ref.	Rvk	Rvk-Ref	Mr1%	Mr1%-Ref	Mr2%	Mr2%-Ref.
				mm	µm	nm	nm	nm	nm	nm	nm	%	%	%	%
PTB	DE	NS	Mai 01	0,3	3										
UME	TY	MPC	Sep 01	0,3	0										
METAS	CH	FTS	Okt 01	0,3	3										
CGM	DK	FTS	Jan 02			116	116,00	1407	1407,00	12	12,00	10,4	10,40	99,9	99,90
SP	SE	FTS	Mai 02	0,3	3										
NPL	UK	NS4	Jul 02	0,3	2,5										
SMU	CS	FTS	Nov 02	0,8	3	125	125,00	505	505,00	627	627,00	5,89	5,89	77,3	77,30
NMi-VSL	NL	FTS	Mrz 03	0,3	3										
Mittelwert:						120,50		956,00		319,50		8,15		88,60	
STABW:						6,36		637,81		434,87		3,19		15,98	

Some selected Diagrams

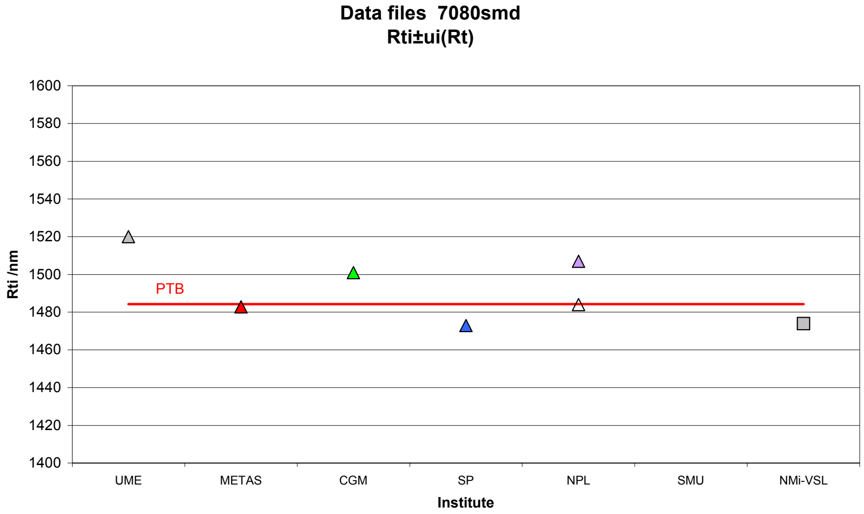




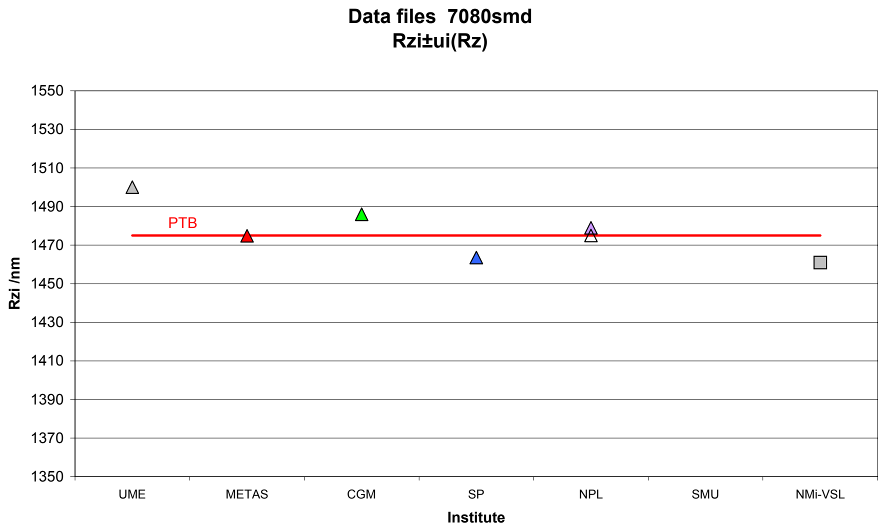
 # open symbol shows corrected value of NPL



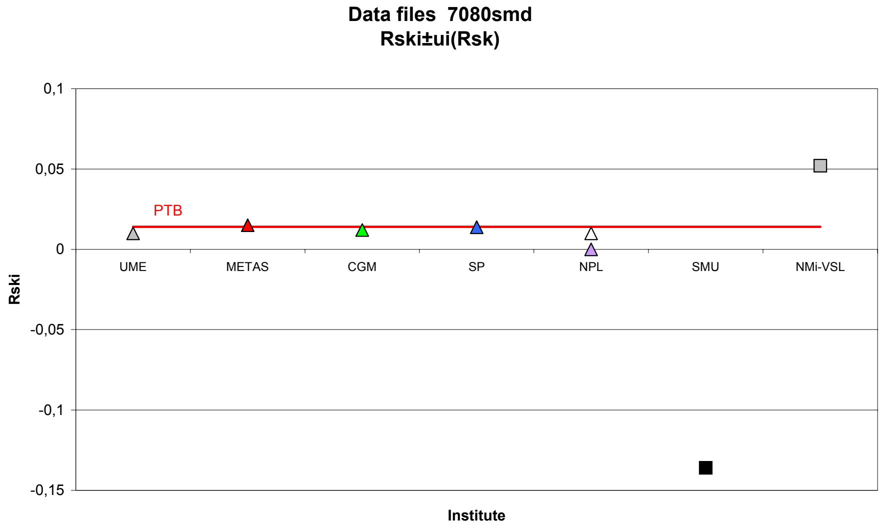
 # open symbol shows corrected value of NPL



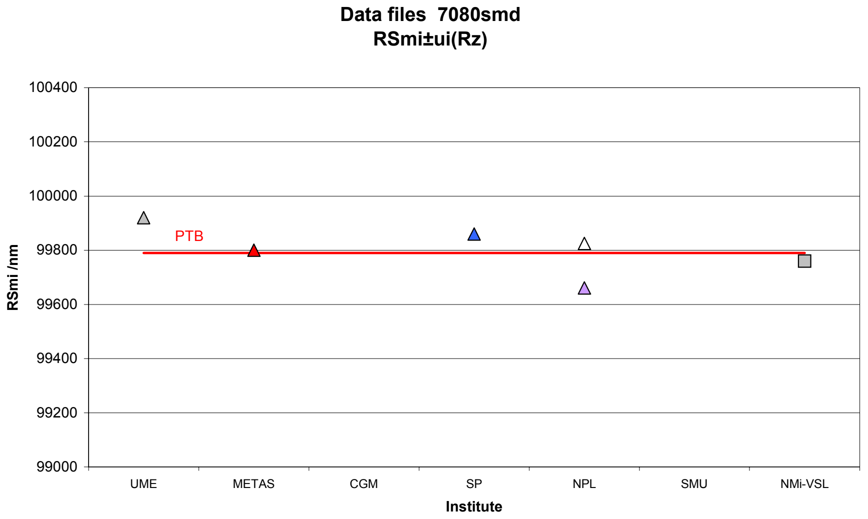
 # open symbol shows corrected value of NPL



 # open symbol shows corrected value of NPL



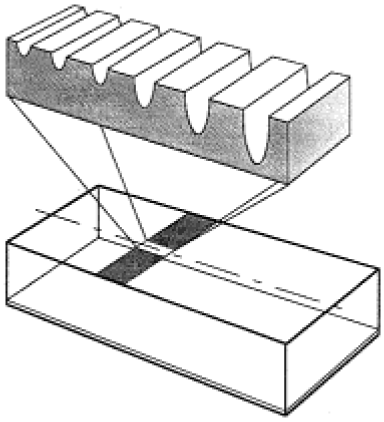
 # open symbol shows corrected value of NPL



 # open symbol shows corrected value of NPL

Appendix E1

Degree of Equivalence

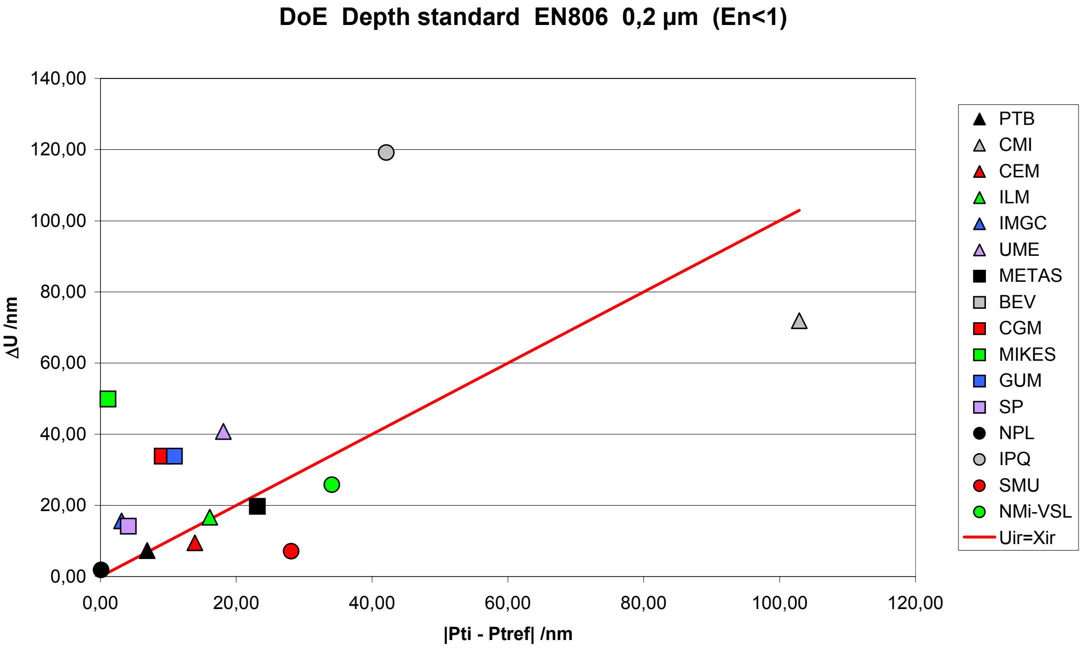


Depth Setting Standard

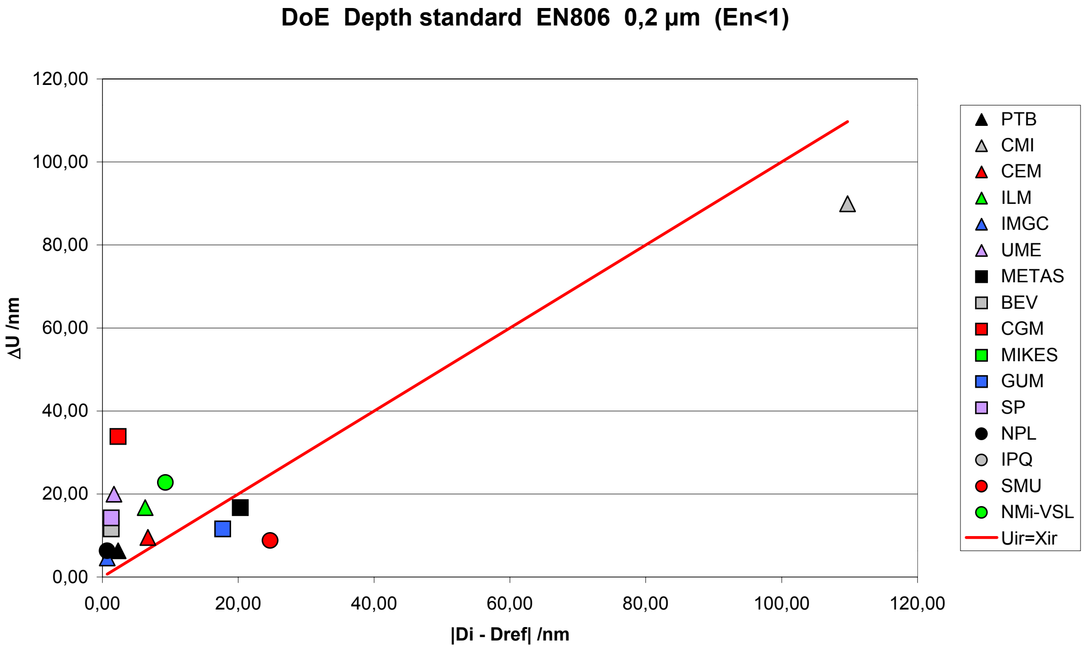
Type A

1 DEPTH STANDARD EN806 R1 0,2 µM

Degree of Equivalence for *Pt*

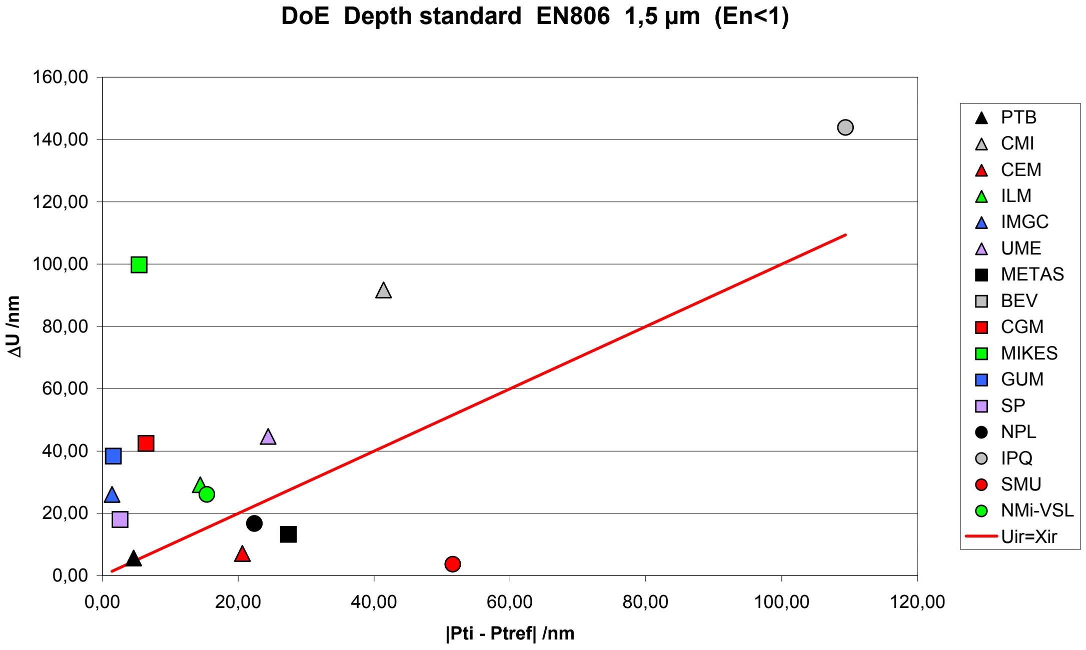


Degree of Equivalence for *D*

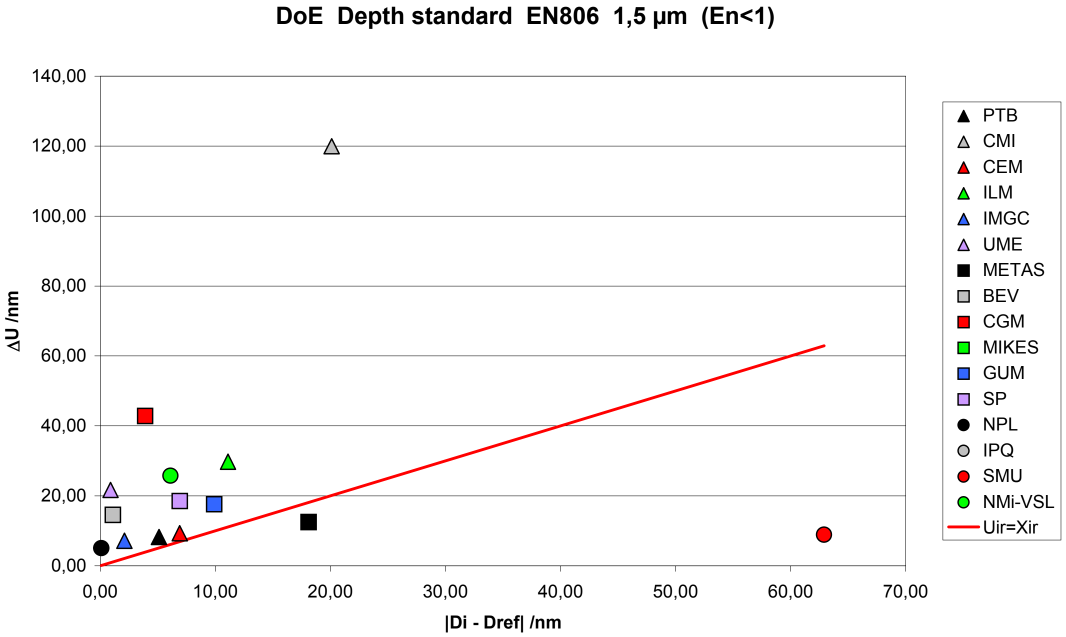


2 DEPTH STANDARD EN806 R2 1,5 µM

Degree of Equivalence for *Pt*

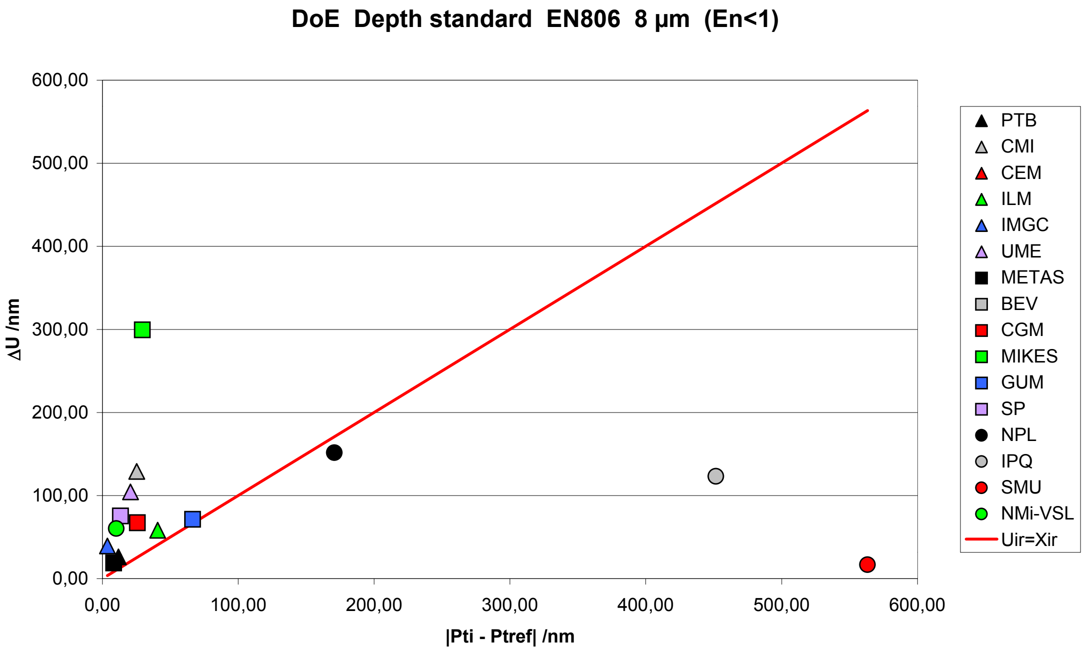


Degree of Equivalence for *D*



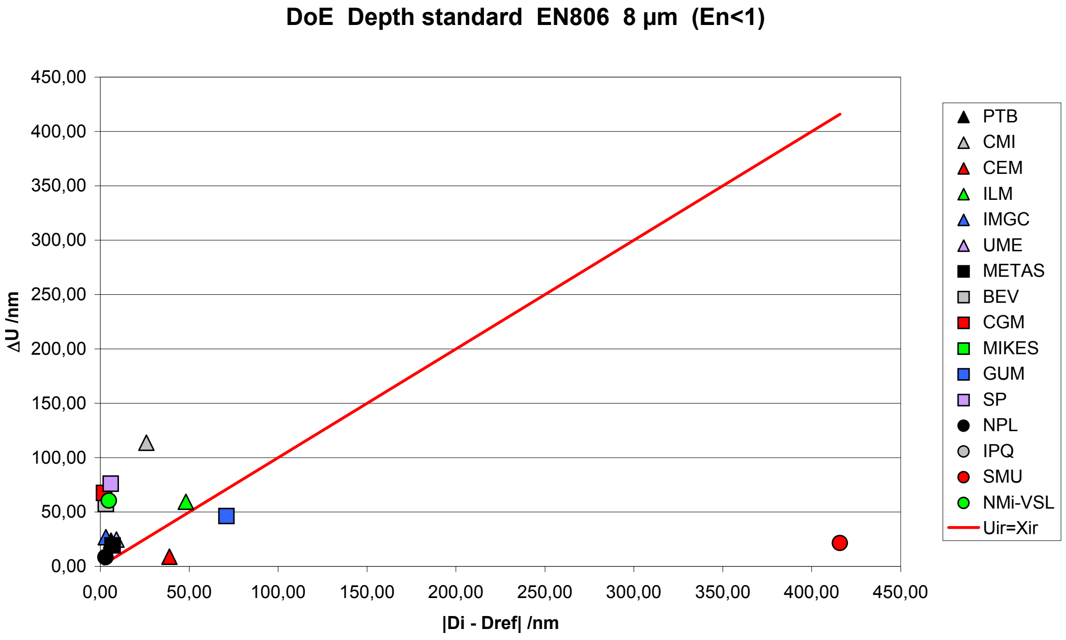
3 DEPTH STANDARD EN806 R3 8,0 µM

Degree of Equivalence for *Pt*



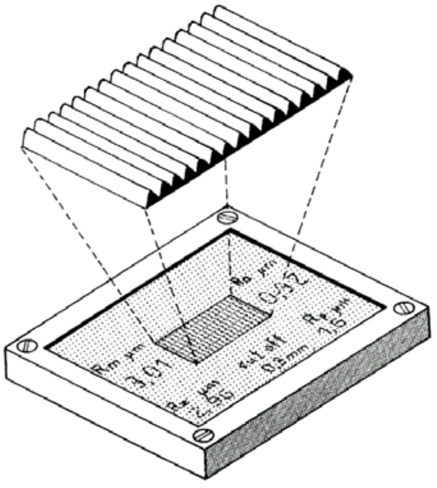
*) DoE(*U*ir) for CEM cannot be calculated, since $u_i < u_{ref}$

Degree of Equivalence for *D*



Appendix E2

Degree of Equivalence

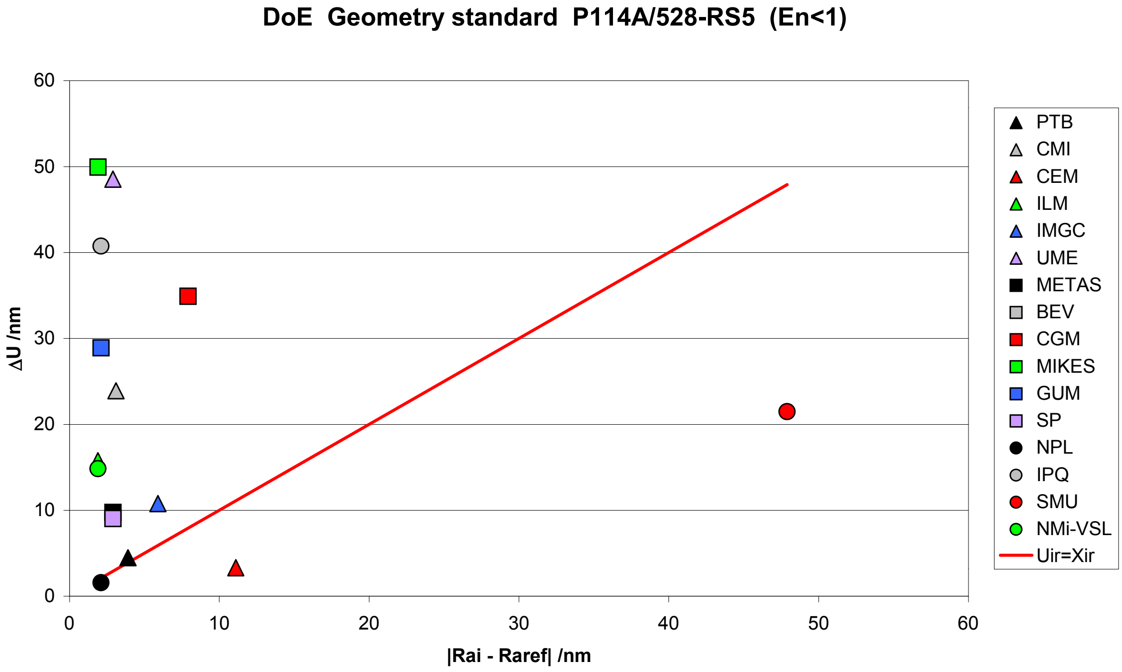


Roughness Standard

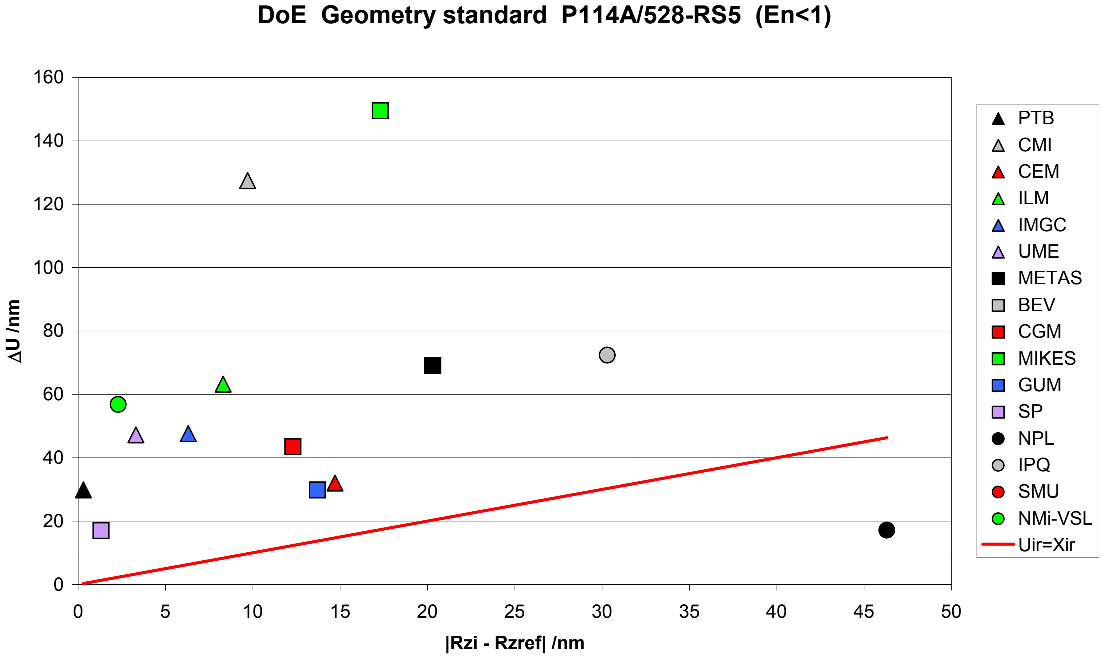
Type C

1 ROUGHNESS STANDARD P114A

Degree of Equivalence for Ra

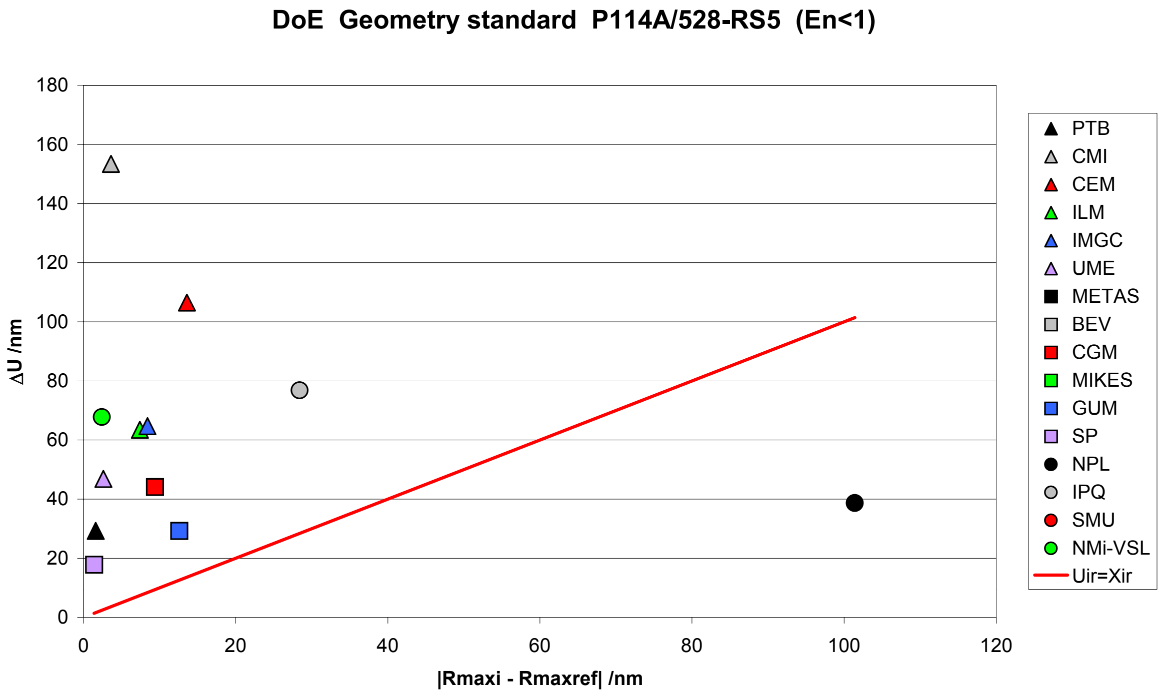


Degree of Equivalence for Rz



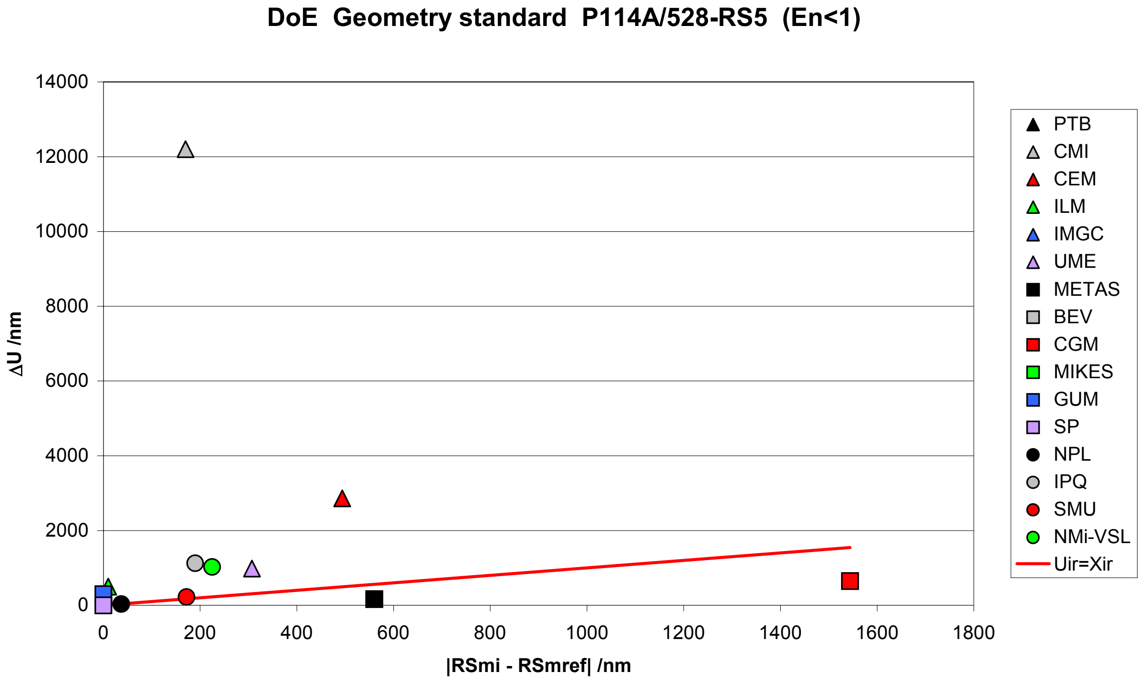
DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$

Degree of Equivalence for Rmax



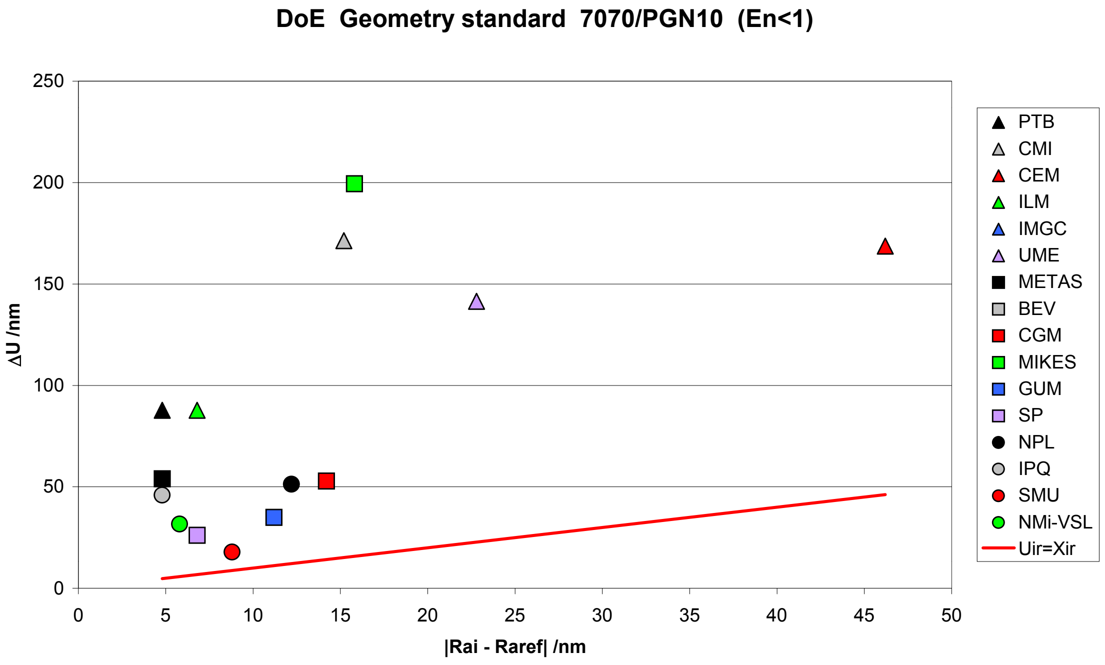
DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$

Degree of Equivalence for RSm

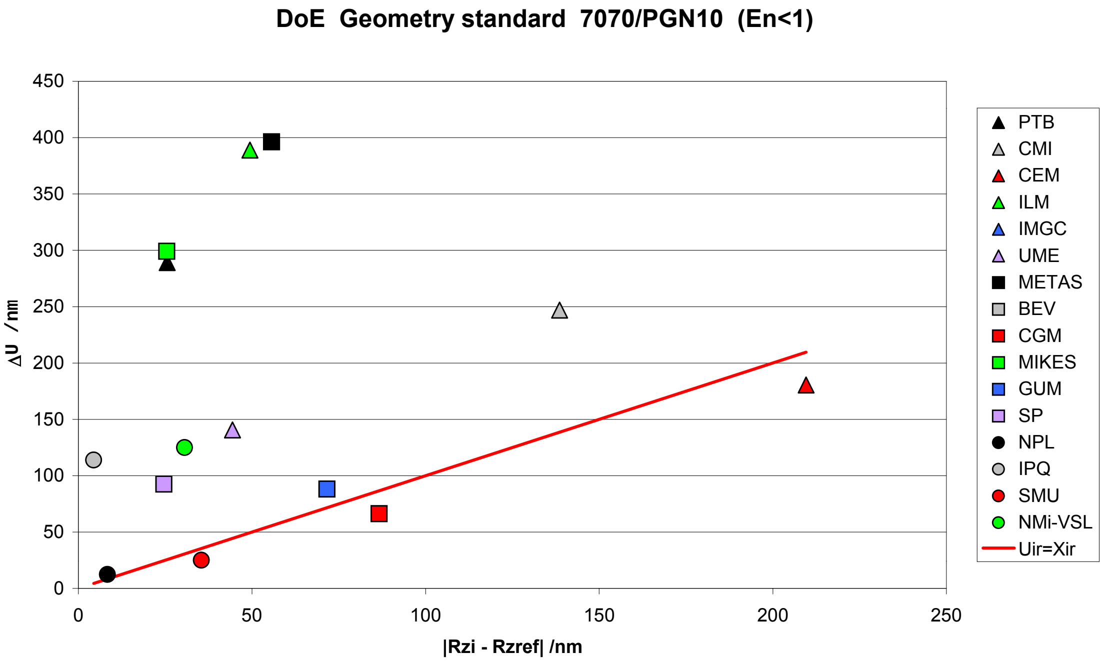


2 ROUGHNESS STANDARD 7070/PGN10

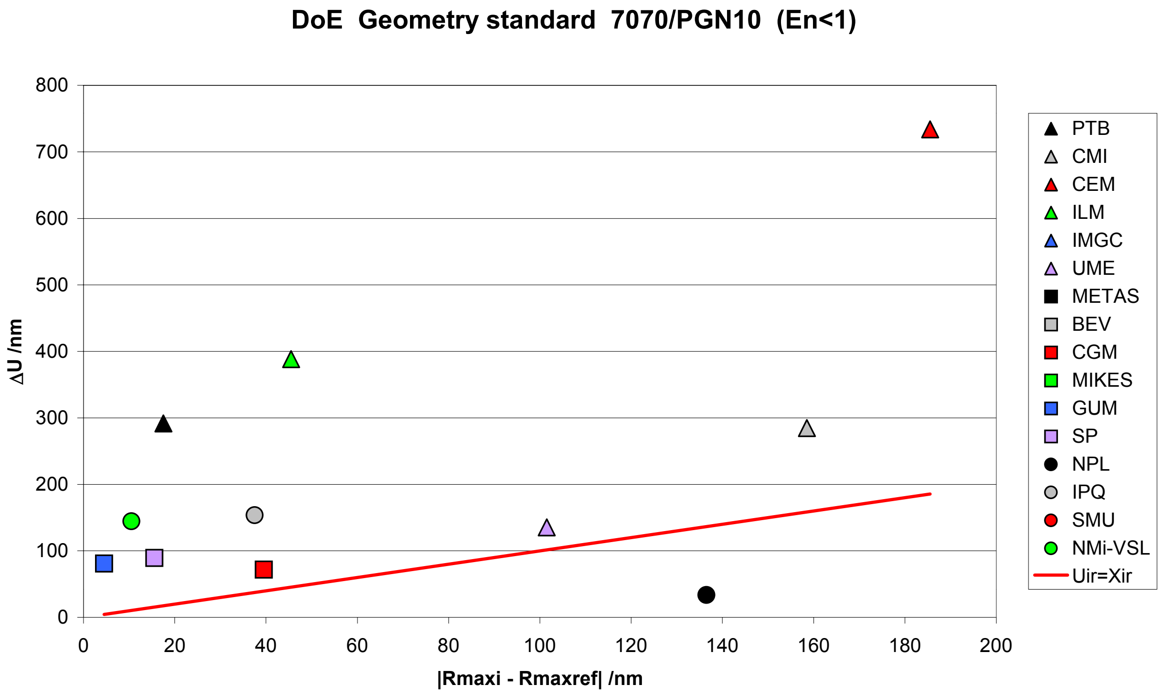
Degree of Equivalence for Ra



Degree of Equivalence for Rz

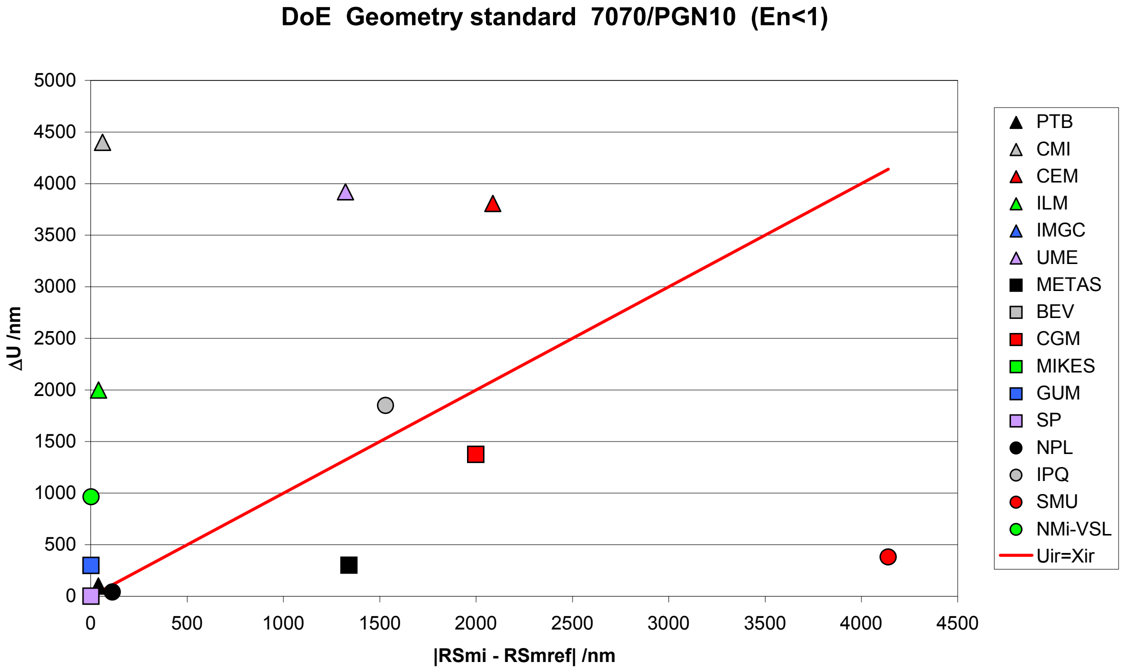


Degree of Equivalence for Rmax



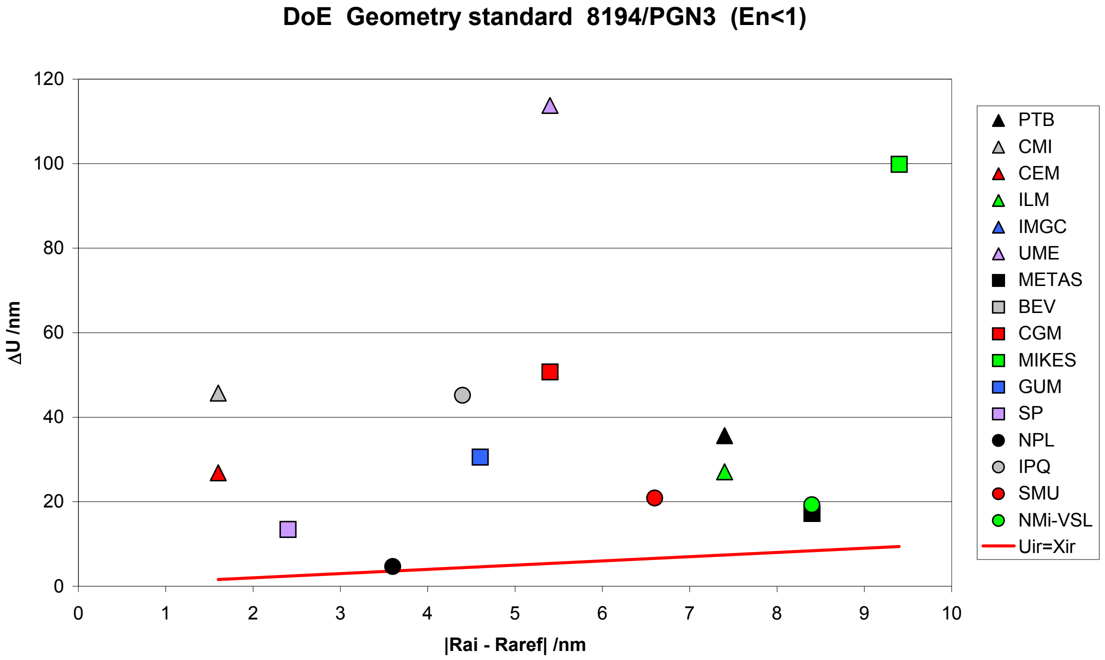
DoE (Uir) for SMU cannot be calculated, since $U_i < U_{ref}$

Degree of Equivalence for RSm

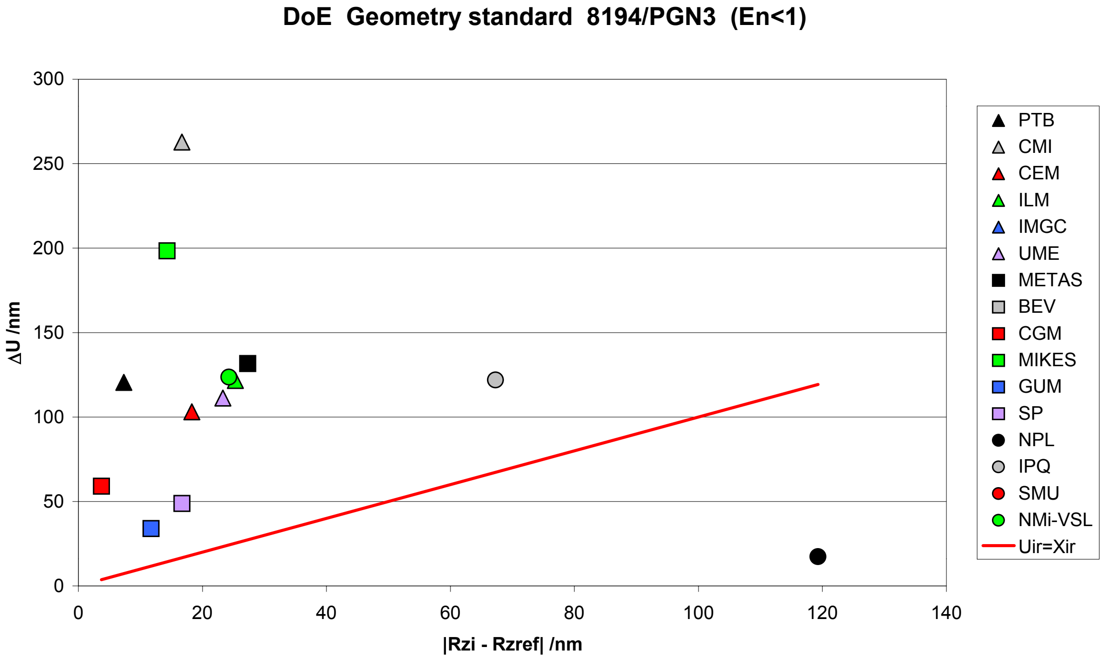


3 ROUGHNESS STANDARD 8194/PGN3

Degree of Equivalence for Ra

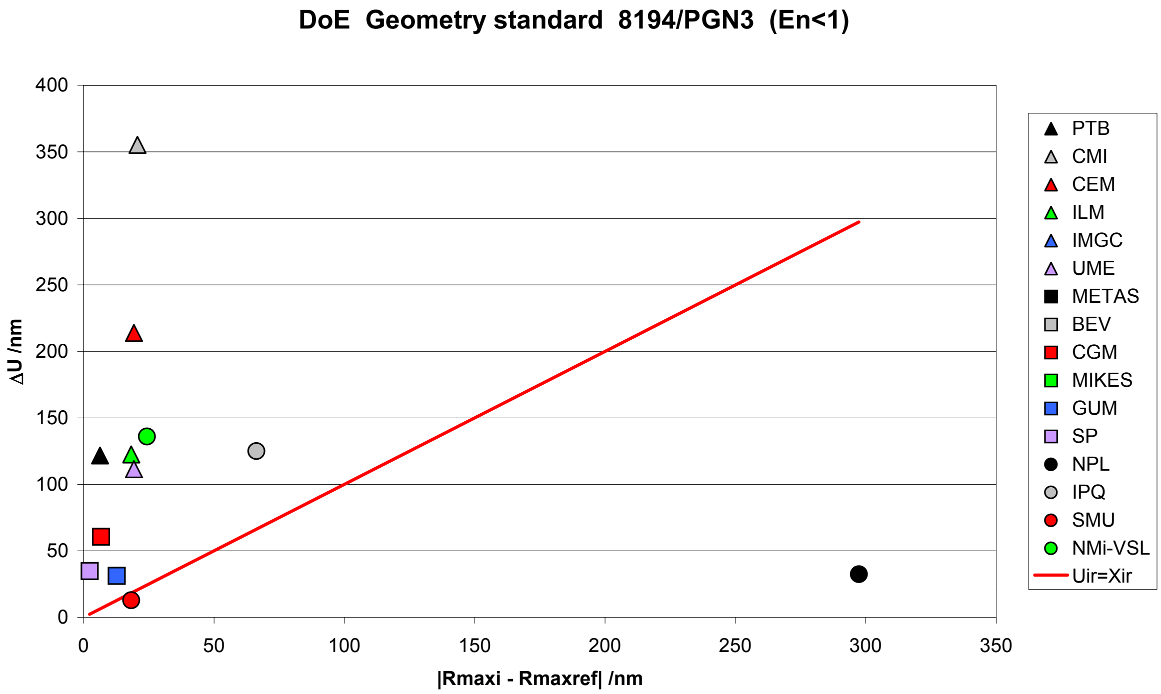


Degree of Equivalence for Rz

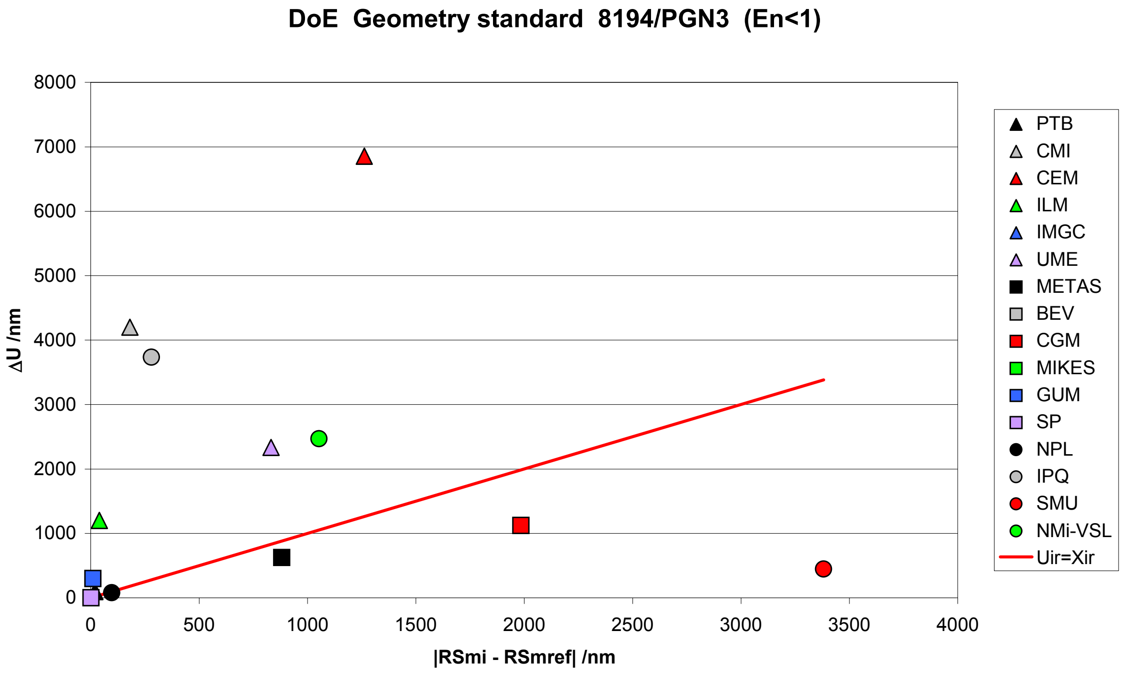


DoE (*U*ir) for SMU cannot be calculated, since $U_i < U_{ref}$

Degree of Equivalence for Rmax

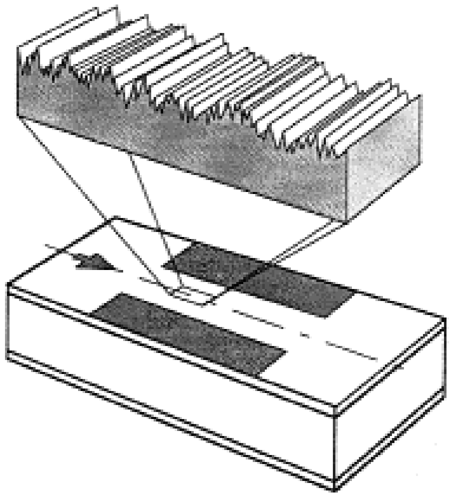


Degree of Equivalence for RSm



Appendix E3

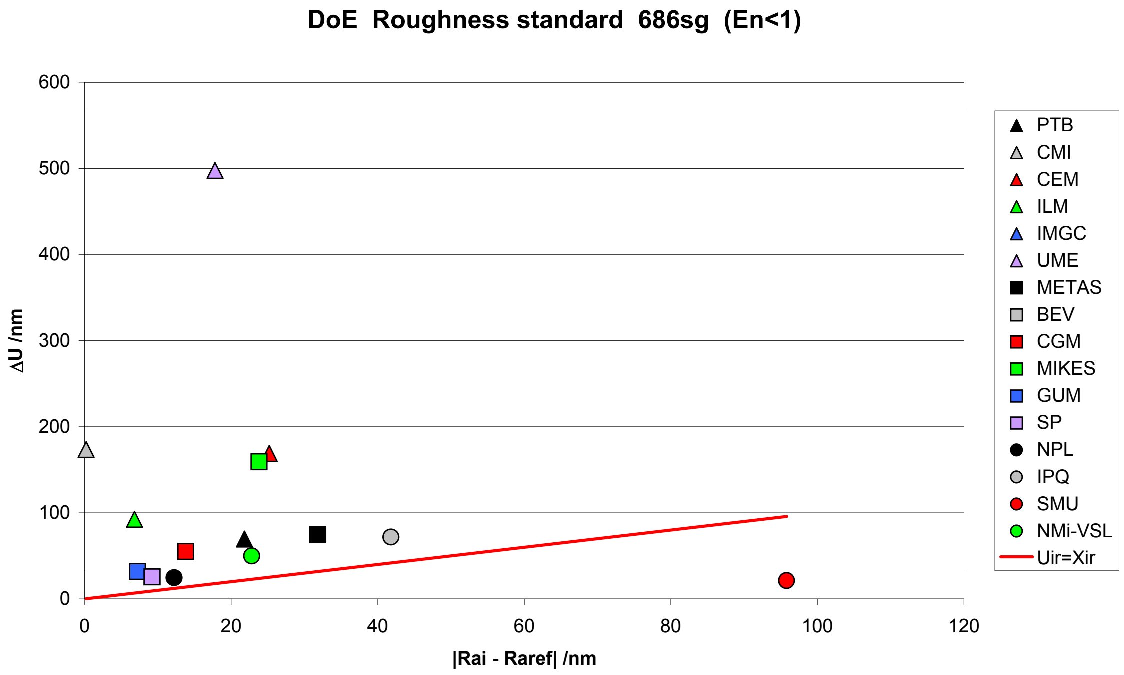
Degree of Equivalence



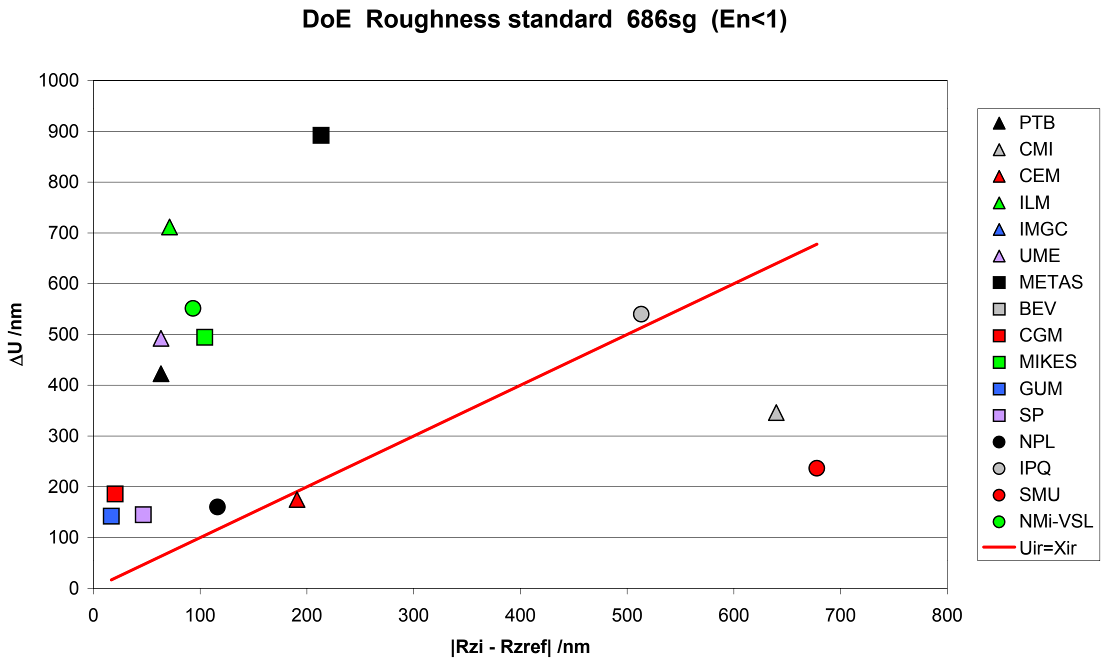
Roughness Standard
Type D

1. ROUGHNESS STANDARD 686SG

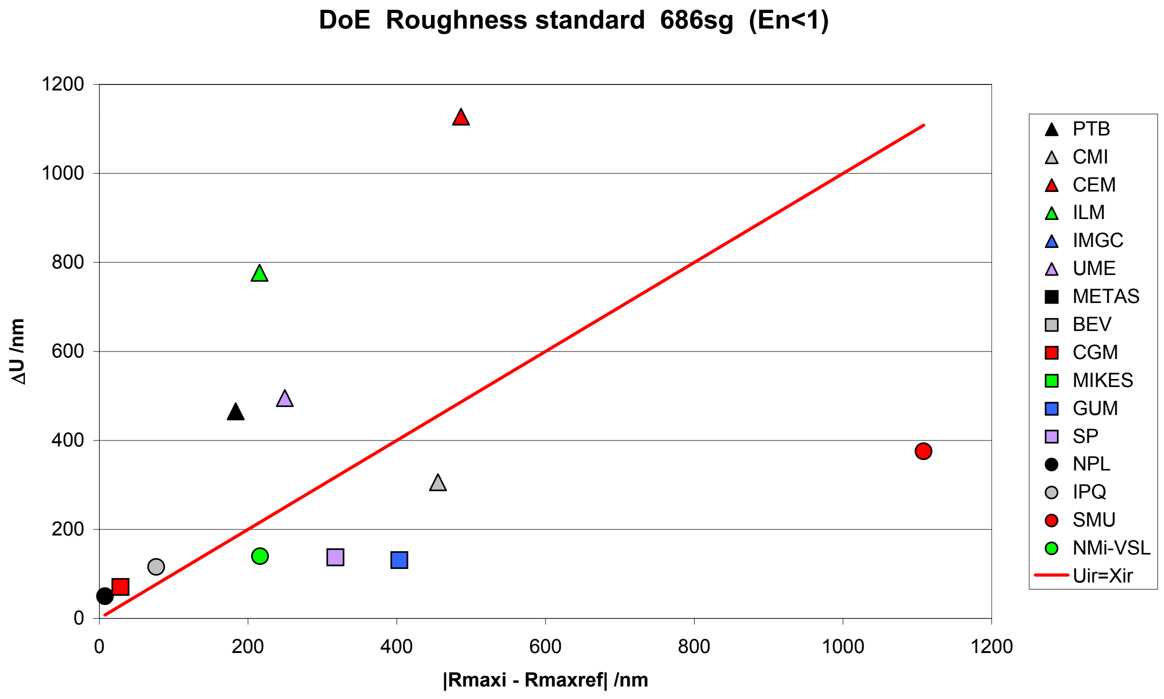
Results of *Ra*



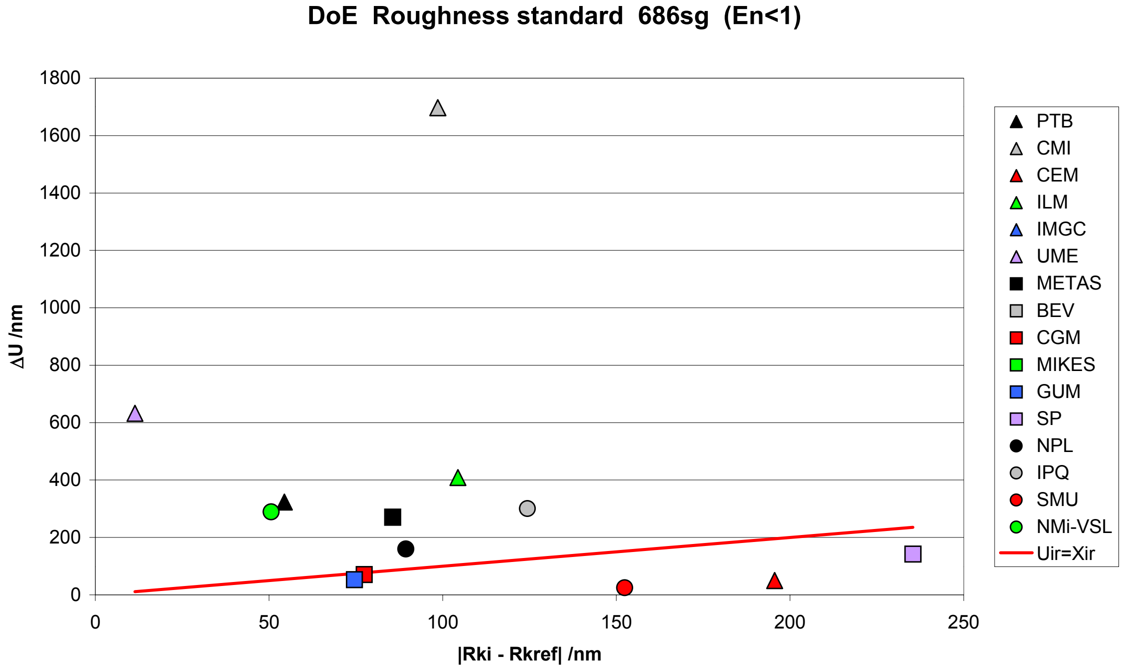
Results of *Rz*



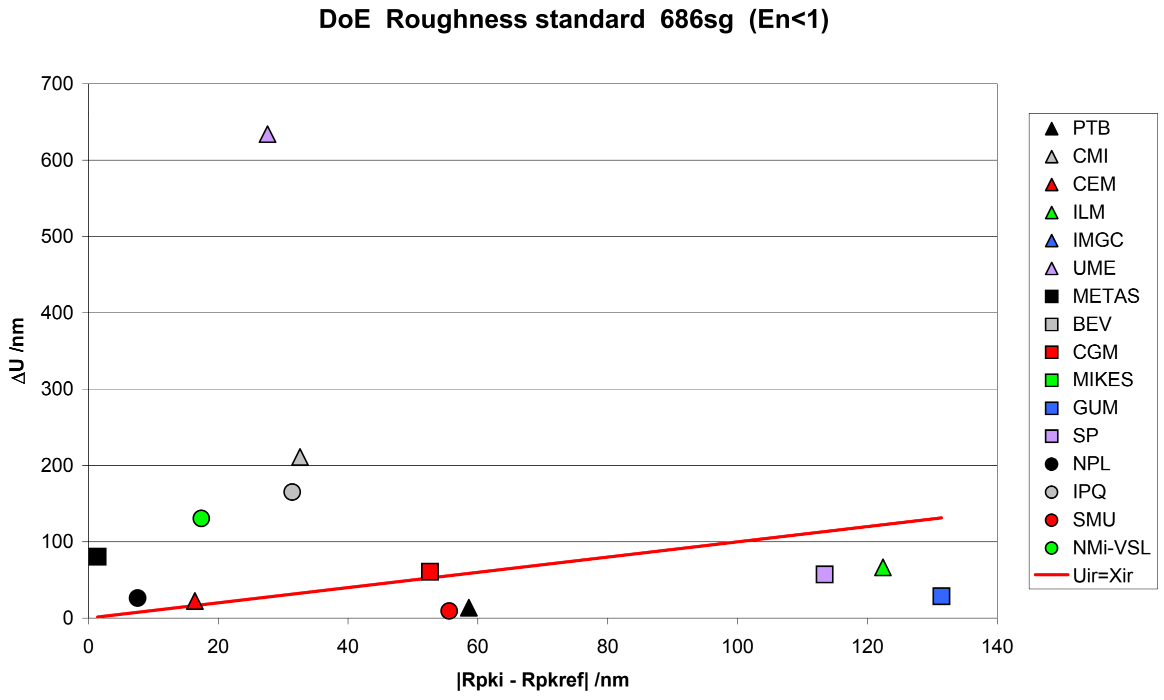
Results of *Rmax*



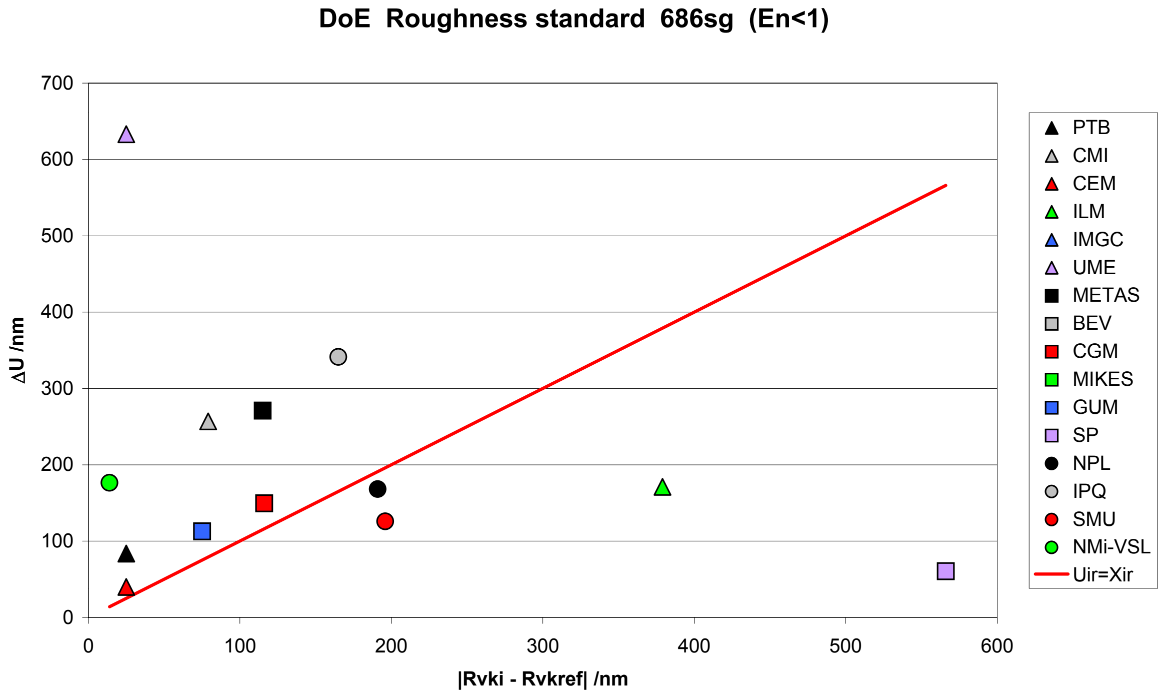
Results of *Rk*



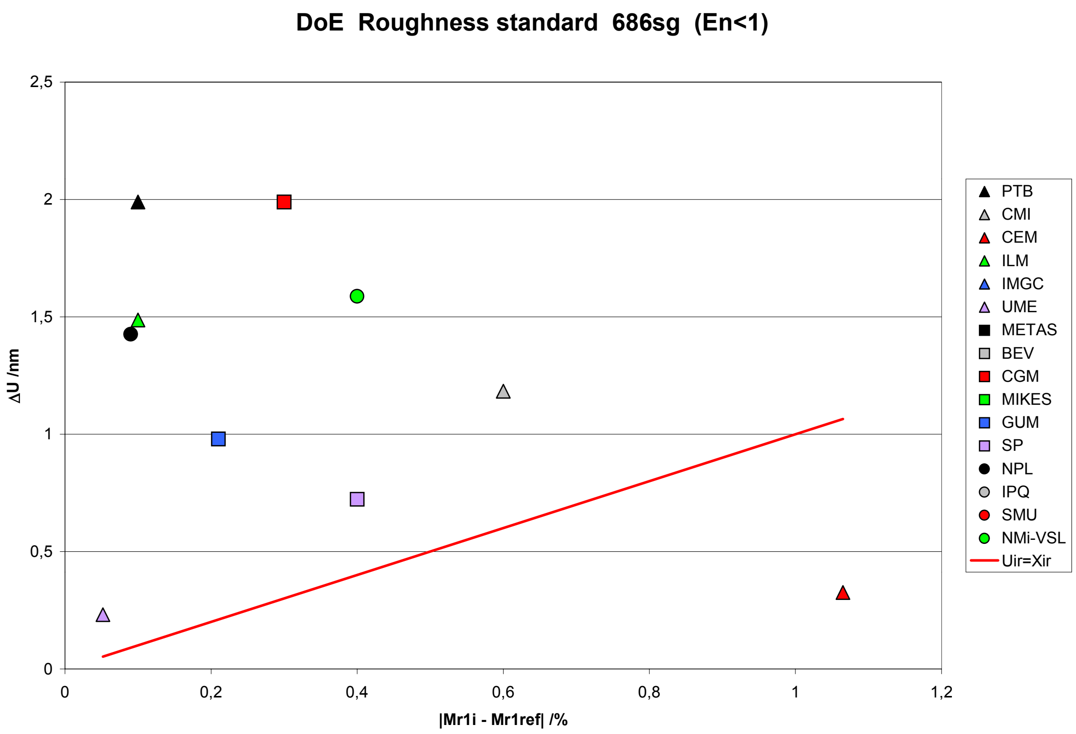
Results of *Rpk*



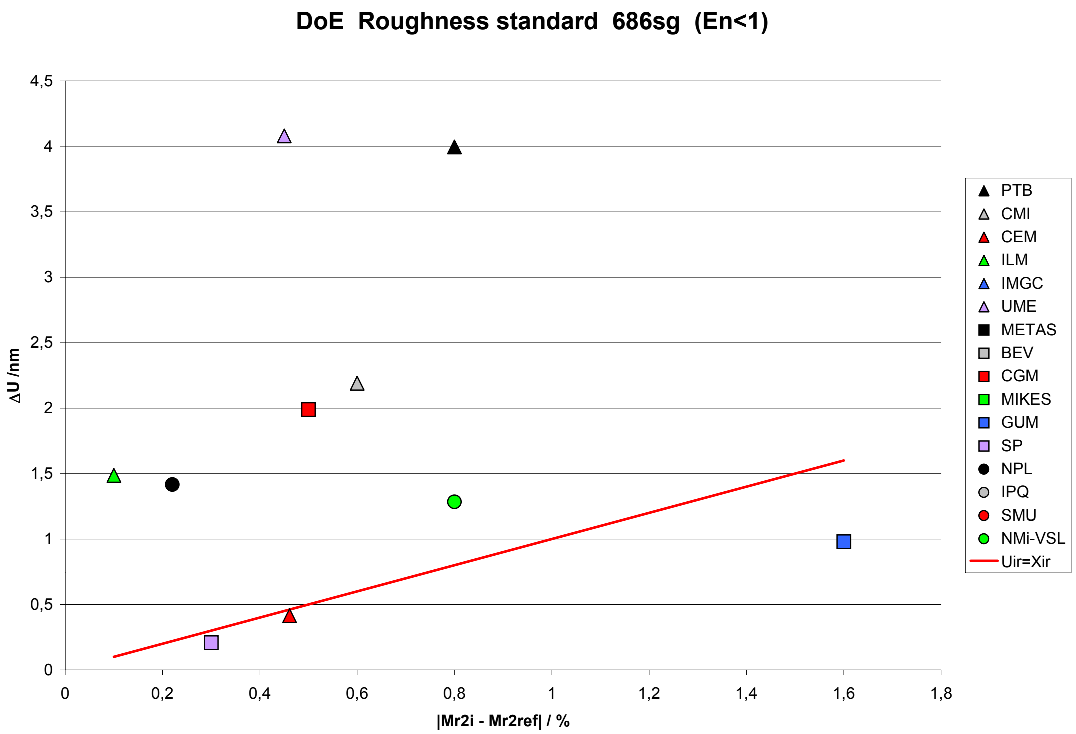
Results of *Rvk*



Results of *Mr1*

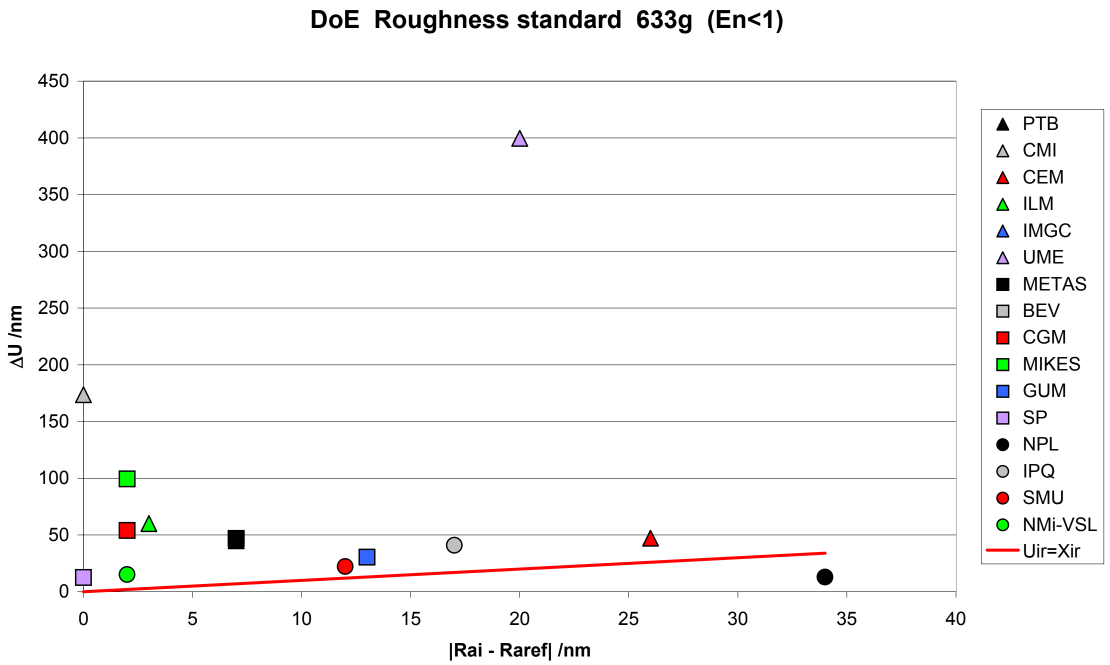


Results of *Mr2*

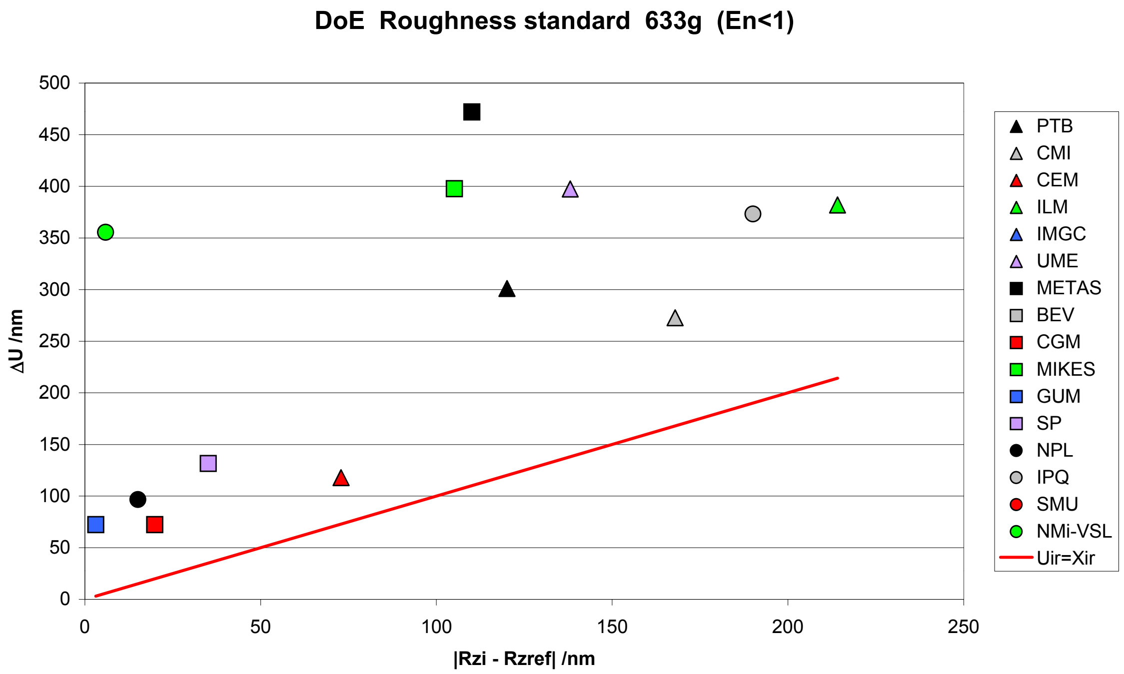


2. ROUGHNESS STANDARD 633G

Results of *Ra*

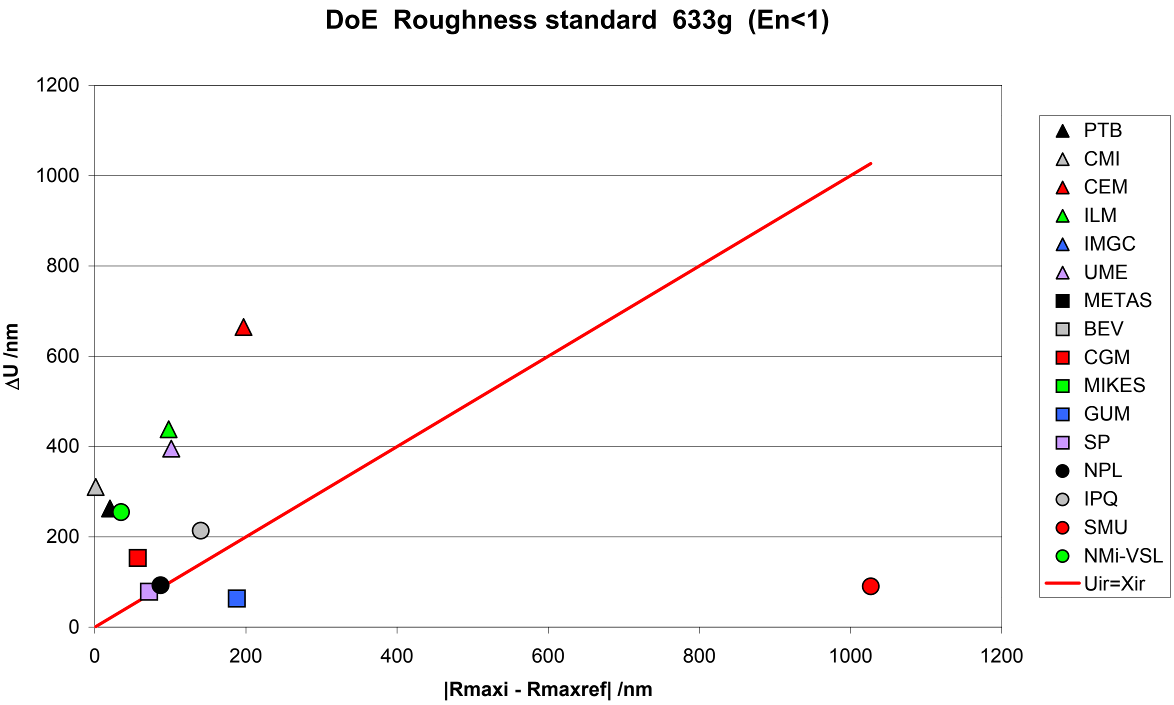


Results of *Rz*

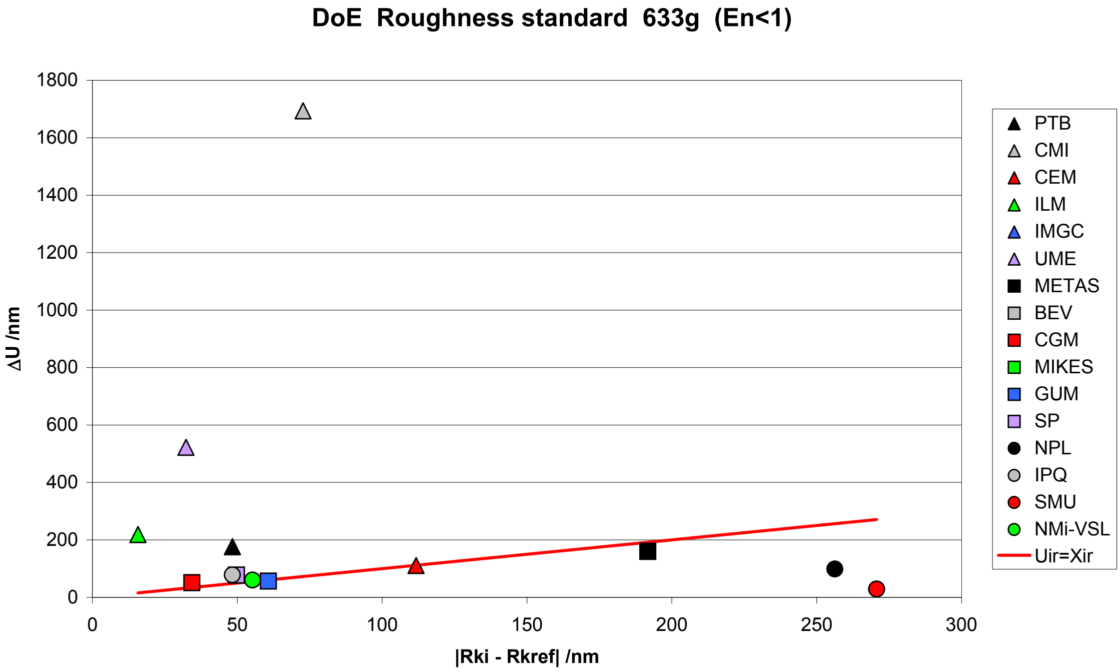


DoE (*U*ir) for SMU cannot be calculated, since *U*i < *U*ref

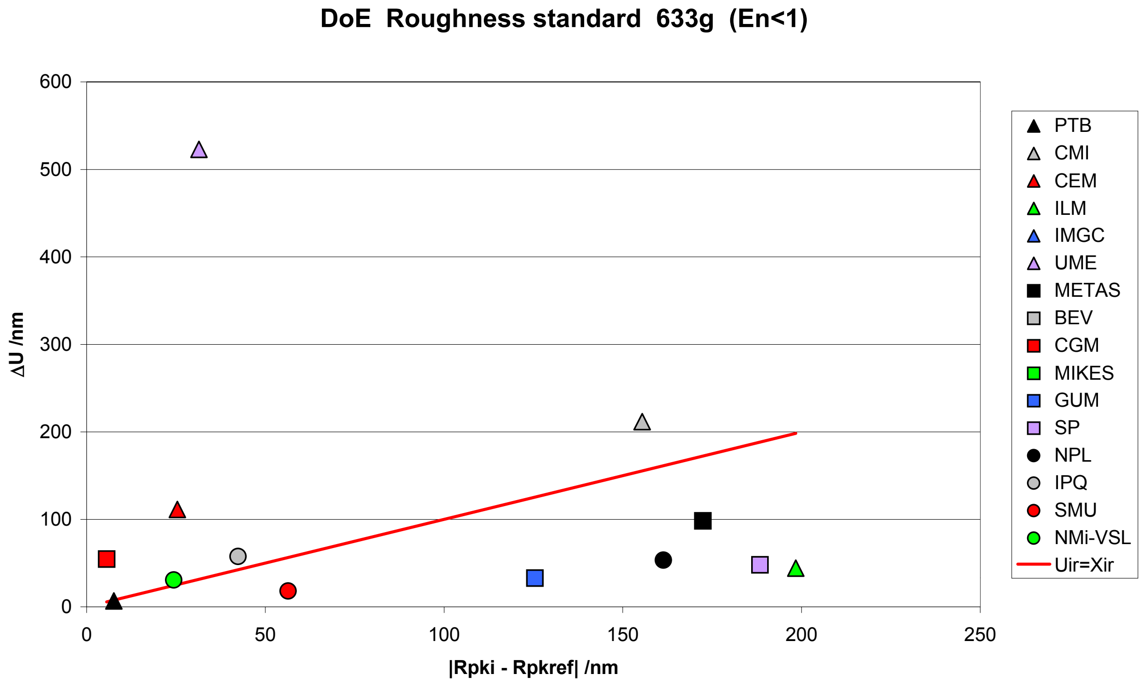
Results of *Rmax*



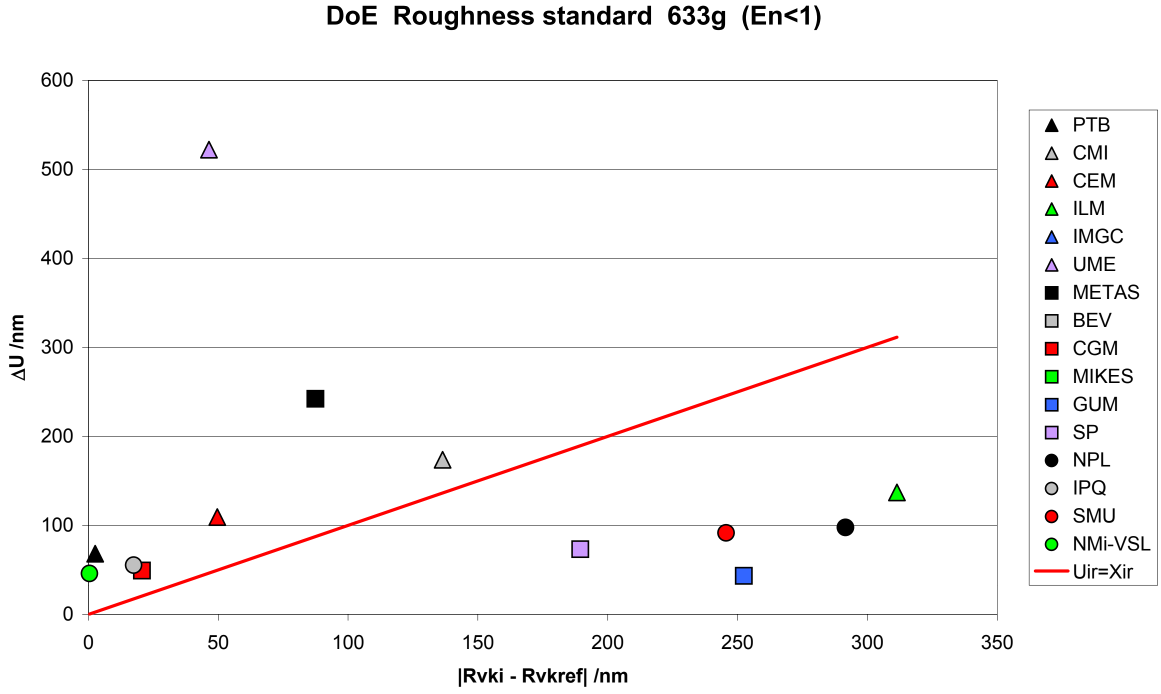
Results of *Rk*



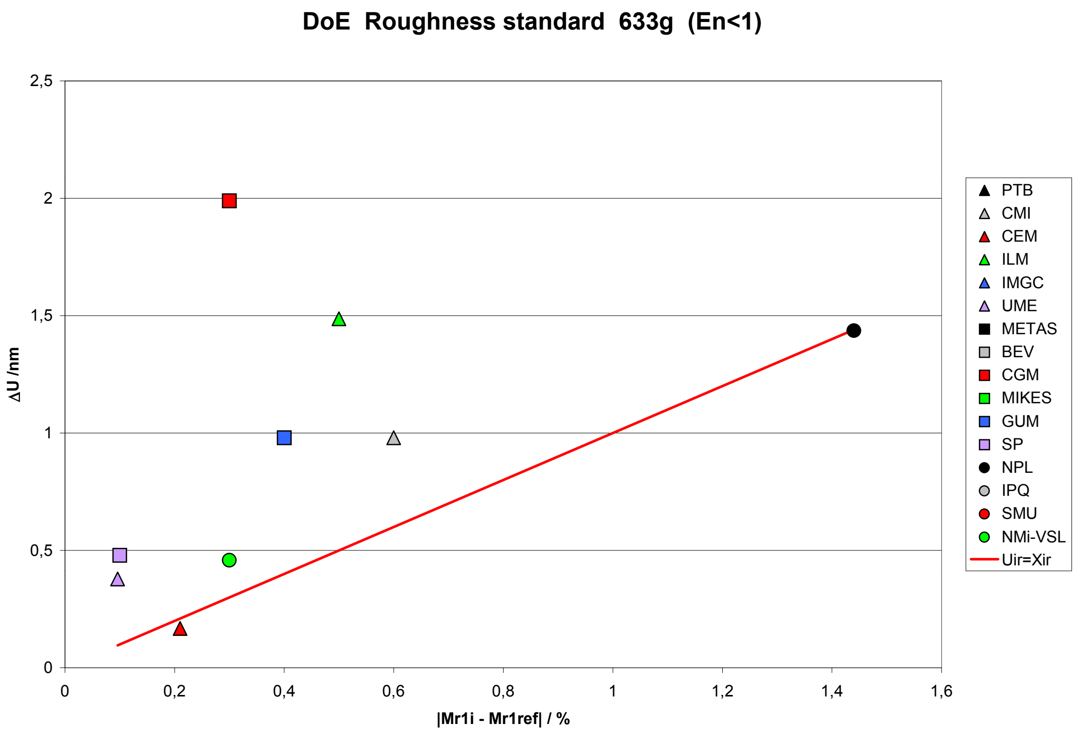
Results of *Rpk*



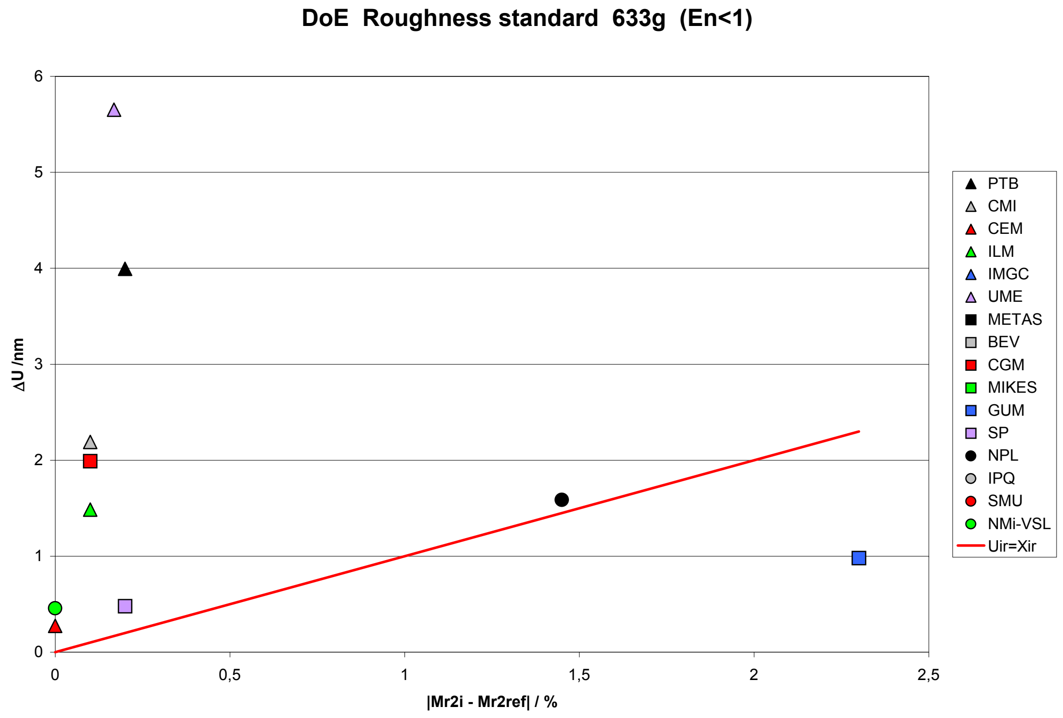
Results of *Rvk*



Results of *Mr1*

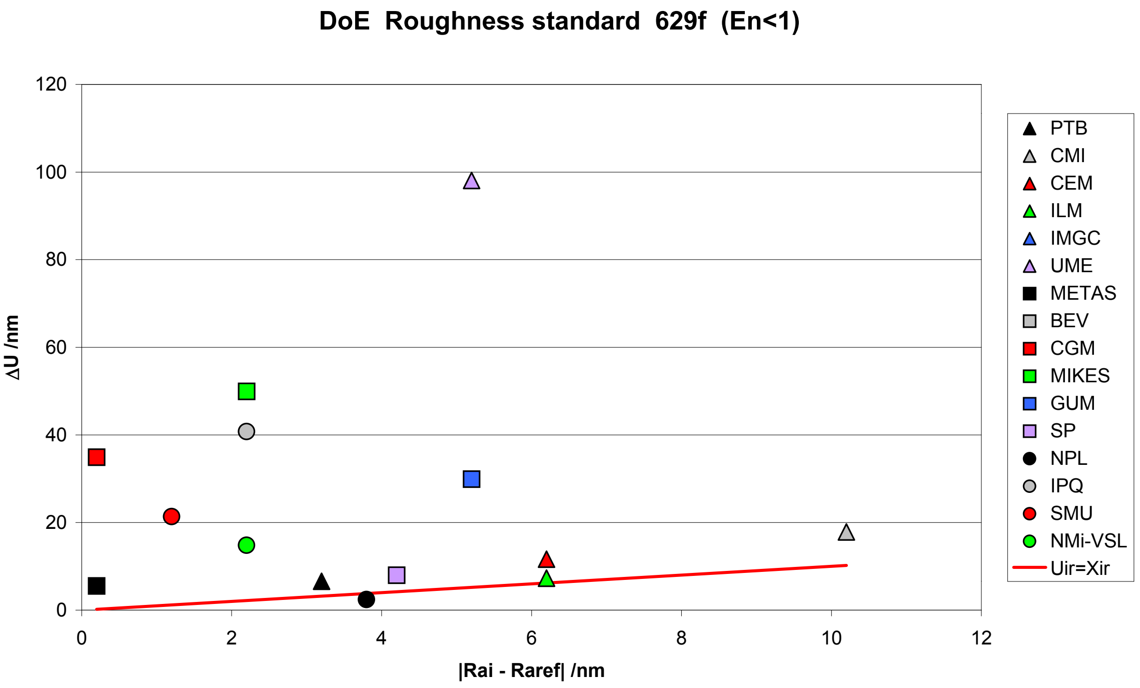


Results of *Mr2*

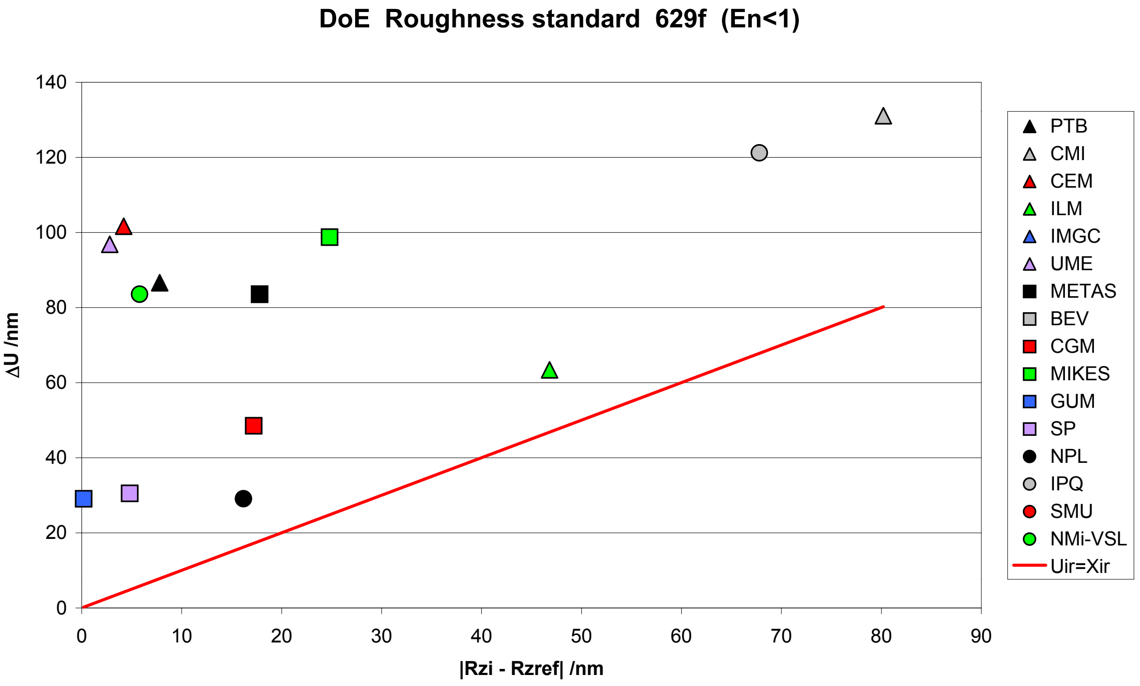


3. ROUGHNESS STANDARD 629F

Results of *Ra*

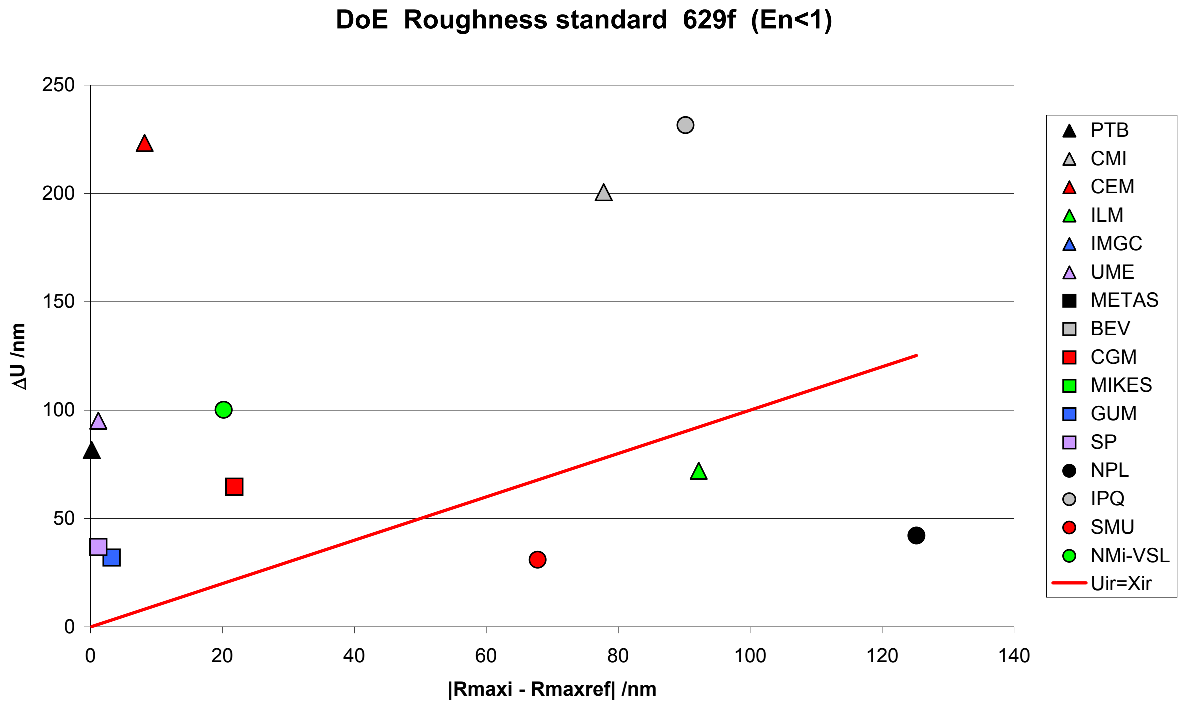


Results of *Rz*

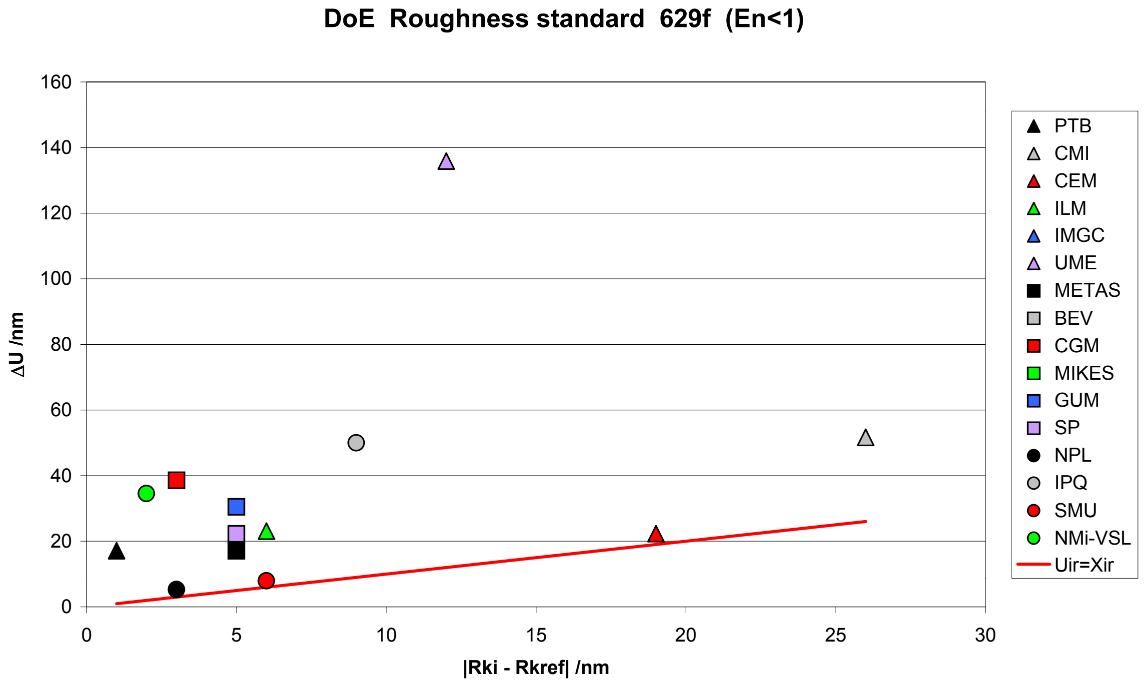


DoE (*U*ir) for SMU cannot be calculated, since *U*i < *U*ref

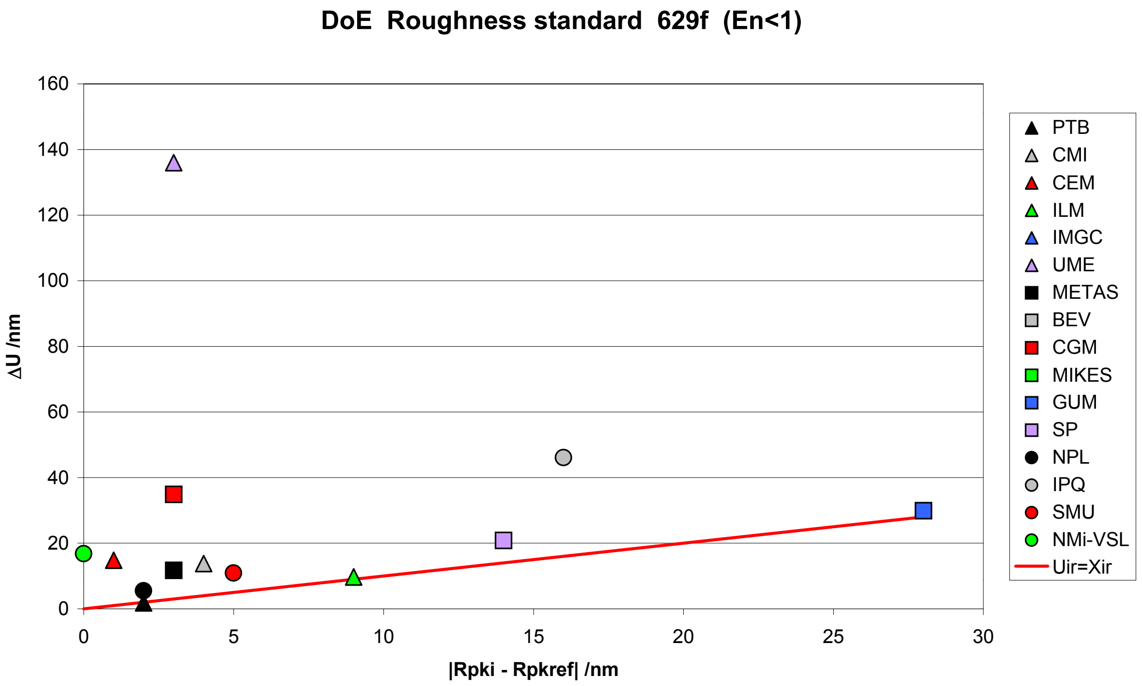
Results of *Rmax*



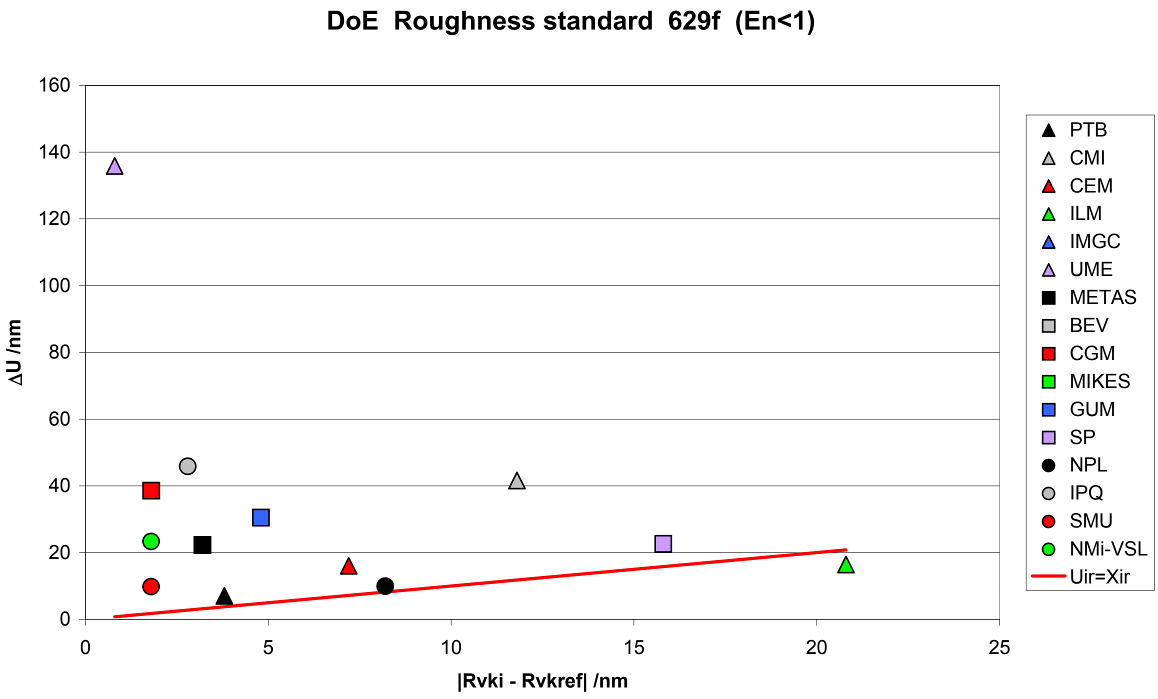
Results of *Rk*



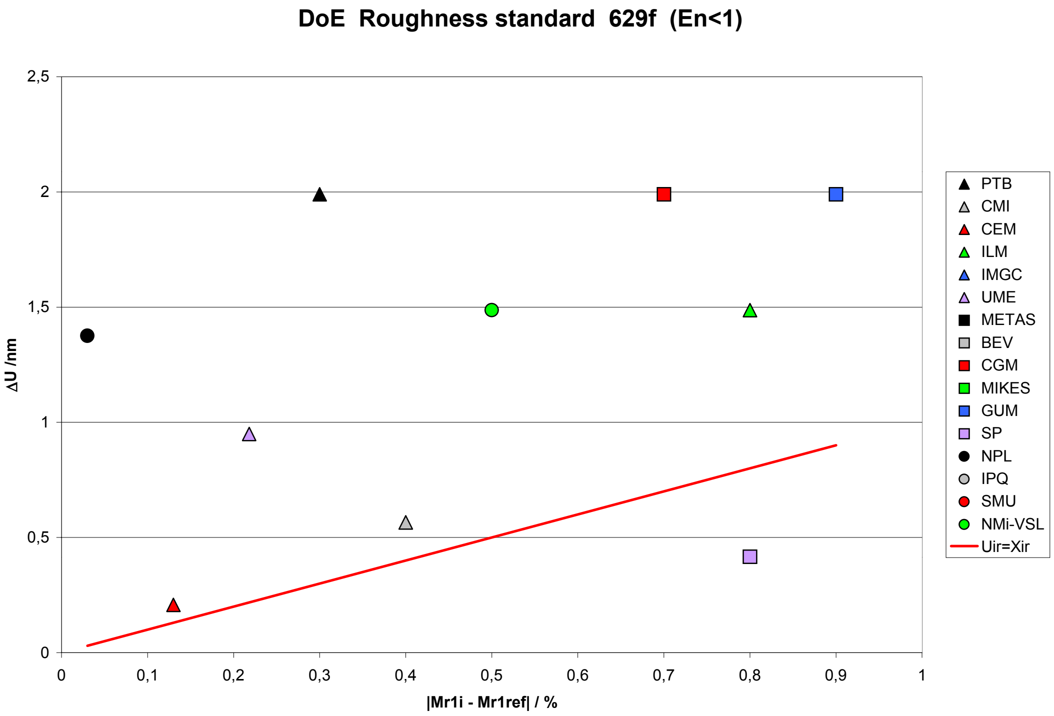
Results of *Rpk*



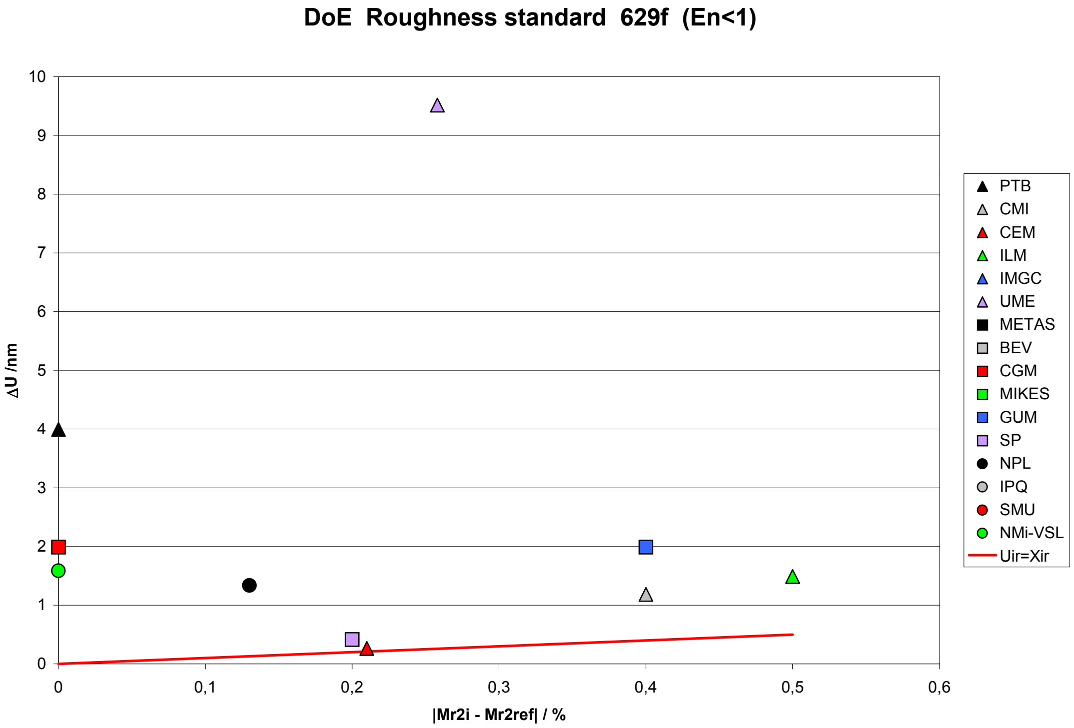
Results of *Rvk*



Results of *Mr1*

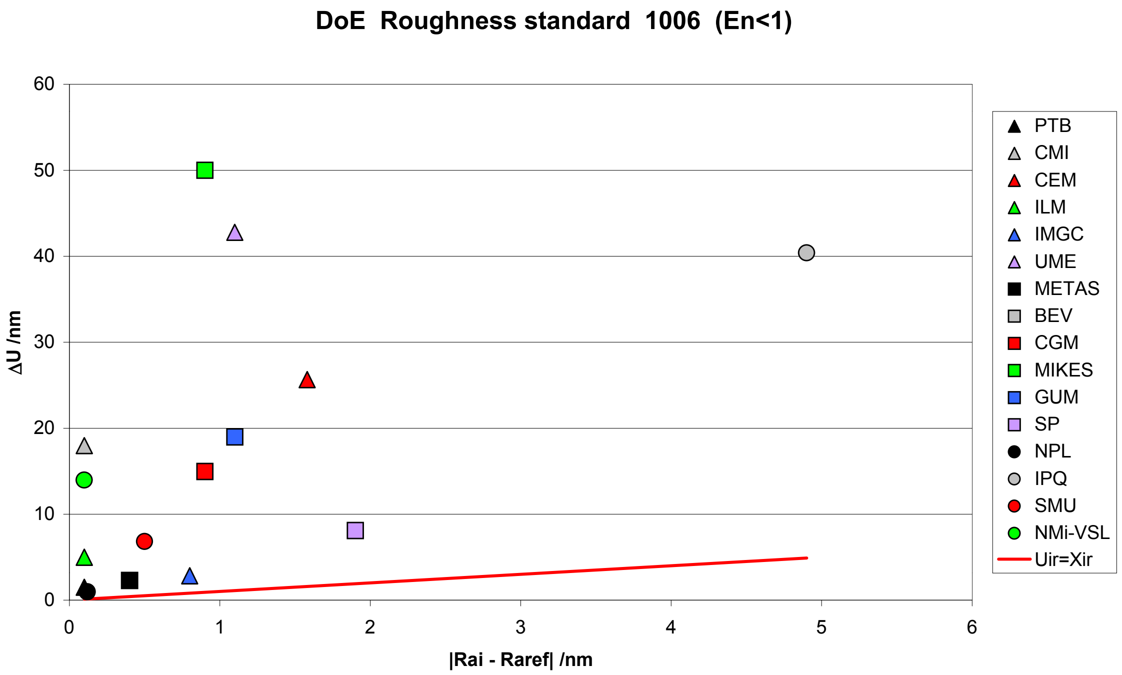


Results of *Mr2*

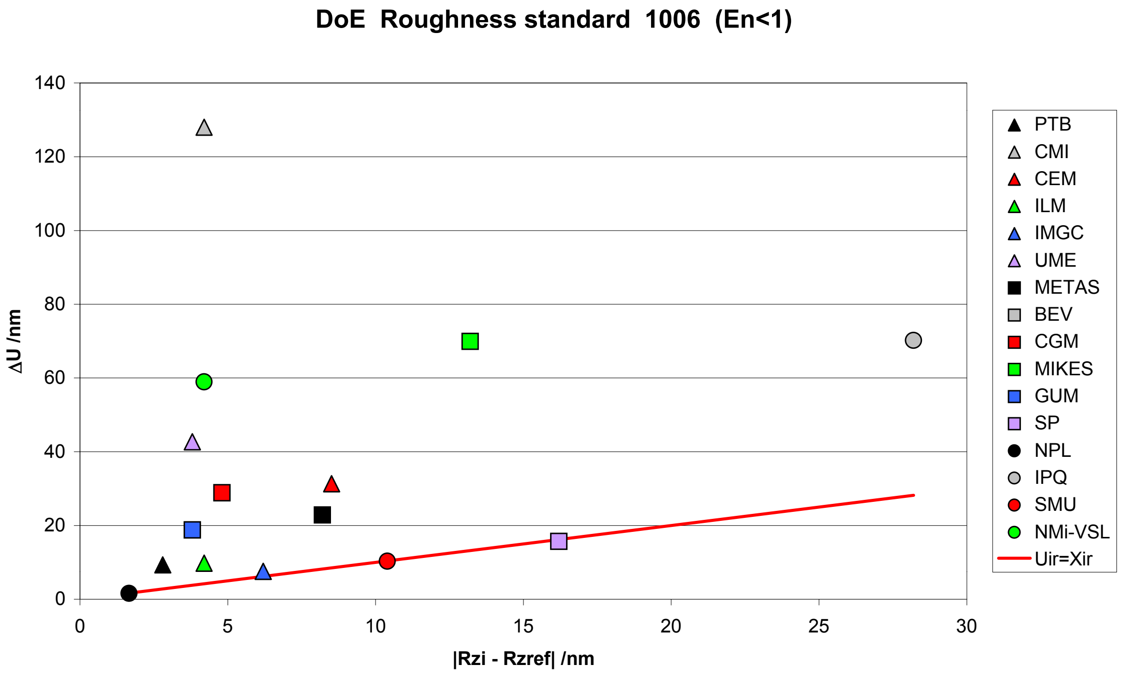


4. ROUGHNESS STANDARD 1006

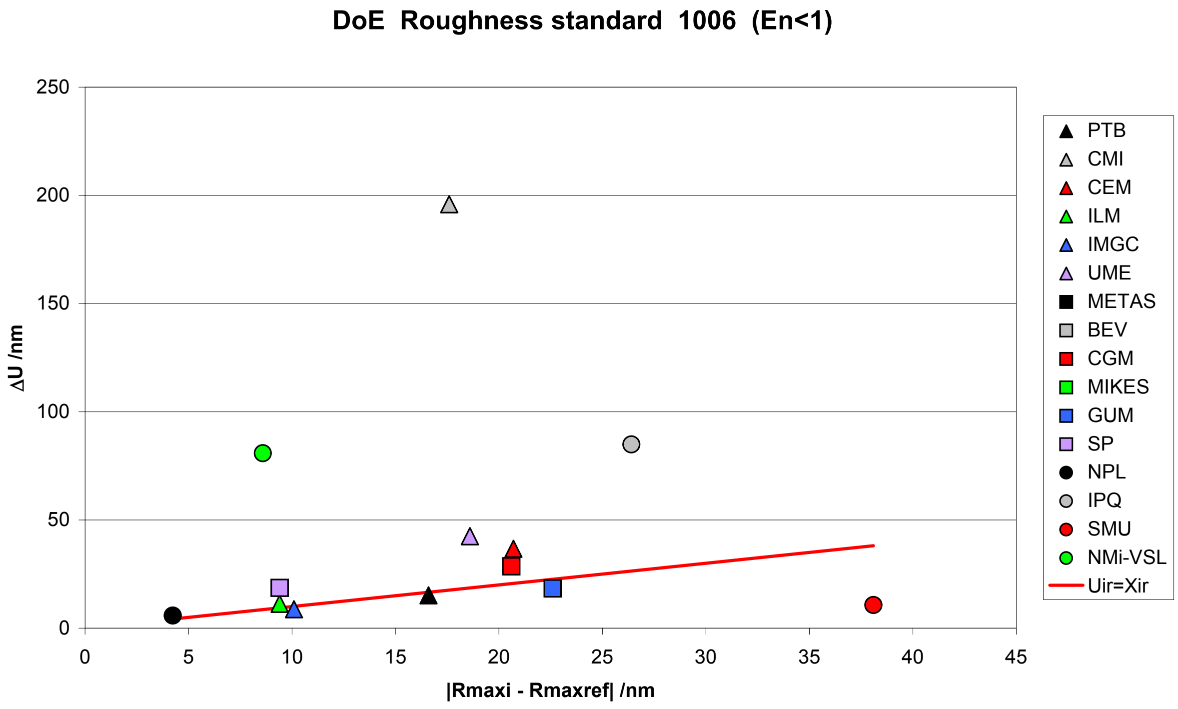
Results of *Ra*



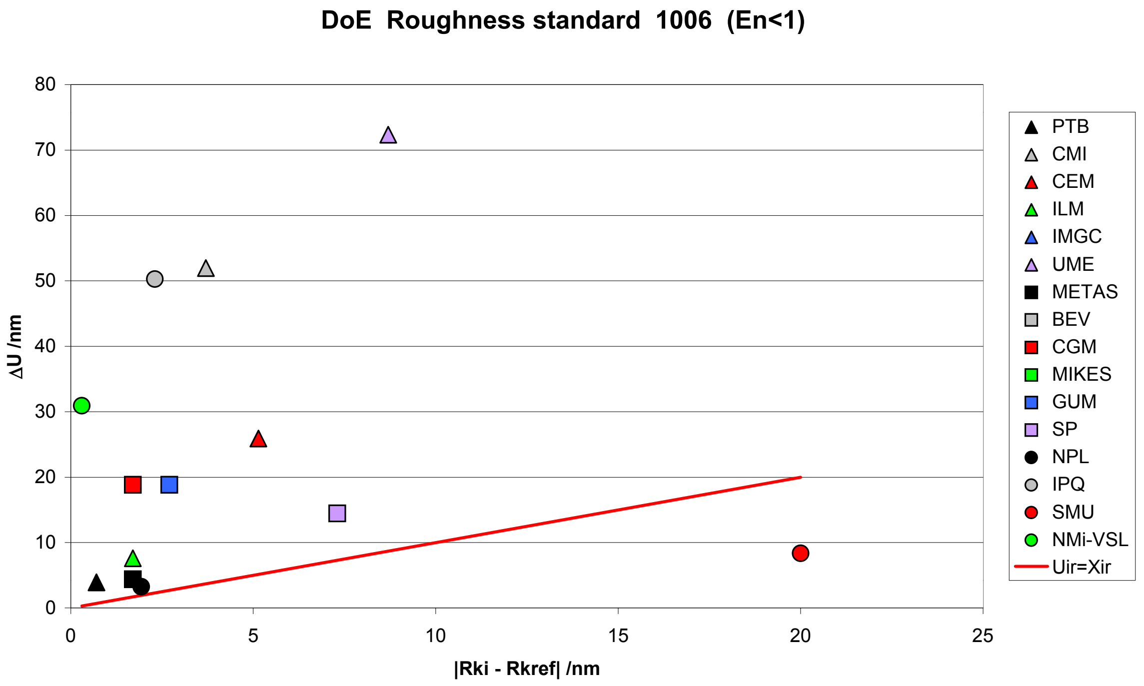
Results of *Rz*



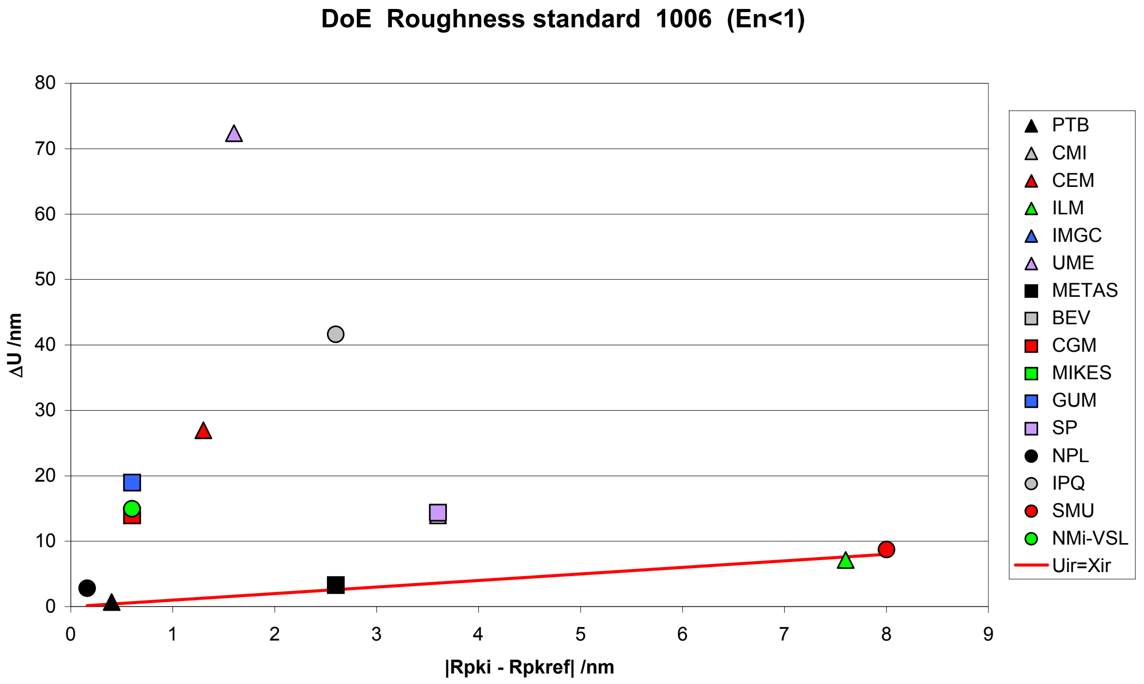
Results of *Rmax*



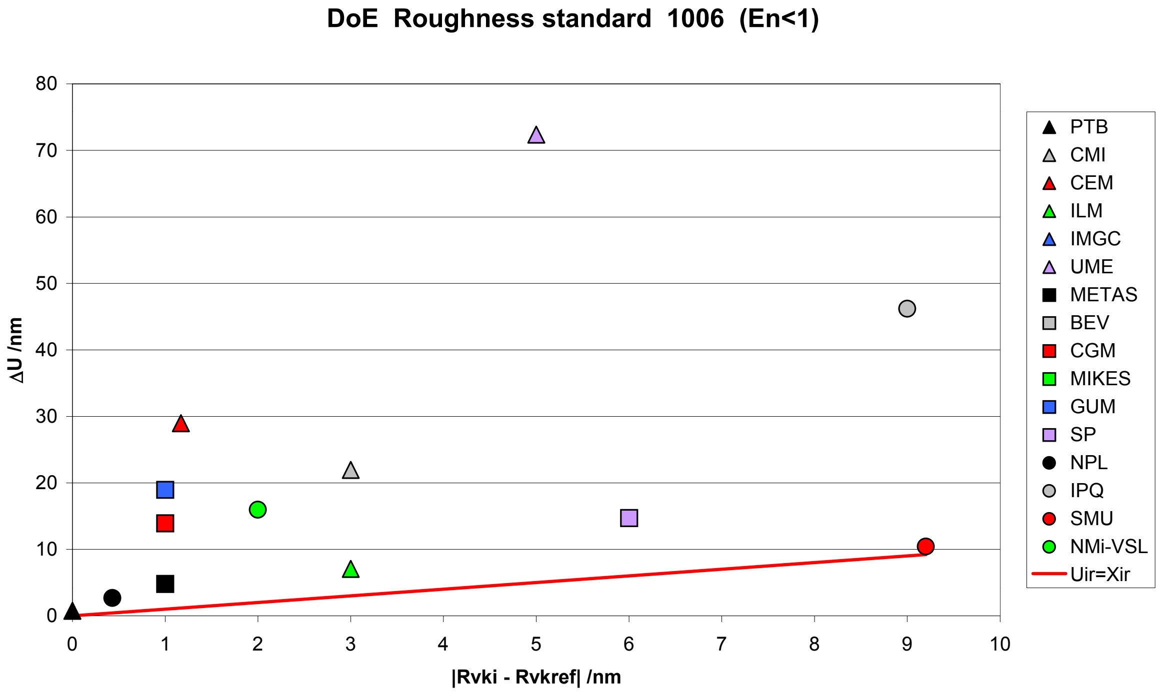
Results of *Rk*



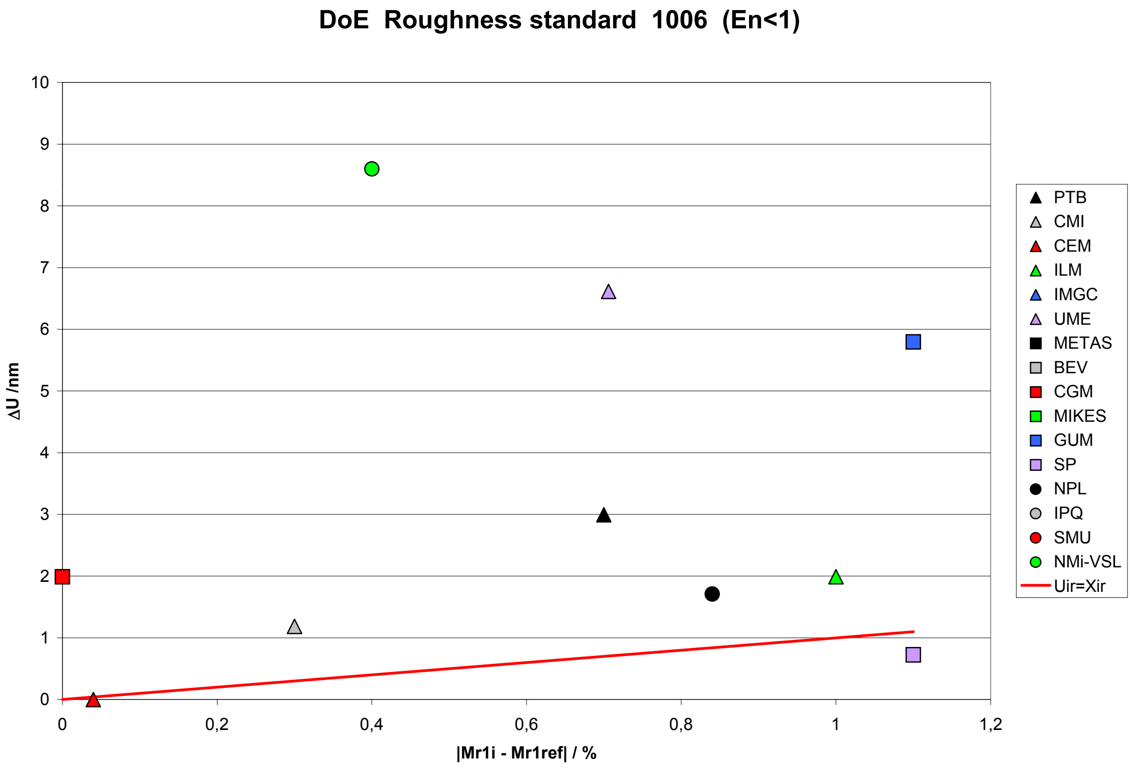
Results of *Rpk*



Results of *Rvk*



Results of *Mr1*



Results of *Mr2*