Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Physikalisch-Technische Bundesanstalt

COOMET Supplementary Comparison
COOMET.L-S18
(COOMET project: 673/UA-a/15)

Involute gear measurement standards

Final report
September 2017

Coordinator:

Physikalisch-Technische Bundesanstalt

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Project duration:

November 2015 – October 2016

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1 Organization

The choice and the provision of the gear measurement standards were executed by the National Scientific Center (NSC) Ukraine. The list of participants and the circulation scheme were made by the Physikalisch-Technische Bundesanstalt (PTB) Germany. With this information a technical protocol was written by the pilot National Metrology Institute (NMI), PTB, [1] and sent to the participants.

1.1 Participants

From the beginning 4 NMIs with worldwide reputation for gear metrology participated at this international comparison.

No.	COUNTRY	CONTACT PERSON / ADDRESS
1	GERMANY (Pilot) PTB	Karin Kniel Department Coordinate Metrology Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany Fon +49-531-592-5300 Fax +49-531-592-695300 Karin.Kniel@ptb.de
2	UKRAINE National Scientific Center (NSC) Institute of Metrology	Vladimir S. Kupko Kharkov State Research Institute of Metrology (KhSRIM) 42 Mironositskaya St. 61002 Kharkov Ukraine kupko@metrology.kharkov.ua
3	REPUBLIC OF BELARUS Belarussian State Institute of Metrology (BelGIM)	Makarevich Vladimir Bronislavovich Production and research department of measurements of geometric quantities Starovilensky trakt, 93, Minsk 220053 Republic of Belarus Tel.: +375 (17) 233-35-82 Fax: +375 (17) 288-09-38 E-mail: makarevich@belgim.by

4	RUSSIA Russian Research Institute For Metrological Service	Prof. Valeriy Lysenko VNIIMS, Russian Research Institute For Metrological Service 46, Ozernaya st. Moscow 119361 Russia Tel.: +7 495 781 86 53 Email: lysenko@vniims.ru

Table 1: List of all participants

1.2 Schedule

An initial time schedule was drawn as shown in Table 2. The circulation of the standards was scheduled for 12 months starting on October 2016 with the participation of 4 NMIs .

	NMI	Country	Period
1	PTB	Germany	before project start
2	NSC	Ukraine	2016-02-29 – 2016-05-30
3	BelGIM	Republic of Belarus	2016-06-03 – 2016-08-03
4	VNIIMS	Russia	2016-08-07 – 2016-10-10

Table 2: Initial timetable

The measurement results were given partly delayed and only on demand. Furthermore, the evaluations were partly not made according to the determined standard (ISO 1328-1) as the effective guidelines and standards were clearly defined in the technical protocol. This led to false results. The participants were asked to check their results and give a feedback.

Because the PTB (Germany) is the only participant in the present comparison who has successfully participated in the latest international comparison on gears EURAMET.L-S24, the calibration values of PTB will be used as reference values for this comparison. By this procedure, the results of this comparison can also be linked to the results of the prior comparison EURAMET.L-S24.

A check for statistical consistency of the results with their associated uncertainties will be made by calculation of the normalized error E_n for each laboratory and for each measurand.

It must be pointed out that the gear parameters must be entered with the accuracy stated in the particular table of the measurement standards to avoid deviations due to rounding errors.

2 Description of the measurement standards

2.1 Profile measurement standard

Figure 1: Profile measurement standard (Involute): d_1 = 120 mm and d_2 = 300 mm, right flanks

Gear Parameter:

Profile measurement standard	d_1 = 120 mm	d_2 = 300 mm
Helix angle β	0°	0°
Modul m_n	6.0977 mm	7.9827 mm
Number of teeth z	21	40
Pressure angle α_n	20°	20°
Facewidth b	15 mm	15 mm

Measurands

The chosen measurands according the respective standards [2, 3] were:

- Profile slope deviation $f_{H\alpha}$ in µm
- Profile form deviation $f_{f\alpha}$ in µm
- Profile total deviation F_α in µm

Measurement procedure

The right flank profile had to be measured in the centre of the tooth flank. The measurement points should be distributed equidistantly over the length of roll. The stylus sphere used for probing should be close to 3 mm in diameter. The evaluation referred to the following parameters.

d_1: Length of roll foot $L_{\alpha Start}$: 13.78 mm
Length of roll tip $L_{\alpha End}$: 41.34 mm

d_2: Length of roll foot $L_{\alpha Start}$: 32.0 mm
Length of roll tip $L_{\alpha End}$: 64.0 mm

References

The datum face of the measurement standard was marked by the serial number (3-0). The reference axis of the measurement standard should be numerically determined. For this purpose, the reference bands (diameter approx. 20 mm for the upper circle and 36 mm for the lower circle) of the gear measurement standard should be probed in the centre. In each of these transversal planes at least 36 points, which were distributed equally spaced over the circumference, should be recorded. Through the points, a circle should be fitted using the least squares method to define the centre of the circle. The axis of the gear measurement standard should be defined from the centers of the two circles. The reference point for the height of the profile measurement should be determined on top of each of the tooth, 2 mm from the tip circle in the direction of the reference axis.
During the measurement, the temperature should be as close to the reference temperature 20°C as possible.

2.2 Helix measurement standard

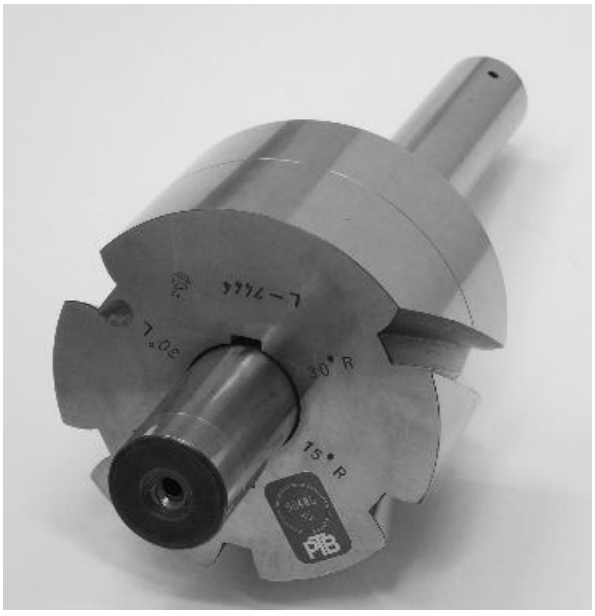

Figure 2: Helix measurement standard (0°, 15°, 30°, left- and right-hand, left flanks)

Gear parameter:

Helix angle β	0°	15° l+r	30° l+r
Modul m_n	4.0 mm	3.8637 mm	3.4641 mm
Number of teeth z	25	25	25
Pressure angle α_n	20°	20°	20°
Facewidth b	70 mm	70 mm	70 mm

Measurands

The chosen measurands according the respective standards [2, 3] were:

• helix slope deviation $f_{H\beta}$ in µm
• helix form deviation $f_{f\beta}$ in µm
• helix total deviation F_{β} in µm

Measurement procedure

The helix measurements should be performed in the centre of the measurement standard on a measurement cylinder with d_M = 100 mm. The stylus sphere should be close to 3.0 mm in diameter. The evaluation range is L_{β} = 56 mm (centric on the gear measurement standard).

References

The datum face of the measurement standard was marked by the engravings respective the calibration mark. The reference axis of the measurement standard should be numerically determined. For this purpose, the reference bands (diameter approx. 32 mm) of the gear measurement standard should be probed in the centre. In each of these transversal planes at least 36 points, which were distributed equally spaced over the circumference, should be recorded. Through the points, a circle should be fitted using the least squares method. The axis of the gear measurement standard should be defined from the centres of the two circles. During the measurement, the temperature should as close to the reference temperature 20 °C as possible.

2.3 Pitch measurement standard

Figure 3: Pitch measurement standard

Gear parameter:

Helix angle β	0°
Modul m_n	3.0 mm
Number of teeth z	34
Pressure angle α_n	20°
Facewidth b	25,4 mm
Tip diameter d_a	108 mm

Measurands

The chosen measurands according the respective standards [2, 3] were:

• Cumulative pitch deviation F_P in µm (left- and right flank)
• Single pitch deviation f_P in µm (left- and right flank)

Measurement procedure

The measurement standard should be fixed with an internal three-jaw chuck at the inside hollow shaft. The pitch should be measured in the single-flank facility. The stylus sphere should be close to 3.0 mm in diameter. The diameter of the measurement circle is d_M = 102 mm.

References

The reference side of the measurement standard was marked with the serial number 4693. The reference axis of the measurement standard should be numerically determined. For this purpose, two circles in the boring, one 6.2 mm from the reference surface (upper side) of the gear standard, the other one 26.2 mm from the reference surface, should be probed. In each case at least 36 points, which were distributed equally spaced over the circumference, should be recorded. Through these points, a circle should be fitted using the least squares method and the circle centre should be determined. The axis of the gear measurement standard should be defined from the centres of the two circles.
During the measurement, the temperature should as close to the reference temperature 20 °C as possible.

3 General measurement instructions

3.1 Traceability

Length measurements should be independently traceable to the latest realization of the *mètre* as set out in the current ”*Mise en Pratique*”[4]. This means that the length unit was transferred to the ball and bore plates with the CMM by one of the following methods: laser interferometer, gauge blocks, ball beams, ball bar or step gauges. Whatever the instrument or standard used, it should be traceable to the definition of the length unit through calibrations performed in house. Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

The mentioned measurands should be evaluated according to the following International Standards:

3.2 Guidelines and standards

Following guidelines and written standards were taken into account:

- International Vocabulary of Metrology [5]
- ISO standards: 1328-1, 21771 [2, 6, 7]

3.3 Measurement uncertainty

The uncertainty of measurement should be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* [8]. Due to differences of equipment, methods and procedures applied between laboratories, a complete list of uncertainty sources to be taken in account has not been given here.

4 Measurement results

All measurement results for profile, helix and pitch are summarized in the following tables. Moreover, the individual specified expanded uncertainty is presented. All participants assumed the standard measurement uncertainty with coverage factor on $k = 2$.

4.1 Profile measurements

d_1 = 120 mm						
participant	Profile slope deviation		Profile total deviation		Profile form deviation	
	$fH\alpha$ in µm	U in µm	$F\alpha$ in µm	U in µm	$ff\alpha$ in µm	U in µm
PTB Germany	-2.16	0.70	4.63	0.90	3.60	0.50
NSC Ukraine	-1.20	1.47	4.30	1.50	3.70	1.40
BelGIM Belarus	-2.28	1.00	4.14	1.00	4.11	1.00
VNIIMS Russia	-4.40	0.51	6.06	0.51	4.47	0.51
d_2 = 300 mm						
participant	Profile slope deviation		Profile total deviation		Profile form deviation	
	$fH\alpha$ in µm	U in µm	$F\alpha$ in µm	U in µm	$ff\alpha$ in µm	U in µm
PTB Germany	0.37	0.70	0.85	0.90	0.68	0.50
NSC Ukraine	-0.60	1.47	1.40	1.50	1.20	1.40
BelGIM Belarus	-0.07	1.00	0.85	1.00	0.87	1.00
VNIIMS Russia	-1.43	0.51	1.93	0.51	1.12	0.51

Table 3: Summarized results of all profile measurements

4.2 Helix measurements

0° helix						
participant	Helix slope deviation		Helix total deviation		Helix form deviation	
	$fH\beta$ in µm	U in µm	$F\beta$ in µm	U in µm	$ff\beta$ in µm	U in µm
PTB Germany	1.35	0.70	1.99	1.00	0.78	0.60
NSC Ukraine	1.40	1.61	2.50	1.70	1.70	1.40
BelGIM Belarus	1.46	1.00	2.09	1.00	0.95	1.00
VNIIMS Russia	1.64	0.91	2.11	0.91	0.97	0.90

Table 4: Summarized results of the 0° helix measurements

15° helix, left hand						
participant	Helix slope deviation		Helix total deviation		Helix form deviation	
	$fH\beta$ in µm	U in µm	$F\beta$ in µm	U in µm	$ff\beta$ in µm	U in µm
PTB Germany	-3.23	0.80	3.41	1.10	0.99	0.60
NSC Ukraine	-3.50	1.62	3.80	1.71	1.30	1.40
BelGIM Belarus	-4.04	1.00	4.62	1.00	1.70	1.00
VNIIMS Russia	2.74	0.92	4.04	0.93	1.92	0.91

Table 5: Summarized results of the 15° helix, left hand measurements

15° helix, right hand						
participant	Helix slope deviation		Helix total deviation		Helix form deviation	
	$fH\beta$ in µm	U in µm	$F\beta$ in µm	U in µm	$ff\beta$ in µm	U in µm
PTB Germany	-0.93	0.80	1.87	1.10	1.44	0.60
NSC Ukraine	-0.30	1.62	2.40	1.71	2.40	1.40
BelGIM Belarus	-1.09	1.00	2.30	1.00	1.74	1.00
VNIIMS Russia	-0.45	0.92	2.69	0.93	2.60	0.91

Table 6: Summarized results of the 15° helix, right hand measurements

30° helix, left hand						
participant	Helix slope deviation		Helix total deviation		Helix form deviation	
	$fH\beta$ in µm	U in µm	$F\beta$ in µm	U in µm	$ff\beta$ in µm	U in µm
PTB Germany	-7.38	1.00	7.93	1.20	1.53	0.60
NSC Ukraine	-8.80	1.64	9.10	1.72	1.30	1.40
BelGIM Belarus	-7.21	1.00	7.95	1.00	1.75	1.00
VNIIMS Russia	5.92	0.97	7.04	0.96	3.02	0.91

Table 7: Summarized results of the 30° helix, left hand measurements

30° helix, right hand						
participant	Helix slope deviation		Helix total deviation		Helix form deviation	
	$fH\beta$ in µm	U in µm	$F\beta$ in µm	U in µm	$ff\beta$ in µm	U in µm
PTB Germany	-1.80	1.00	2.59	1.20	1.88	0.60
NSC Ukraine	-0.90	1.64	2.00	1.72	1.90	1.40
BelGIM Belarus	-2.08	1.00	2.90	1.00	2.18	1.00
VNIIMS Russia	-1.35	0.97	3.59	0.96	3.06	0.91

Table 8: Summarized results of the 30° helix, right hand measurements

4.3 Pitch measurements

Pitch, left flank						
participant	Single pitch deviation			Cumulative pitch deviation		
	$f_{p\,max}$ in µm	U in µm	pitch	F_p in µm	U in µm	pitch
PTB Germany	2.06	0.5	3	6.30	0.5	22 - 1
NSC Ukraine	1.90	1.43	4	6.90	2.34	24 - 33
BelGIM Belarus	1.78	1.00	28	8.13	1.00	34 - 14[1]
VNIIMS Russia	1.97	0.53	34	6.18	0.64	4 - 11[1]

Table 9: Summarized results of the pitch, left flank measurements

[1] The finally specified pitch numbers do not match the measurement results in the submitted reports.

Pitch, right flank						
participant	Single pitch deviation			Cumulative pitch deviation		
	$f_{p\,max}$ in µm	U in µm	pitch	F_p in µm	U in µm	pitch
PTB Germany	-2.91	0.5	32	7.92	0.5	25 - 2
NSC Ukraine	-2.70	1.43	33	8.70	2.34	26 - 3
BelGIM Belarus	-3.17	1.00	1	9.99	1.00	34 - 11
VNIIMS Russia	-2.29	0.53	1	7.62	0.64	34 - 11

Table 10: Summarized results of the pitch, right flank measurements

5 Evaluation of the normalized error E_n

5.1 General information

In case of this intercomparison the PTB operated as the reference laboratory due to this fact the PTB values are used as reference values.

A check for statistical consistency of the results with their associated uncertainties can be made by calculation of the normalized error E_n for each laboratory and for each measurand. The E_n value indicates if the measurement value and its corresponding measurement uncertainty are comparable to the results of the reference laboratory. In detail that means that the E_n value is the internationally agreed parameter which shows if the individual value x_i together with its determined expanded measurement uncertainty U_i and the expanded measurement uncertainty of the corresponding reference value U_{ref} is reliable in comparison with the reference value x_{ref}. The absolute value $|E_n|$ must be less than 1 to meet this quality criterion for indicating that the laboratory is in the position to obtain a qualified result.

Due to prior agreement with the COOMET [1] and other experts and guidelines for measurement uncertainty evaluation [9, 10, 11, 12, 13, 14], the E_n value was calculated according to the approach shown in equation 2:

$$E_n(k=2) = \frac{x_i - x_{ref}}{\sqrt{\left|U_i^2 + U_{ref}^2\right|}} \qquad (2)$$

As recommended by the WG-MRA “Guidance Document” GD-1 [13] the calculation of the E_n value was based on the expanded measurement uncertainty.

5.2 Results with respect to E_n(k=2) evaluation based on expanded uncertainty

In total 28 measurands for all the standards (profile, helix and pitch) had to be measured by each participant. All received results were analysed and evaluated. In Table 11 the normalized error E_n for each parameter are listed.

Key to the colour: highlighted grey colour cells represent where the comparability value is not fulfilled

		NSC	BelGIM	VNIIMS
profile d_1 = 120 mm	$f_{H\alpha}$	0.59	0.10	2.59
	$f_{f\alpha}$	0.07	0.46	1.22
	F_α	0.19	0.36	1.38
profile d_2 = 300 mm	$f_{H\alpha}$	0.60	0.36	2.08
	$f_{f\alpha}$	0.35	0.17	0.62
	F_α	0.31	0.00	1.04
helix 0°	$f_{H\beta}$	0.03	0.09	0.25
	$f_{f\beta}$	0. 60	0.15	0.18
	F_β	0.26	0.07	0.09
helix 15° left hand	$f_{H\beta}$	0.15	0.63	4.90
	$f_{f\beta}$	0.20	0.61	0.85
	F_β	0.19	0.81	0.44
helix 15° right hand	$f_{H\beta}$	0.35	0.12	0.39
	$f_{f\beta}$	0.63	0.26	1.06
	F_β	0.26	0.29	0.57
helix 30° left hand	$f_{H\beta}$	0.74	0.12	9.55
	$f_{f\beta}$	0.15	0.19	1.37
	F_β	0.56	0.01	0.58
helix 30° right hand	$f_{H\beta}$	0.46	0.20	0.32
	$f_{f\beta}$	0.02	0.26	1.08
	F_β	0.25	0.20	0.65
pitch left flank	F_P	0.25	1.64	0.15
	f_P[2]	0.11	0.25	0.12
pitch right flank	F_P	0.33	1.85	0.37
	f_P[2]	0.14	0.23	0.85
$\sum E_n$>1		0	2	10

Table 12: Measurement results based on the normalized error E_n (k = 2)

[2] Concerning the comparison of the results for the single pitch deviation (see Table 9 and 10): The maximum single pitch deviation fp max is defined as the maximum absolute value of the measured single pitch deviations fp which is signed. Due to this definition the comparison of the results is based on the absolute values.

6 Conclusion

Summarizing, the international comparison for involute gear standards organized by COOMET has been successfully conducted. It was the second international comparison on complex dimensional measurands as gear quality parameters.

The comparison of the presented results however shows that discrepancies of the values of the compared measurands of some participating NMIs in some cases were too big and below the expectations, which leaves room for further improvement.

7 Acknowledgements

All participants express gratitude for the support of COOMET that made the comparison a success. It is a great step forward in positive direction.

8 References

[1] COOMET Project 673/UA-a/15: Involute Gear Standards, TechnicalProtocol_Gear Comp_COOMET.L-S18 (673UA-a15)_2016-03-29.pdf

[2] ISO 1328-1 (2013): Cylindrical gears - ISO system of flank tolerance classification - Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth

[3] Mise en pratique: http://www.bipm.org/en/publications/mep.html, Access: July 2011

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[5] VIM: International Vocabulary of Metrology – Basic and General Concepts and Associated Terms VIM, 3rd edition, JCGM 200:2008

[6] ISO 18653 (2003): Gears - Evaluation of instruments for the measurement of individual gears

[7] ISO 21771 (2007): Gears - Cylindrical involute gears and gear pairs — Concepts and geometry

[8] JCGM 100 (2008): Evaluation of measurement data – Guide to the expression of uncertainty in measurement. http://www.bipm.org/utils/common/documents/ jcgm/ JCGM_100_2008_E.pdf, Access: July 2011

[9] DKD-Arbeitsanweisung DKD-AA-5 (2009), Ausgabe Nr. 5: Grundsätze und Verfahren für Vergleichsmessungen

[10] Wöger, W.: Remarks on the En-criterion used in measurement comparisons. PTB-Mitteilungen 109, 1/99

[11] En-Toolkit: User‘s guide. http://inms.web-p.cisti.nrc.ca/qde/montecarlo/EnToolkit.html, Access: November 2011

[12] En-Toolkit: Presentation. http://inms.web-p.cisti.nrc.ca/qde/montecarlo/EnToolkit.html, Access: November 2011

[13] Lewis, A.: Running of MRA comparisons in length metrology and monitoring their impact on CMCs. CCL/WG-MRA/GD-1, March 2011

[14] Key Engineering Materials Vol. 613 (2014) pp 26-33: Recommendation for unified rules for key comparison evaluation, Trans Tec Publications, Switzerland

Appendix A: Measurement reports of the participants

The following measurement reports were prepared by each participant. They comprise the description of the measurement procedure as well as the measurement results. Each report is completely listed in this document.

Participant 1: Germany (PTB)

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Kalibrierschein

Calibration Certificate

Gegenstand: *Object:*	Profilnormal, d_1 = 128 mm, d_2 = 319 mm *Profile measurement standard d_1 = 128 mm, d_2 = 319 mm*
Hersteller: *Manufacturer:*	Keine Angabe *No declaration*
Typ: *Type:*	Stirnradnormal (β = 0°, R) *Cylindrical gear standard (β = 0°, R)*
Kennnummer: *Serial No.:*	3 - 0
Auftraggeber: *Applicant:*	Physikalisch-Technische Bundesanstalt Fachbereich 5.3 Bundesallee 100 38116 Braunschweig Deutschland
Anzahl der Seiten: *Number of pages:*	7
Geschäftszeichen: *Reference No.:*	5.3-2015-060
Kalibrierzeichen: *Calibration mark:*	50484 PTB 15
Datum der Kalibrierung: *Date of calibration:*	2015-10-29

Im Auftrag
On behalf of PTB

Dr. rer. nat. M. Stein

Braunschweig, 2015-12-09

Siegel
Seal

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 7

Im Auftrag
On behalf of PTB

K. Hierse

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Seite 2 zum Kalibrierschein vom 2015-12-09, Kalibrierzeichen: 50484 PTB 15
Page 2 of the Calibration Certificate dated 2015-12-09, calibration mark: 50484 PTB 15

Kalibriergegenstand
Calibration standard

Profilnormal
Profile measurement standard

Verzahnungsparameter:
Gear parameters:

Teilkreisdurchmesser d *Reference diameter d*	128 mm	319 mm
Schrägungswinkel β *Helix angle β*	0°	0°
Normalmodul m_n *Normal module m_n*	6,0977 mm	7,9827 mm
Zähnezahl z *Number of teeth z*	21	40
Normaleingriffswinkel α_n *Normal pressure angle α_n*	20°	20°
Profilverschiebungsfaktor x *Profile shift coefficient x*	0	0
Zahnbreite b *Facewidth b*	15 mm	15 mm

Anmerkung:
Remark:

Es ist zu beachten, dass die Verzahnungsparameter mit der im Kalibrierschein angegebenen Genauigkeit eingegeben werden müssen, um Abweichungen durch Rundungsfehler zu vermeiden.

It must be pointed out here that the gear parameters must be entered with the accuracy stated in the calibration certificate so as to avoid deviations due to rounding errors.

General note concerning the English translation:

This Calibration Certificate is written in German. In case of any conflict between the German language version and the English translation of it, the German version shall prevail.

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Braunschweig und Berlin
Nationales Metrologieinstitut

Stirnradnormal Kennummer 3 - 0
Cylindrical gear standard serial No. 3 - 0

Kalibrierverfahren
Calibration procedure

Profil
Profile

Die Profile des Normals wurden auf einem rückgeführten Koordinatenmessgerät kalibriert. Die einzelnen Messwerte wurden durch ein Mehrlagenmessverfahren ermittelt. Hierzu wurde das Normal in vier um 90° versetzten Stellungen, gestürzt und ungestürzt, mehrfach gemessen. Die Messergebnisse sind die gemittelten Werte aus allen Messungen.
Die Kalibrierwerte der Profilmessungen beziehen sich jeweils auf den Auswertebereich. Abweichungen außerhalb des Auswertebereichs bleiben unberücksichtigt.

The profiles of the measurement standard were calibrated on a coordinate measuring machine for which traceability has been proved. The individual measurement values were determined by a multiple orientation measurement procedure. For this purpose, the standard was measured in four positions displaced by 90° (tumbled and untumbled). The measurement results are the averaged values from all measurements.
The calibration values of profiles measurements each refer to the evaluation range. Deviations outside the evaluation range remain disregarded.

Bezüge
References

Die Bezugsseite des Normals ist durch die Kennnummer gekennzeichnet.
Die Referenzachse des Normals wurde numerisch ermittelt. Hierzu wurden an der Welle des Normals zwei Bezugskreise (siehe Skizze des Normals) gemessen und deren Mittelpunkte nach der Methode der kleinsten Fehlerquadrate bestimmt. Durch die Mittelpunkte der Kreise wurde die Referenzachse des Verzahnungsnormals gelegt.

The datum face of the measurement standard is marked by the serial number.
The reference axis of the measurement standard was numerically determined. For this purpose, two reference circles in the shaft of the gear measurement standard (see sketch of the measurement standard) were measured and their centres were delermined in accordance with the least squares method. The reference axis of the gear measurement standard was laid through the centres of the circles.

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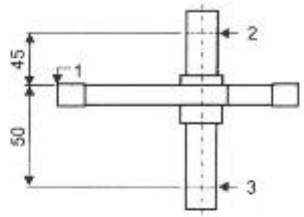

(1) Bezugsseite (Höhenbezug)
datum face (reference for the height)

(2) oberer Bezugskreis
upper reference circle

(3) unterer Bezugskreis
lower reference circle

Skizze des Normals
Sketch of the measurement standard

Umgebungsbedingungen
Environmental conditions

Temperatur während der Messung *Temperature during the measurement*	(20 + 0,2) °C

Normative Verweise
Normative references

Die Bezeichnung am Verzahnungsnormal und die Auswertungen erfolgten, sofern nicht explizit anders beschrieben, unter Berücksichtigung der folgenden Richtlinien und Normen:

For identification and evaluations on the gear artifact, the following guidelines and standards were taken into account unless otherwise explicitly noted:

ISO 1328-1, September 2013 (E);
VDI/VDE 2607, Februar 2000;
VDI/VDE 2612, Mai 2000;
DIN ISO 21771 August 2014
DIN 21772 Juli 2012
DIN 3999, November 1974;

Messunsicherheit
Measurement uncertainty

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor $k = 2$ ergibt. Sie wurde gemäß dem „Guide to the Expression of Uncertainty in Measurement (GUM)" ermittelt. Der Wert der Messgröße liegt dann im Regelfall mit einer Wahrscheinlichkeit von annähernd 95 % im zugeordneten Überdeckungsintervall.

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor k = 2. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement (GUM)". The value of the measurand then normally lies, with a probability of 95 %, within the attributed coverage interval.

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Profil
Profile

Die Messungen wurden auf der Grundlage der auf Seite 2 aufgelisteten und der folgenden Angaben durchgeführt:

The measurements were based on the parameters listed on page 2 with the following additional parameters:

Teilkreisdurchmesser *d* *Reference diameter d*	128 mm	319 mm
Antastkugeldurchmesser *Stylus sphere diameter*	3 mm	3 mm
Punkteanzahl je Bezugskreis *Number of points per reference circle*	36	36
Punktedichte auf Profil *Point density on the profile*	5/mm	5/mm
Lage des Profils *Position of the profile*	*b*/2	*b*/2
Start der Auswertung $L_{\alpha Start}$ (in Wälzlänge) *Start of evaluation $L_{\alpha Start}$ (length of roll)*	13,78 mm	32,0 mm
Ende der Auswertung $L_{\alpha End}$ (in Wälzlänge) *End of evaluation $L_{\alpha End}$ (length of roll)*	41,34 mm	64,0 mm

Ergebnisse Profil
Results profile

Teilkreis-durchmesser *d* ***Reference diameter d***	**Profil-Winkelabweichung** ***Profile slope deviation***	**Profil-Formabweichung** ***Profile form deviation***	**Profil-Gesamtabweichung** ***Total profile deviation***
	$f_{H\alpha}$ in µm	**$f_{f\alpha}$ in µm**	**F_α in µm**
128 mm	-2,16 ± 0,7	3,60 ± 0,5	4,63 ± 0,9
319 mm	0,37 ± 1,0	0,68 ± 0,5	0,85 ± 1,2

Diagramme
Diagrams

Bei den folgenden Diagrammen zu den Profilergebnissen ist zu beachten, dass ein Diagramm aus den Mehrlagenmessungen ausgesucht wurde, das den Kalibrierwerten am nächsten kommt.

At the following diagrams relating to the profile results please note that one diagram was selected from the multiple orientation measurement procedure which best approaches the calibrated values.

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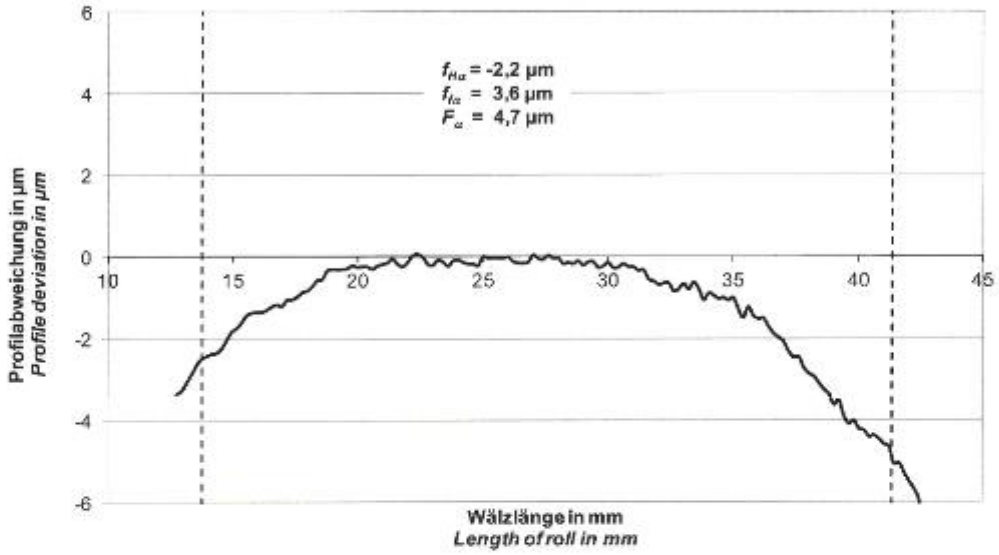
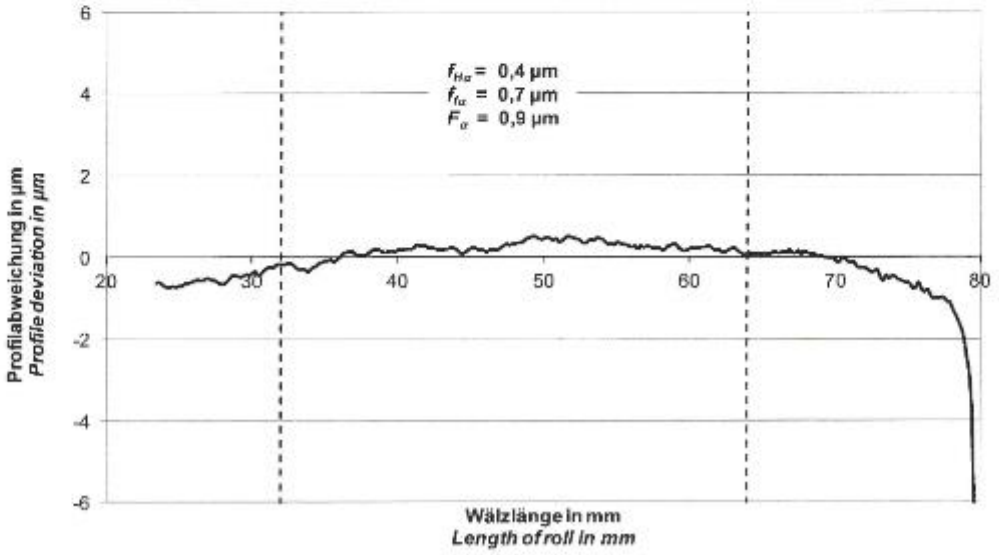
Seite 6 zum Kalibrierschein vom 2015-12-09, Kalibrierzeichen: 50484 PTB 15
Page 6 of the Calibration Certificate dated 2015-12-09, calibration mark: 50484 PTB 15

Profil: d = 128 mm, Rechtsflanke
Profile: d = 128 mm, right flank



Profil: d = 319 mm, Rechtsflanke
Profile: d = 319 mm, right flank



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Die Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig und Berlin ist das nationale Metrologieinstitut und die technische Oberbehörde der Bundesrepublik Deutschland für das Messwesen. Die PTB gehört zum Geschäftsbereich des Bundesministeriums für Wirtschaft und Energie. Sie erfüllt die Anforderungen an Kalibrier- und Prüflaboratorien auf der Grundlage der DIN EN ISO/IEC 17025.

Zentrale Aufgabe der PTB ist es, die gesetzlichen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI) darzustellen, zu bewahren und weiterzugeben. Die PTB steht damit an oberster Stelle der metrologischen Hierarchie in Deutschland. Die Kalibrierscheine der PTB dokumentieren eine auf nationale Normale rückgeführte Kalibrierung.

Dieser Ergebnisbericht ist in Übereinstimmung mit den Kalibrier- und Messmöglichkeiten (CMCs), wie sie im Anhang C des gegenseitigen Abkommens (MRA) des Internationalen Komitees für Maße und Gewichte enthalten sind. Im Rahmen des MRA wird die Gültigkeit der Ergebnisberichte von allen teilnehmenden Instituten für die im Anhang C spezifizierten Messgrößen, Messbereiche und Messunsicherheiten gegenseitig anerkannt (nähere Informationen unter http://www.bipm.org).

CIPM MRA

The Physikalisch-Technische Bundesanstalt *(PTB) in Braunschweig and Berlin is the National Metrology Institute and the supreme technical authority of the Federal Republic of Germany for metrology. The PTB comes under the auspices of the Federal Ministry of Economics and Energy. It meets the requirements for calibration and testing laboratories as defined in DIN EN ISO/IEC 17025.*

The central task of PTB is to realize, to maintain and to disseminate the legal units in compliance with the International System of Units (SI). PTB thus is at the top of the metrological hierarchy in Germany. The calibration certificates issued by PTB document a calibration traceable to national measurement standards.

This certificate is consistent with the Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details, see http://www.bipm.org).

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Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Kalibrierschein

Calibration Certificate

Gegenstand: *Object:*	Flankenliniennormal, d = 100 mm *Helix measurement standard d = 100 mm*
Hersteller: *Manufacturer:*	Keine Angabe *No declaration*
Typ: *Type:*	Stirnradnormal (β = 0°, 15° l + r, 30° l + r, L) *Cylindrical gear standard (β = 0°, 15° l + r, 30° l + r, L)*
Kennnummer: *Serial No.:*	L-7444-1
Auftraggeber: *Applicant:*	Physikalisch-Technische Bundesanstalt Fachbereich 5.3 Bundesallee 100 38116 Braunschweig Deutschland
Anzahl der Seiten: *Number of pages:*	9
Geschäftszeichen: *Reference No.:*	5.3-2015-060
Kalibrierzeichen: *Calibration mark:*	50485 PTB 15
Datum der Kalibrierung: *Date of calibration:*	2015-11-13

Im Auftrag
On behalf of PTB

Dr. rer. nat. M. Stein

Braunschweig, 2015-11-25

Siegel
Seal

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 7

Im Auftrag
On behalf of PTB

K. Hierse

391 00B n

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Seite 2 zum Kalibrierschein vom 2015-11-25, Kalibrierzeichen: 50485 PTB 15
Page 2 of the Calibration Certificate dated 2015-11-25, calibration mark: 50485 PTB 15

Kalibriergegenstand
Calibration standard

Flankenliniennormal
Helix measurement standard

Verzahnungsparameter:
Gear parameters:

Schrägungswinkel β *Helix angle β*	0°	15° l + r	30° l + r
Normalmodul m_n *Normal module m_n*	4,0 mm	3,8637 mm	3,4641 mm
Zähnezahl z *Number of teeth z*	25	25	25
Normaleingriffswinkel α_n *Normal pressure angle α_n*	20°	20°	20°
Profilverschiebungsfaktor x *Profile shift coefficient x*	0	0	0
Zahnbreite b *Facewidth b*	70 mm	70 mm	70 mm

Anmerkung:
Remark:

Es ist zu beachten, dass die Verzahnungsparameter mit der im Kalibrierschein angegebenen Genauigkeit eingegeben werden müssen, um Abweichungen durch Rundungsfehler zu vermeiden.

It must be pointed out here that the gear parameters must be entered with the accuracy stated in the calibration certificate so as to avoid deviations due to rounding errors.

General note concerning the English translation:

This Calibration Certificate is written in German. In case of any conflict between the German language version and the English translation of it, the German version shall prevail.

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Stirnradnormal Kennnummer Nr. L-7444-1
Cylindrical gear standard serial No. L-7444-1

Kalibrierverfahren
Calibration procedure

Flankenlinie
Helix

Die Flankenlinien des Normals wurden auf einem rückgeführten Koordinatenmessgerät kalibriert. Die einzelnen Messwerte wurden durch ein Mehrlagenmessverfahren ermittelt. Hierzu wurde das Normal in vier um 90° versetzten Stellungen, gestürzt und ungestürzt, mehrfach gemessen. Die Messergebnisse sind die gemittelten Werte aus allen Messungen.
Die Kalibrierwerte der Flankenlinienmessungen beziehen sich jeweils auf den Auswertebereich. Abweichungen außerhalb des Auswertebereichs bleiben unberücksichtigt.

The helices of the measurement standard were calibrated on a coordinate measuring machine for which traceability has been proved. The individual measurement values were determined by a multiple orientation measurement procedure. For this purpose, the standard was measured in four positions displaced by 90° (tumbled and untumbled). The measurement results are the averaged values from all measurements.
The calibration values of helix measurements each refer to the evaluation range. Deviations outside the evaluation range remain disregarded.

Bezüge
References

Die Bezugsseite des Normals ist durch die Kennnummer gekennzeichnet.
Die Referenzachse des Normals wurde numerisch ermittelt. Hierzu wurden an der Welle des Normals zwei Bezugskreise (siehe Skizze des Normals) gemessen und deren Mittelpunkte nach der Methode der kleinsten Fehlerquadrate bestimmt. Durch die Mittelpunkte der Kreise wurde die Referenzachse des Verzahnungsnormals gelegt.

The datum face of the measurement standard is marked by the serial number.
The reference axis of the measurement standard was numerically determined. For this purpose, two reference circles in the shaft of the gear measurement standard (see sketch of the measurement standard) were measured and their centres were determined in accordance with the least squares method. The reference axis of the gear measurement standard was laid through the centres of the circles.

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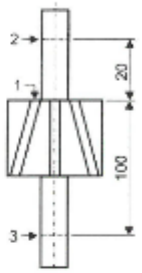

(1) Bezugsseite (Höhenbezug)
datum face (reference for the height)

(2) oberer Bezugskreis
upper reference circle

(3) unterer Bezugskreis
lower reference circle

Skizze des Normals
Sketch of the measurement standard

Umgebungsbedingungen
Environmental conditions

Temperatur während der Messung *Temperature during the measurement*	(20 ± 0,2) °C

Normative Verweise
Normative references

Die Bezeichnung am Verzahnungsnormal und die Auswertungen erfolgten, sofern nicht explizit anders beschrieben, unter Berücksichtigung der folgenden Richtlinien und Normen:

For identification and evaluations on the gear artifact, the following guidelines and standards were taken into account unless otherwise explicitly noted:

ISO 1328-1, September 2013 (E);
VDI/VDE 2607, Februar 2000;
VDI/VDE 2612, Mai 2000;
DIN ISO 21771 August 2014
DIN 21772 Juli 2012
DIN 3999, November 1974;

Messunsicherheit
Measurement uncertainty

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor $k = 2$ ergibt. Sie wurde gemäß dem „Guide to the Expression of Uncertainty in Measurement (GUM)“ ermittelt. Der Wert der Messgröße liegt dann im Regelfall mit einer Wahrscheinlichkeit von annähernd 95 % im zugeordneten Überdeckungsintervall.

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor $k = 2$. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement (GUM)". The value of the measurand then normally lies, with a probability of 95 %, within the attributed coverage interval.

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Flankenlinie
Helix

Die Messungen wurden auf der Grundlage der auf Seite 2 aufgelisteten und der folgenden Angaben durchgeführt:

The measurement conducted was based on the parameters listed on page 2 with the following additional parameters:

Antastkugeldurchmesser *Stylus sphere diameter*	3 mm
Punkteanzahl je Bezugskreis *Number of points per reference circle*	36
Punktedichte auf Flankenlinie *Point density on the helix*	2/mm
Messkreisdurchmesser (Flankenlinie) d_M *Diameter of measurement circle (helix)* d_M	100 mm
Start der Auswertung $L_{\beta Start}$ (über Zahnbreite) *Start of evaluation* $L_{\beta Start}$ *(along facewidth)*	7 mm
Ende der Auswertung $L_{\beta End}$ (über Zahnbreite) *End of evaluation* $L_{\beta End}$ *(along facewidth)*	63 mm

Ergebnisse Flankenlinie
Results helix

Schrägungswinkel β ***Helix angle β***	**Flankenlinien-Winkelabweichung** ***Helix slope deviation*** **$f_{H\beta}$ in µm**	**Flankenlinien-Formabweichung** ***Helix form deviation*** **$f_{f\beta}$ in µm**	**Flankenlinien-Gesamtabweichung** ***Total helix deviation*** **F_β in µm**
0° L	1,35 r ± 0,7 (1,38 ± 0,7)	0,78 ± 0,6	1,99 ± 1,0
15° l L	-3,23 ± 0,8	0,99 ± 0,6	3,41 ± 1,1
15° r L	-0,93 ± 0,8	1,44 ± 0,6	1,87 ± 1,1
30° l L	-7,38 ± 1,0	1,53 ± 0,6	7,93 ± 1,2
30° r L	-1,80 ± 1,0	1,88 ± 0,6	2,59 ± 1,2

Abkürzungen in der Tabelle: l/r linkssteigend/rechtssteigend, L Linksflanke
Abbreviations in the table: l/r left hand/right hand, L left flank

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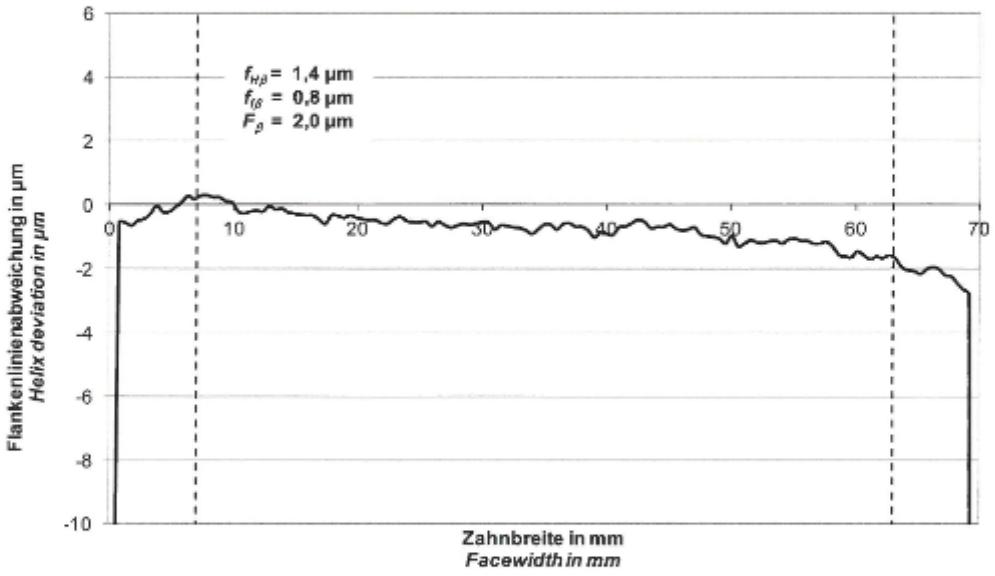
Seite 6 zum Kalibrierschein vom 2015-11-25, Kalibrierzeichen: 50485 PTB 15
Page 6 of the Calibration Certificate dated 2015-11-25, calibration mark: 50485 PTB 15

Diagramme
Diagrams

Bei den folgenden Diagrammen zu den Flankenlinienergebnissen ist zu beachten, dass ein Diagramm aus den Mehrlagenmessungen ausgesucht wurde, das den Kalibrierwerten am nächsten kommt.

At the following diagrams relating to the helix results please note that one diagram was selected from the multiple orientation measurement procedure which best approaches the calibrated values.

Flankenlinie: 0°, Linksflanke
Helix: 0°, left flank



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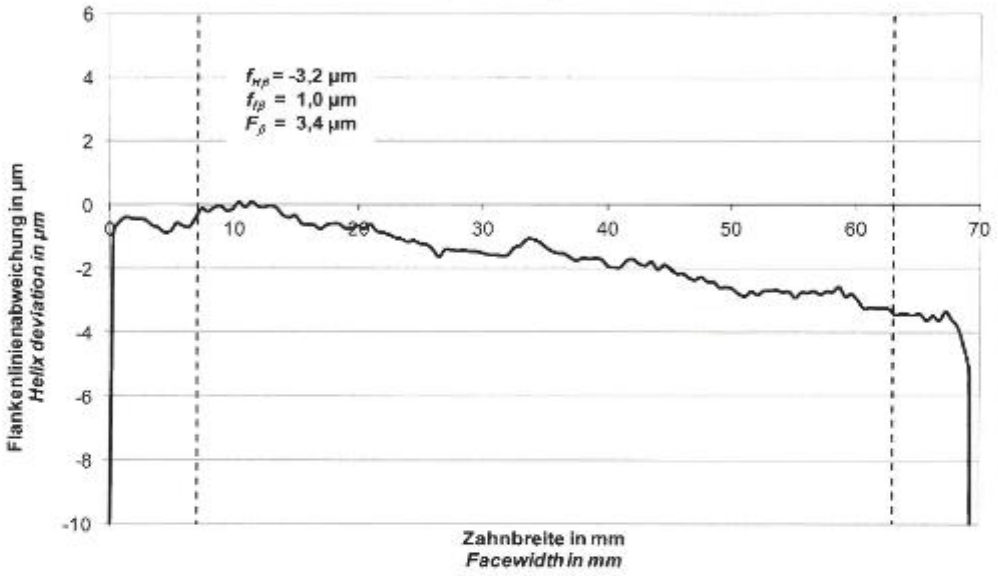
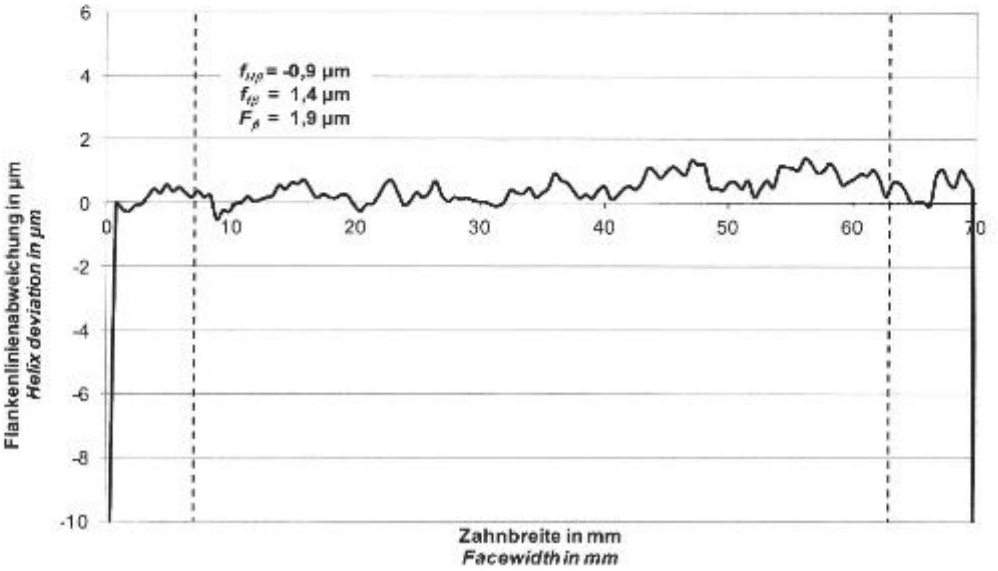
Seite 7 zum Kalibrierschein vom 2015-11-25, Kalibrierzeichen: 50485 PTB 15
Page 7 of the Calibration Certificate dated 2015-11-25, calibration mark: 50485 PTB 15

Flankenlinie: 15°, linkssteigend, Linksflanke
Helix: 15°, left hand, left flank



Flankenlinie: 15°, rechtssteigend, Linksflanke
Helix: 15°, right hand, left flank



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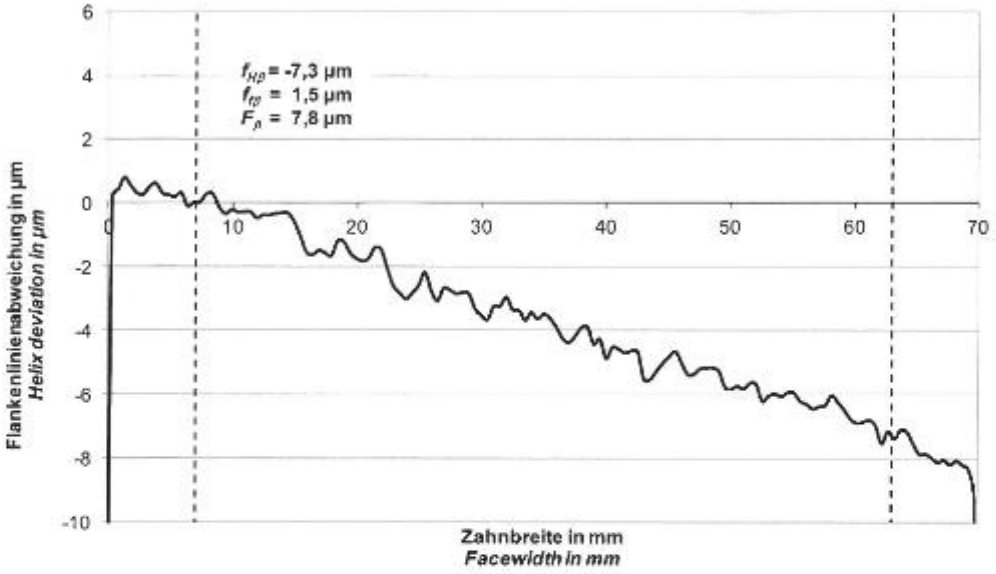
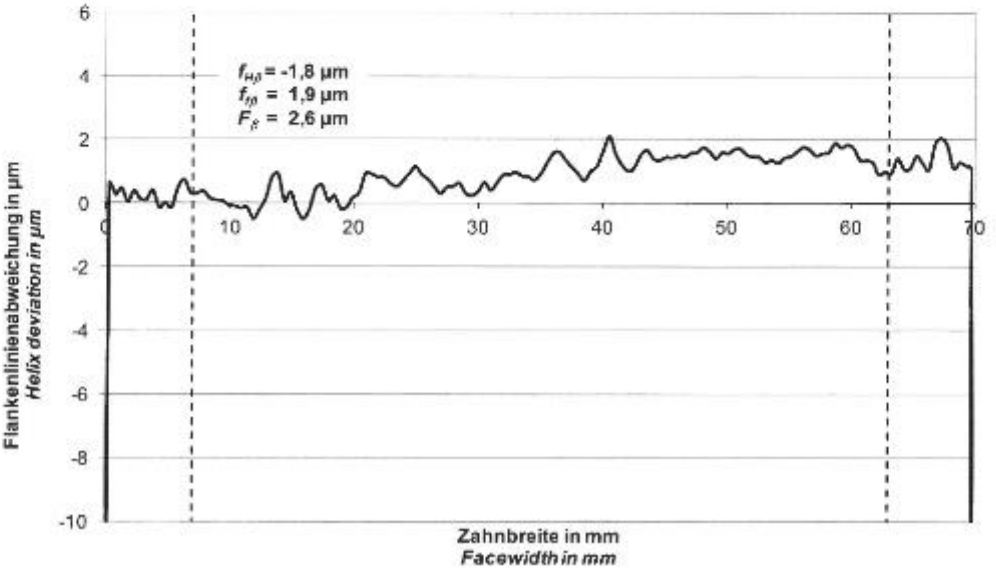
Seite 8 zum Kalibrierschein vom 2015-11-25, Kalibrierzeichen: 50485 PTB 15
Page 8 of the Calibration Certificate dated 2015-11-25, calibration mark: 50485 PTB 15

Flankenlinie: 30°, linkssteigend, Linksflanke
Helix: 30°, left hand, left flank



Flankenlinie: 30°, rechtssteigend, Linksflanke
Helix: 30°, right hand, left flank



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Dieser Ergebnisbericht ist in Übereinstimmung mit den Kalibrier- und Messmöglichkeiten (CMCs), wie sie im Anhang C des gegenseitigen Abkommens (MRA) des Internationalen Komitees für Maße und Gewichte enthalten sind. Im Rahmen des MRA wird die Gültigkeit der Ergebnisberichte von allen teilnehmenden Instituten für die im Anhang C spezifizierten Messgrößen, Messbereiche und Messunsicherheiten gegenseitig anerkannt (nähere Informationen unter http://www.bipm.org).

CIPM MRA

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This certificate is consistent with the Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details, see http://www.bipm.org).

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Kalibrierschein
Calibration Certificate

Gegenstand: *Object:*	Teilungsnormal d = 102 mm *Pitch measurement standard d = 102 mm*
Hersteller: *Manufacturer:*	Keine Angabe *No declaration*
Typ: *Type:*	Teilungsnormal (z = 34) *Pitch measurement standard (z = 34)*
Kennnummer: *Serial No.:*	4693
Auftraggeber: *Applicant:*	Physikalisch-Technische Bundesanstalt Fachbereich 5.3 Bundesallee 100 38116 Braunschweig Deutschland
Anzahl der Seiten: *Number of pages:*	10
Geschäftszeichen: *Reference No.:*	5.3-2015-060
Kalibrierzeichen: *Calibration mark:*	54190 PTB 15
Datum der Kalibrierung: *Date of calibration:*	2015-12-09

Im Auftrag
On behalf of PTB

Dr. rer. nat. M. Stein

Braunschweig, 2015-12-09

Siegel
Seal

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 7

Im Auftrag
On behalf of PTB

Dipl.-Ing. (FH) A. Wedmann

391 005 n

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Seite 2 zum Kalibrierschein vom 2015-12-09, Kalibrierzeichen: 54190 PTB 15
Page 2 of the Calibration Certificate dated 2015-12-09, calibration mark: 54190 PTB 15

Kalibriergegenstand
Calibration standard

Teilungsnormal
Pitch measurement standard

Verzahnungsparameter:
Gear parameters:

Schrägungswinkel β *Helix angle β*	0°
Normalmodul m_n *Normal module m_n*	3,0 mm
Zähnezahl z *Number of teeth z*	34
Normaleingriffswinkel α_n *Normal pressure angle α_n*	20°
Profilverschiebungsfaktor x *Profile shift coefficient x*	0
Zahnbreite b *Facewidth b*	25,4 mm

Anmerkung:
Remark:

Es ist zu beachten, dass die Verzahnungsparameter mit der im Kalibrierschein angegebenen Genauigkeit eingegeben werden müssen, um Abweichungen durch Rundungsfehler zu vermeiden.

It must be pointed out here that the gear parameters must be entered with the accuracy stated in the calibration certificate so as to avoid deviations due to rounding errors.

General note concerning the English translation:

This Calibration Certificate is written in German. In case of any conflict between the German language version and the English translation of it, the German version shall prevail.

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Teilungsnormal, Kennnummer 4693
Pitch measurement standard serial No. 4693

Kalibrierverfahren
Calibration procedure

Teilung
Pitch

Die Bezugskreise wurden im scannenden Antastmodus gemessen. Die Teilung wurde in der Mitte der Zahnbreite in der Einflankenanlage gemessen. Hierbei wurden die Teilungsabweichungen an rechter und linker Flanke in gleicher Aufspannung ermittelt. Anschließend wurde der Drehtisch gegenüber dem Normal jeweils um eine Teilung gedreht und der Messvorgang z-mal wiederholt. Die Teilungsmessungen wurden immer an dem Zahn Nr. 1 begonnen.

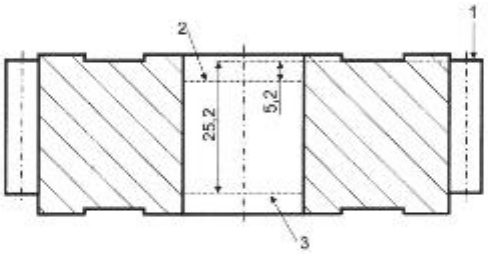
The reference circles were measured in scanning mode. The pitch was measured in the single-flank contact at the middle of the facewidth. At this, the pitch deviations at the right and at the left flank were determined in one setting. After that, the rotary table was turned by the amount of one pitch against the measurement standard and the measuring process was z-times repeated. The pitch measurements started always at the tooth number 1.

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Bezüge
References

Die Bezugsseite des Normals ist durch die Kennnummer gekennzeichnet.
Die Referenzachse des Normals wurde numerisch ermittelt. Hierzu wurden in der Bohrung des Normals zwei Bezugskreise (siehe Skizze des Normals) gemessen und deren Mittelpunkte nach der Methode der kleinsten Fehlerquadrate bestimmt. Durch die Mittelpunkte der Kreise wurde die Referenzachse des Verzahnungsnormals gelegt.

The datum face of the measurement standard is marked by the serial number.
The reference axis of the measurement standard was numerically determined. For this purpose, two reference circles in the bore of the gear measurement standard (see sketch of the measurement standard) were measured and their centres were determined in accordance with the least squares method. The reference axis of the gear measurement standard was laid through the centres of the circles.



(1) Bezugsseite (Höhenbezug)
datum face (reference for the height)
(2) oberer Bezugskreis
upper reference circle
(3) unterer Bezugskreis
lower reference circle

Skizze des Normals
Sketch of the measurement standard

Umgebungsbedingungen
Environmental conditions

Temperatur während der Messung *Temperature during the measurement*	(20 ± 0,2) °C

Normative Verweise
Normative references

Die Bezeichnung am Verzahnungsnormal und die Auswertungen erfolgten, sofern nicht explizit anders beschrieben, unter Berücksichtigung der folgenden Richtlinien und Normen:

For identification and evaluations on the gear artifact, the following guidelines and standards were taken into account unless otherwise explicitly noted:

ISO 1328-1, September 2013 (E);
VDI/VDE 2607, Februar 2000;
VDI/VDE 2612, Mai 2000;
DIN ISO 21771 August 2014
DIN 21772 Juli 2012
DIN 3999, November 1974;

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Messunsicherheit
Measurement uncertainty

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor $k = 2$ ergibt. Sie wurde gemäß dem „Guide to the Expression of Uncertainty in Measurement (GUM)“ ermittelt. Der Wert der Messgröße liegt dann im Regelfall mit einer Wahrscheinlichkeit von annähernd 95 % im zugeordneten Überdeckungsintervall.

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor k = 2. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement (GUM)". The value of the measurand then normally lies, with a probability of 95 %, within the attributed coverage interval.

Teilung
Pitch

Die Messung wurde auf der Grundlage der auf Seite 2 aufgelisteten und der folgenden Angaben durchgeführt:

The measurement conducted was based on the parameters listed on page 2 with the following additional parameters:

Antastkugeldurchmesser *Stylus sphere diameter*	3 mm
Messkreisdurchmesser (Teilung) d_M *Diameter of measurement circle (pitch) d_M*	102 mm

Hinweis: Bei den in der folgenden Tabelle angegebenen Werten handelt es sich um gerundete Werte. Aus diesem Grund kann nicht mit der angegebenen Genauigkeit der Einzelteilungsfehler f_p auf die Summenteilungsfehler F_p gerechnet werden. Die Messunsicherheitsangaben sind hiervon unbeeinflusst.

Note: The values given in the following table contains rounded values. For this reason the single pitch deviations f_p can in general not be calculated from the cumulative pitch deviations F_p and vice versa due to rounding errors. The measurement uncertainties are uninfluenced from this.

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Ergebnisse Teilung
Results pitch

Teilung Nr.* *Pitch No.**	Linksflanke *Left flank*		Rechtsflanke *Right flank*	
	F_{pk} in µm	f_p in µm	F_{pk} in µm	f_p in µm
1	-0,42	-0,42	0,07	0,07
2	-0,16	0,26	-2,30	-2,37
3	1,90	2,06	-1,84	0,46
4	2,75	0,85	-1,43	0,41
5	2,69	-0,06	0,11	1,54
6	2,32	-0,37	-0,01	-0,12
7	1,65	-0,67	1,43	1,44
8	1,44	-0,21	2,33	0,90
9	2,87	1,43	2,71	0,38
10	3,24	0,37	3,04	0,33
11	3,41	0,17	1,53	-1,51
12	2,74	-0,67	2,00	0,47
13	2,96	0,22	2,87	0,87
14	4,38	1,42	3,27	0,40
15	3,46	-0,92	2,97	-0,30
16	3,64	0,18	2,19	-0,78
17	3,18	-0,46	2,57	0,38
18	4,17	0,99	2,91	0,34
19	4,43	0,26	3,28	0,37
20	4,24	-0,19	4,59	1,31
21	5,65	1,41	2,75	-1,84
22	5,88	0,23	2,58	-0,17
23	5,38	-0,50	3,27	0,69
24	4,87	-0,51	5,18	1,91
25	4,84	-0,03	5,62	0,44
26	4,76	-0,08	4,84	-0,78
27	4,18	-0,58	2,99	-1,85
28	3,29	-0,89	3,33	0,34
29	3,48	0,19	3,87	0,54
30	2,28	-1,20	3,85	-0,02
31	0,75	-1,53	3,40	-0,45
32	-0,30	-1,05	0,49	-2,91
33	-0,26	0,04	0,66	0,17
34	0,00	0,26	0,00	-0,66

* Die Zählung der Teilung beginnt zwischen dem letzten und dem ersten Zahn.
The counting of the pitch starts between the last and the first tooth.

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Linksflanke ***Left flank***		
Messgröße ***Measurand***	**Messwert (Teilung Nr.)** ***Measurement value (Pitch No.)***	**Unsicherheit** ***U(k = 2)*** ***Uncertainty U(k = 2)***
Teilungs-Gesamtabweichung F_p *Cumulative pitch deviation* F_p	6,30 µm (22 - 1)	± 0,5 µm
Teilungs-Einzelabweichung $f_{p\,max}$ *Single pitch deviation* $f_{p\,max}$	2,06 µm (3)	± 0,5 µm

Rechtsflanke ***Right flank***		
Messgröße ***Measurand***	**Messwert (Teilung Nr.)** ***Measurement value (Pitch No.)***	**Unsicherheit** ***U(k = 2)*** ***Uncertainty U(k = 2)***
Teilungs-Gesamtabweichung F_p *Cumulative pitch deviation* F_p	7,92 µm (25 - 2)	± 0,5 µm
Teilungs-Einzelabweichung $f_{p\,max}$ *Single pitch deviation* $f_{p\,max}$	-2,91 µm (32)	± 0,5 µm

Diagramme
Diagrams

Die Diagramme zu den Teilungsmessungen entsprechen den angegebenen Messergebnissen.

The diagrams relating to the pitch measurements equate to the specified measurements results.

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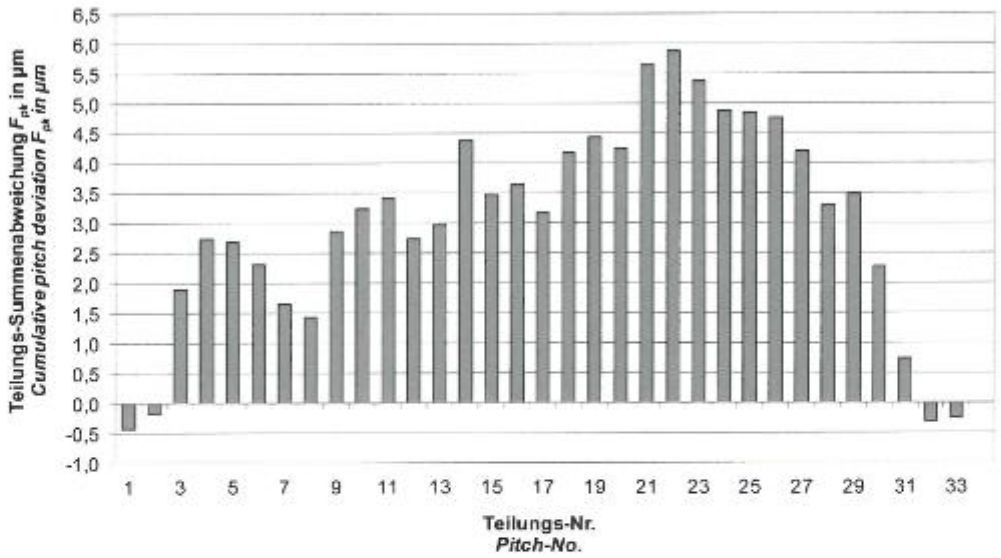
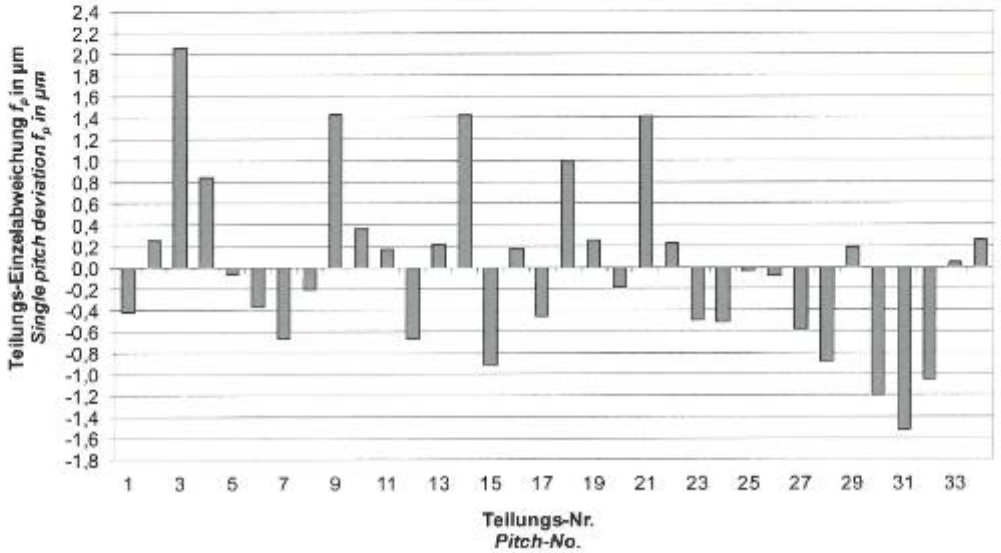
Teilungs-Summenabweichung: Linksflanke
Cumulative pitch deviation: left flank



Teilungs-Einzelabweichung: Linksflanke
Single pitch deviation: left flank



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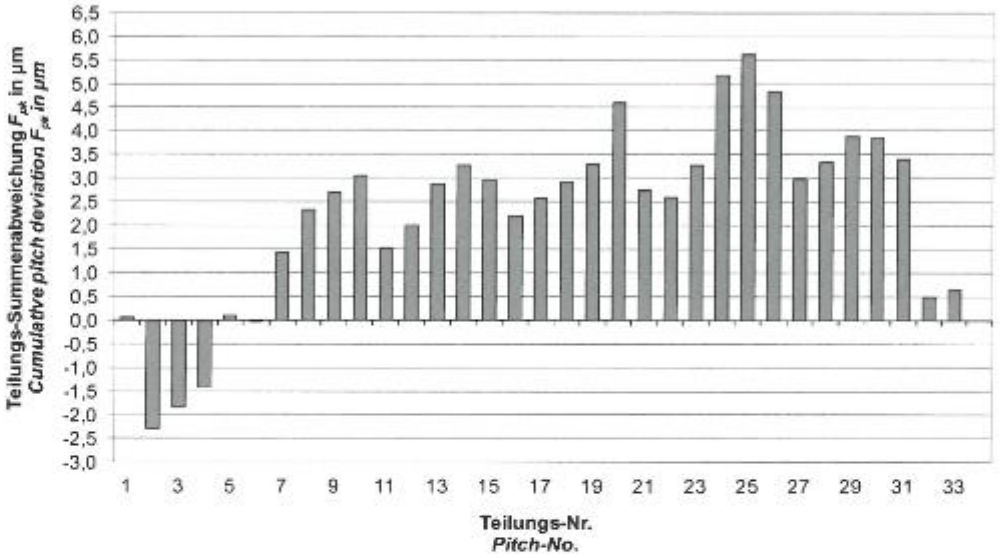
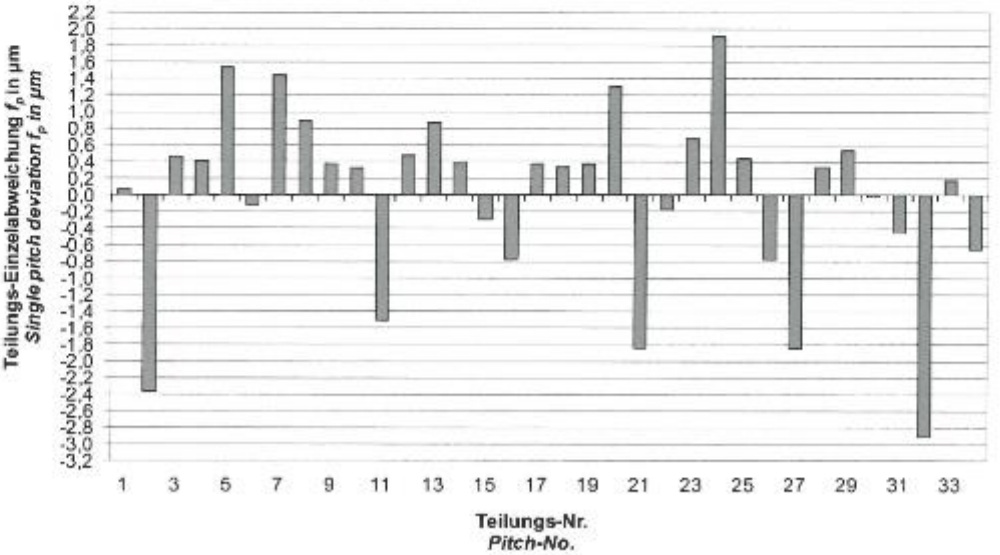
Seite 9 zum Kalibrierschein vom 2015-12-09, Kalibrierzeichen: 54190 PTB 15
Page 9 of the Calibration Certificate dated 2015-12-09, calibration mark: 54190 PTB 15

Teilungs-Summenabweichung: Rechtsflanke
Cumulative pitch deviation: right flank



Teilungs-Einzelabweichung: Rechtsflanke
Single pitch deviation: right flank



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Die Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig und Berlin ist das nationale Metrologieinstitut und die technische Oberbehörde der Bundesrepublik Deutschland für das Messwesen. Die PTB gehört zum Geschäftsbereich des Bundesministeriums für Wirtschaft und Energie. Sie erfüllt die Anforderungen an Kalibrier- und Prüflaboratorien auf der Grundlage der DIN EN ISO/IEC 17025.

Zentrale Aufgabe der PTB ist es, die gesetzlichen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI) darzustellen, zu bewahren und weiterzugeben. Die PTB steht damit an oberster Stelle der metrologischen Hierarchie in Deutschland. Die Kalibrierscheine der PTB dokumentieren eine auf nationale Normale rückgeführte Kalibrierung.

Dieser Ergebnisbericht ist in Übereinstimmung mit den Kalibrier- und Messmöglichkeiten (CMCs), wie sie im Anhang C des gegenseitigen Abkommens (MRA) des Internationalen Komitees für Maße und Gewichte enthalten sind. Im Rahmen des MRA wird die Gültigkeit der Ergebnisberichte von allen teilnehmenden Instituten für die im Anhang C spezifizierten Messgrößen, Messbereiche und Messunsicherheiten gegenseitig anerkannt (nähere Informationen unter http://www.bipm.org).

CIPM MRA

The Physikalisch-Technische Bundesanstalt *(PTB) in Braunschweig and Berlin is the National Metrology Institute and the supreme technical authority of the Federal Republic of Germany for metrology. The PTB comes under the auspices of the Federal Ministry of Economics and Energy. It meets the requirements for calibration and testing laboratories as defined in DIN EN ISO/IEC 17025.*

The central task of PTB is to realize, to maintain and to disseminate the legal units in compliance with the International System of Units (SI). PTB thus is at the top of the metrological hierarchy in Germany. The calibration certificates issued by PTB document a calibration traceable to national measurement standards.

This certificate is consistent with the Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details, see http://www.bipm.org).

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38116 Braunschweig
DEUTSCHLAND

Abbestraße 2-12
10587 Berlin
DEUTSCHLAND

Participant 2: Ukraine (NSC)

A1. Measurement results

A1.1 Inspection of the measurement surfaces

Notes:

The box with the profile measurement standard has been broken, no visible damage.

A1.2 Description of the measurement instrument

Make and type of instrument

(If you use a non-commercial or significant modified commercial equipment, please add drawings, explaining papers etc.)

Coordinate measuring machine: Clobal S.E./ADV Serial number: Clob0012731A

Traceability path

It is part of the national standard involved in comparisons.

Description of measuring technique

In accordance with the technical protocol.

Range of artifact temperature during measurements & description of temperature measurement method

Temperature during measurement was within 20°C ± 0,3°C. We used three thermometers with uncertainty $U_{0,95}$ = ____ Thermometers are placed on the table of coordinate measuring machine artifact and +0.5 m above the artifact.

A2. Measurement results

A2.1 Measurements results of the profile measurement standard

- Number of data points 40

- Use of a digital filter (yes / no)
If yes, which filter? Gauss 50

d_1: 120 mm

Profile slope deviation fH_α in µm	1,2
Profile form deviation ff_α in µm	4,0
Profile total deviation F_α in µm	4,6

d_2: 300 mm

Profile slope deviation fH_α in µm	1,3
Profile form deviation ff_α in µm	2,4
Profile total deviation F_α in µm	2,5

A2.2 Measurements results of the helix measurement standard

- Number of data points 40

- Use of a digital filter (yes / no)
If yes, which filter? Gauss 50

Helix angle β	Helix slope deviation $f_{H\beta}$ in µm	Helix form deviation $f_{f\beta}$ in µm	Helix total deviation F_β in µm
0° R	1,4	1,7	2,5
15° l R	-3,5	1,3	3,8
15° r R	-0,3	2,4	2,4
30° l R	-8,8	1,3	9,1
30° r R	-0,9	1,9	2,0

A2.3 Measurements results of the pitch measurement standard

Pitch No. *	Left flank		Right flank	
	F_p in µm	f_p in µm	F_p in µm	f_p in µm
1	-3,0	0,6	-3,2	-0,5
2	-3,2	-0,3	-2,6	0,6
3	-2,3	0,9	-4,9	-2,4
4	-0,5	1,9	-4,3	0,7
5	0,7	1,1	-3,6	0,8
6	0,7	0,0	-1,7	2,0
7	0,8	0,2	-1,3	0,5
8	0,3	-0,6	0,6	1,8
9	0,2	-0,1	1,5	1,0
10	1,1	0,9	1,9	0,4
11	1,3	0,3	2,2	0,4
12	0,8	-0,6	0,8	-1,5
13	-0,6	1,2	0,8	0
14	-0,3	0,3	0,9	0,2
15	1,0	1,2	0,7	-0,3
16	-0,4	-1,3	0,4	-0,3
17	-0,2	0,3	-0,9	-1,3
18	-0,5	-0,4	-0,6	0,4
19	0,6	1,1	-0,7	0,2
20	0,7	0,1	-0,3	0,5
21	0,8	0,2	1,0	1,3
22	2,3	1,6	-0,2	-1,2
23	1,9	-0,5	0,4	0,5
24	3,0	1,2	1,6	1,2
25	2,5	-0,6	3,7	2,2
26	2,2	-0,3	3,8	0,2
27	1,9	-0,4	3,4	-0,4
28	1,0	-0,9	1,5	-2,0
29	-0,2	-1,1	1,7	0,2
30	0,1	0,2	1,6	-0,2
31	-1,3	-1,4	1,3	-0,4
32	-2,9	-1,6	0,4	-1,0
33	-3,9	-1,1	-2,3	-2,7
34	-3,6	0,3	-2,7	0,4

Left flank		
	Result	Pitch No.*
Total pitch error F_p	6,9	1 – 34
Maximum F_p	3,0	24
Minimum F_p	-3,9	33
Single pitch error f_p	1,9	4

Right flank		
	Result	Pitch No.*
Total pitch error F_p	8,7	1 – 34
Maximum F_p	3,8	26
Minimum F_p	-4,9	3
Single pitch error f_p	2,7	33

* the counting of the pitch starts between the last and the first tooth

A3. Uncertainty of measurements

A3.1 Profile measurement standard

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
$f_{H\alpha}$	0,72	1,47
$f_{f\alpha}$	0,70	1,4
F_α	0,75	1,5

A3.2 Helix measurement standard

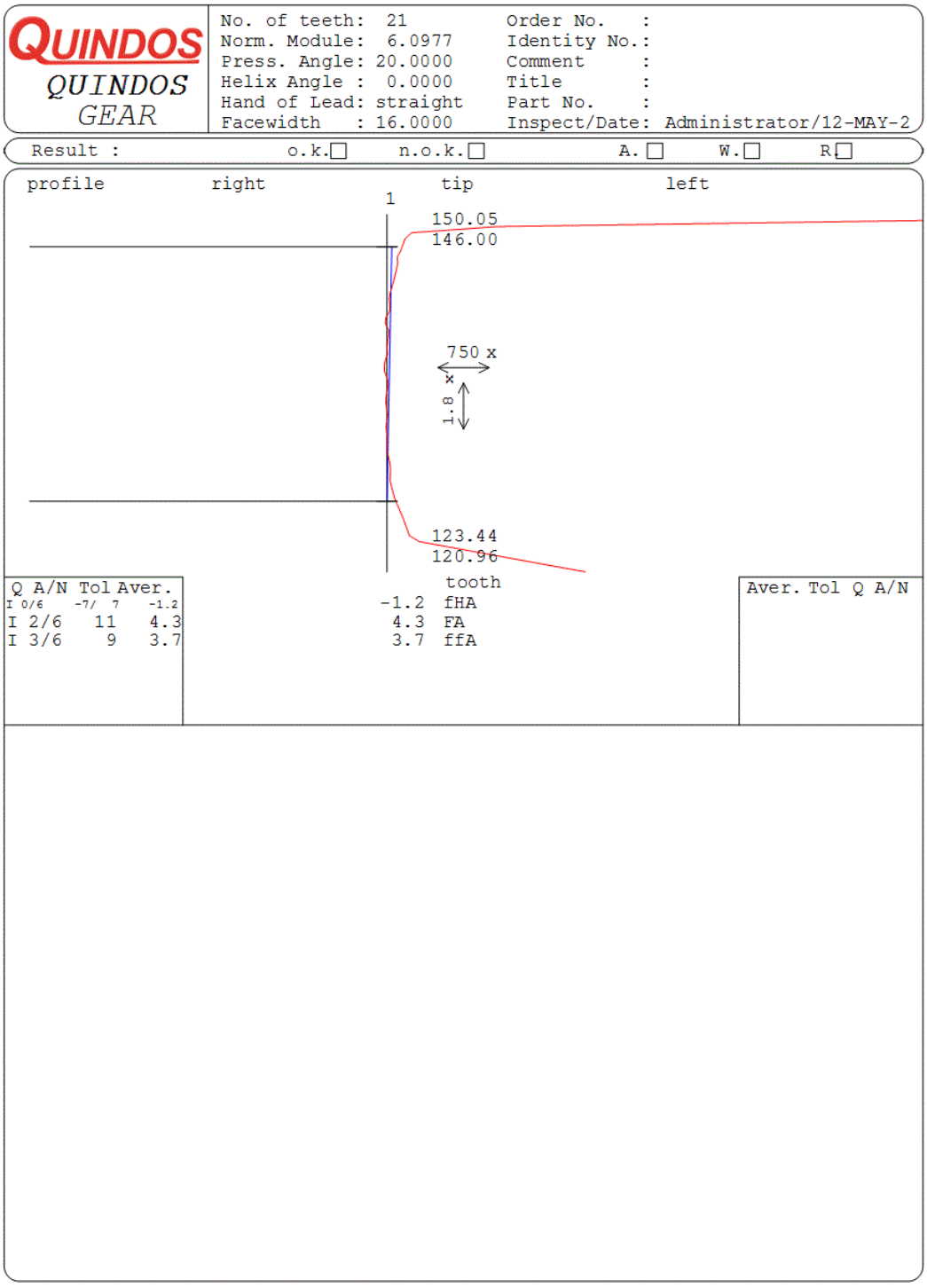
	Combined standard uncertainty u in µm			Expanded measurement uncertainty $U_{95\%}$ in µm		
	0°	15°	30°	0°	15°	30°
$f_{H\beta}$	0,80	0,81	0,82	1,61	1,62	1,64
$f_{f\beta}$	0,70	0,70	0,70	1,4	1,4	1,4
F_β	0,85	0,86	0,86	1,70	1,71	1,72

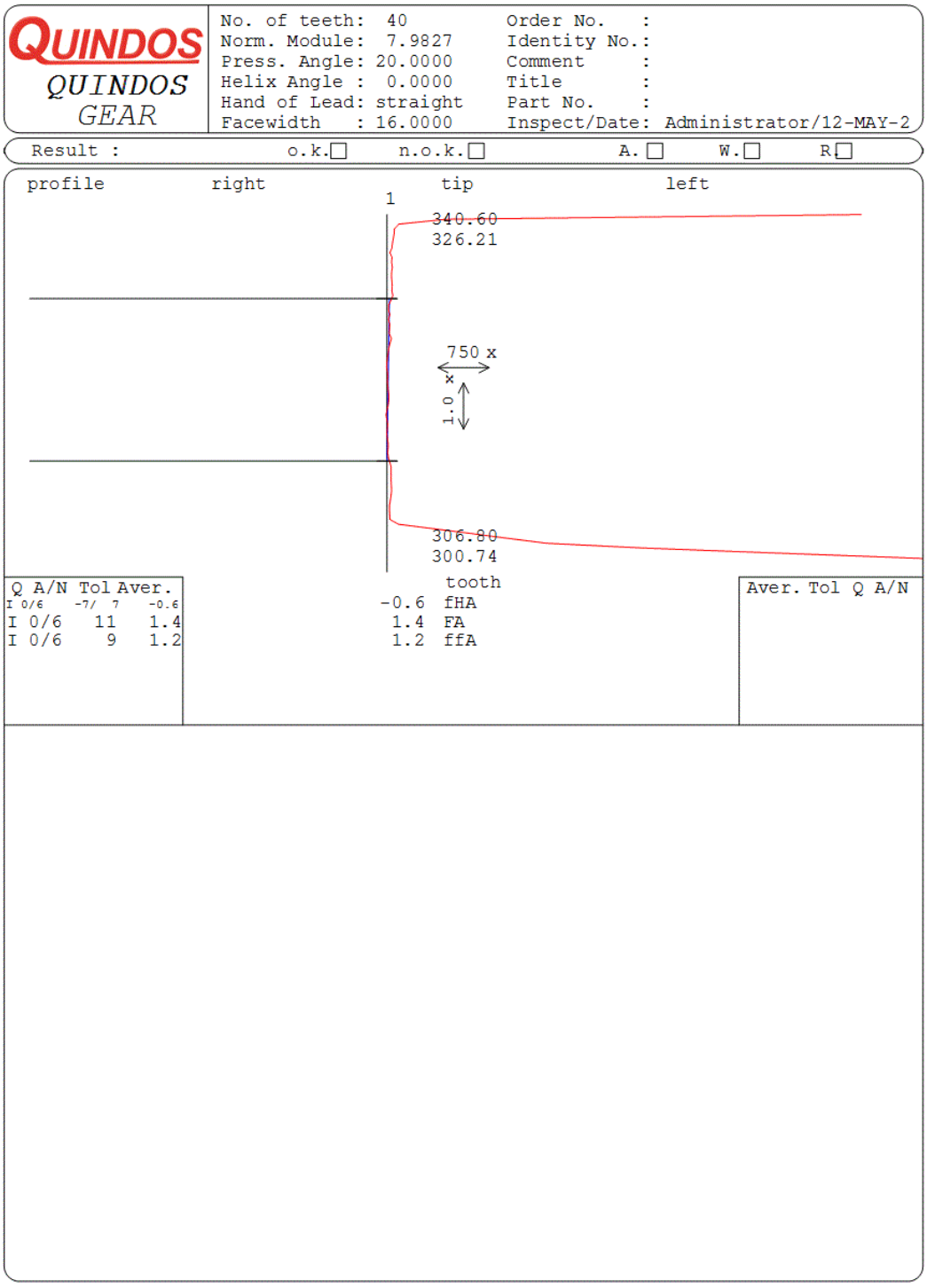
A3.3 Pitch measurement standard

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
F_p	1,17	2,34
f_p	0,72	1,43

The following table includes corrected values which were deliver later.

d_1 = 120 mm						
participant	Profile slope deviation		Profile total deviation		Profile form deviation	
	fHα in µm	*U* in µm	*Fα* in µm	*U* in µm	*ffα* in µm	*U* in µm
NSC Ukraine old	1.20	1.47	4.60	1.50	4.00	1.40
NSC Ukraine new	-1,20	1.47	4.30	1.50	3.70	1.40
d_2 = 300 mm						
participant	Profile slope deviation		Profile total deviation		Profile form deviation	
	fHα in µm	*U* in µm	*Fα* in µm	*U* in µm	*ffα* in µm	*U* in µm
NSC Ukraine old	1.30	1.47	2.50	1.50	2.40	1.40
NSC Ukraine new	-0.60	1.47	1.4	1.50	1.20	1.40


QUINDOS
QUINDOS GEAR
No. of teeth: 21
Norm. Module: 6.0977
Press. Angle: 20.0000
Helix Angle : 0.0000
Hand of Lead: straight
Facewidth : 16.0000
Order No. :
Identity No.:
Comment :
Title :
Part No. :
Inspect/Date: Administrator/12-MAY-2
Result : o.k. n.o.k. A. W. R
profile right tip left
1
150.05
146.00
750 x
x
1.8
123.44
120.96
tooth
Q A/N Tol Aver.
I 0/6 -7/ 7 -1.2
I 2/6 11 4.3
I 3/6 9 3.7
-1.2 fHA
4.3 FA
3.7 ffA
Aver. Tol Q A/N


QUINDOS
QUINDOS GEAR
No. of teeth: 40
Norm. Module: 7.9827
Press. Angle: 20.0000
Helix Angle : 0.0000
Hand of Lead: straight
Facewidth : 16.0000
Order No. :
Identity No.:
Comment :
Title :
Part No. :
Inspect/Date: Administrator/12-MAY-2
Result : o.k. n.o.k. A. W. R
profile right tip left
1
340.60
326.21
750 x
x
1.0
306.80
300.74
tooth
Q A/N Tol Aver.
I 0/6 -7/ 7 -0.6
I 0/6 11 1.4
I 0/6 9 1.2
-0.6 fHA
1.4 FA
1.2 ffA
Aver. Tol Q A/N

Participant 3: Republic of Belarus (BelGIM)

ЕВРО-АЗИАТСКОЕ СОТРУДНИЧЕСТВО ГОСУДАРСТВЕННЫХ МЕТРОЛОГИЧЕСКИХ УЧРЕЖДЕНИЙ (КООМЕТ)
EURO-ASIAN COOPERATION OF NATIONAL METROLOGICAL INSTITUTIONS (COOMET)

November 2016

COOMET Supplementary Comparison

COOMET.L-S18

(COOMET project: 673/UA-a/15)

Involute gear measurement standard

Belarusian State Institute of Metrology (BelGIM)
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E-mail: Makarevich@belgim.by

A1. Measurement results

A1.1 Inspection of the measurement surfaces

- The lid of the helix angle standard container shows some damages.
- The working surfaces of the gear show evidences of corrosion.
- The shaft and the working surface of the tooth helix angle standard bear minor scratches.
- The shaft of the involute standard is scratched

A1.2 Description of the measurement instrument

The measurement instrument is shown in picture 1.

Picture 1 Measurement instrument

The measurement instrument includes the following:
- Carl Zeiss PRISMO® ultra coordinate measuring machine (Germany) with an embedded rotary table;
- VAST gold® scanning probe:
- KMG-CHECK standards used to check the metrological characteristics of the rotary table;
- software: CALIPSO 5.0 intended for all tasks, GEAR PRO 3.4 involute intended for measuring spur and helical gears, GEAR PRO 3.4 bevel intended for measuring bevel gears, CMM-Check intended for measuring KMG-CHECK standards.

Traceability path

All measurements are traceable to the SI units which are realized by the national measurement standard of length (NS RB12-03) of BelGIM.

Description of measuring technique

The measurements were performed as specified in the Technical Report and in the operational documentation for the standard.
All measurements were performed without filters, using a 3 mm diameter probe.
The tooth profile and the helix angle were measured by the continuous scanning method with a resolution equal to 5 points/mm along the profile and 2 points/mm along the helix slope angle.
Each parameter was measured in the automatic mode at least 10 times. Tables 1 to 6 contain the arithmetic mean values of the measured parameters.

Range of artifacts temperature during measurements & description of temperature measurement method

The temperature of the standards was measured by two built-in temperature sensors of the coordinate measuring machine. The measured temperature value was corrected automatically.
The ambient air temperature in the laboratory during the measurements was (19,9 - 20,3) °C.
The relative ambient air humidity in the laboratory was (50 – 65) %.

A2. Measurement results

A2.1 Measurements results of the profile measurement standard

- Number of data points: 5 points per mm

- Use of digital filter: without any filtering

d_1: 120 mm

Table 1

Profile slope deviation $f_{H\alpha}$ in µm	-2,28
Profile form deviation $f_{f\alpha}$ in µm	4,11
Profile total deviation F_α in µm	4,14

d_2: 300 mm

Table 2

Profile slope deviation $f_{H\alpha}$ in µm	-0,07
Profile form deviation $f_{f\alpha}$ in µm	0,87
Profile total deviation F_α in µm	0,85

A2.2 Measurements results of the helix measurement standard

- Number of data points: 2 points per mm

- Use of digital filter: without any filtering

Table 3

Helix angle β	Helix slope deviation $f_{H\beta}$ in µm	Helix form deviation $f_{f\beta}$ in µm	Helix total deviation F_β in µm
0° R	1,46	0,95	2,09
15° l R	4,04	1,70	4,62
15° r R	-1,09	1,74	2,30
30° l R	7,21	1,75	7,95
30° r R	-2,08	2,18	2,90

A2.3 Measurements results of the pitch measurement standard

Table 4

Pitch No.	Left flank		Right flank	
	F_p in µm	f_p in µm	F_p in µm	f_p in µm
1	0,00	0,17	0,00	-3,17
2	-0,82	-0,74	-0,07	-0,07
3	-0,42	0,28	-0,87	-0,79
4	-0,92	-0,45	-1,01	-0,14
5	-1,44	-0,76	-3,81	-2,81
6	-2,99	-1,41	-4,10	-0,28
7	-4,78	-1,62	-4,37	-0,28
8	-4,79	0,03	-4,09	0,28
9	-6,16	-1,20	-3,69	0,40
10	-6,59	-0,62	-5,66	-1,97
11	-6,84	-0,32	-6,82	-1,16
12	-7,22	-0,26	-6,14	0,69
13	-7,41	-0,01	-4,46	1,68
14	-8,13	-0,56	-3,65	0,81
15	-7,58	0,46	-3,84	-0,19
16	-6,19	1,10	-5,32	-1,48
17	-6,93	-0,59	-4,62	0,70
18	-6,55	0,43	-3,72	0,90
19	-6,00	0,52	-3,50	0,23
20	-5,69	0,35	-2,83	0,67
21	-5,94	-0,33	-3,84	-1,01
22	-6,33	-0,31	-3,35	0,49
23	-4,98	1,25	-3,09	0,26
24	-4,50	0,55	-2,00	1,09
25	-4,87	-0,27	-1,32	0,68
26	-4,57	0,15	-2,37	-1,05
27	-4,37	0,20	-2,18	0,19
28	-2,42	1,78	-1,80	0,39
29	-2,67	-0,13	-0,97	0,83
30	-3,23	-0,34	0,70	1,66
31	-3,26	-0,01	0,87	0,17
32	-3,06	0,32	2,16	1,29
33	-2,25	0,76	2,43	0,27
34	-0,54	1,61	3,17	0,74

Table 5

Left flank		
	Result	Pitch No.
Total pitch error F_p in µm	8,13	1-34
Maximum F_p in µm	0,00	34
Minimum F_p in µm	-8,13	14
Single pitch error f_p in µm	1,78	28

Table 6

Right flank		
	Result	Pitch No.
Total pitch error F_p in µm	9,99	1-34
Maximum F_p in µm	3,17	34
Minimum F_p in µm	-6,82	11
Single pitch error f_p in µm	3,17	1

A3. Uncertainty of measurements

A3.1 Profile measurement standard

Table 7

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
$f_{f\alpha}$	0,50	1,00
$f_{H\alpha}$	0,50	1,00
F_α	0,50	1,00

A3.2 Helix measurement standard

Table 8

	Combined standard uncertainty u in µm			Expanded measurement uncertainty $U_{95\%}$ in µm		
	0°	15°	30°	0°	15°	30°
$f_{f\beta}$	0,50	0,50	0,50	1,00	1,00	1,00
$f_{H\beta}$	0,50	0,50	0,50	1,00	1,00	1,00
F_β	0,50	0,50	0,50	1,00	1,00	1,00

A3.3 Pitch measurement standard

Table 9

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
F_p	0,50	1,00
f_p	0,50	1,00

The expanded uncertainty is obtained by multiplying the combined standard uncertainty by a coverage factor k = 2 corresponding to a confidence interval of approximately 95 % assuming a normal distribution.
The evaluation of uncertainty is conducted according to the ISO/IEC Guide 98-3:2008 «Uncertainty of measurement- Part 3:Guide to the expression of uncertainty in measurement (GUM: 1995)».

Note: Any primary measurement records can be obtained at the laboratory upon request.

Head of Department _____ Mr. V. Makarevich
Signature

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The following table includes corrected values which were deliver later.

A2. Measurement results

A2.2 Measurements results of the helix measurement standard

- Number of data points: 2 points per mm

- Use of digital filter: without any filtering

Table 3

Helix angle β	Helix slope deviation $f_{H\beta}$ in µm	Helix form deviation $f_{f\beta}$ in µm	Helix total deviation F_β in µm
15° I R	- 4,04	1,70	4,62
30° I R	- 7,21	1,75	7,95

Head of Department _____ Mr. V. Makarevich

Inspecting engineer _____ A. Kot

Participant 4: Russia (VNIIMS)

A1. Measurement results

A1.1 Inspection of the measurement surfaces

Notes:

The box with the profile measurement standard has been broken, no visible damage.

A1.2 Description of the measurement instrument

Make and type of instrument

(If you use a non-commercial or significant modified commercial equipment, please add drawings, explaining papers etc.)

Coordinate measuring machine: UPMC 850 Serial number: 85164

Traceability path

It is part of the national standard involved in comparisons.

Description of measuring technique

In accordance with the technical protocol.

Range of artifact temperature during measurements & description of temperature measurement method

Temperature during measurement was within 20°C ± 0,3°C. We used three thermometers with uncertainty $U_{0,95}$ = ____ Thermometers are placed on the table of coordinate measuring machine artifact and +0.5 m above the artifact.

A2. Measurement results

A2.1 Measurements results of the profile measurement standard

- Number of data points 500

- Use of a digital filter (yes / no)
If yes, which filter? Gauss 50

d_1: 120 mm

Profile slope deviation fH_α in µm	-4,40
Profile form deviation ff_α in µm	4,47
Profile total deviation F_α in µm	6,06

d_2: 300 mm

Profile slope deviation fH_α in µm	-1,43
Profile form deviation ff_α in µm	1,12
Profile total deviation F_α in µm	1,93

A2.2 Measurements results of the helix measurement standard

- Number of data points 930-1100

- Use of a digital filter (yes / no)
If yes, which filter? Gauss 200

Helix angle β	Helix slope deviation $f_{H\beta}$ in µm	Helix form deviation $f_{f\beta}$ in µm	Helix total deviation F_β in µm
0° R	1,64	0,97	2,11
15° l R	2,74	1,92	4,04
15° r R	-0,45	2,60	2,69
30° l R	5,92	3,02	7,04
30° r R	-1,35	3,06	3,59

A2.3 Measurements results of the pitch measurement standard

Pitch No. *	Left flank		Right flank	
	F_p in µm	f_p in µm	F_p in µm	f_p in µm
1	0,00	0,81	0	-2,29
2	-0,76	-0,76	0,7	0,17
3	-0,31	0,45	-0,73	-0,90
4	0,09	0,40	-0,51	0,22
5	-1,03	-1,12	-3,75	-3,24
6	-2,71	-1,68	-4,01	-0,26
7	-3,71	-1,01	-3,95	0,06
8	-3,54	0,18	-3,457	0,49
9	-4,29	-0,75	-3,10	0,35
10	-4,73	-0,44	-5,08	-1,97
11	-4,57	0,15	-5,33	-0,26
12	-5,18	-0,60	-5,23	0,10
13	-4,84	0,33	-3,13	2,10
14	-6,09	-1,25	-2,76	0,37
15	-5,86	0,24	-3,11	-0,36
16	-4,39	1,47	-4,96	-1,85
17	-4,90	-0,51	-4,16	0,80
18	-4,83	0,06	-3,82	0,35
19	-4,40	0,43	-3,55	0,27
20	-4,99	-0,59	-3,32	0,23
21	-5,00	-0,01	-4,20	-0,88
22	-5,86	-0,85	-3,91	0,29
23	-4,28	1,59	-3,40	0,51
24	-3,88	0,40	-2,50	0,87
25	-4,15	-0,28	-2,36	0,15
26	-3,68	0,47	-4,15	-1,79
27	-2,89	0,79	-3,53	0,62
28	-2,15	0,73	-2,54	1,00
29	-2,02	0,13	-1,68	0,85
30	-3,11	-1,09	-0,47	1,22
31	-3,44	-0,32	-0,44	0,03
32	-3,90	-0,47	1,27	1,71
33	-2,78	1,12	1,69	0,41
34	-0,81	1,97	2,29	0,61

Left flank		
	Result	Pitch No.*
Total pitch error F_p	6,18	1 – 34
Maximum F_p	0,09	4
Minimum F_p	-6,09	11
Single pitch error f_p	1,97	34

Right flank		
	Result	Pitch No.*
Total pitch error F_p	7,62	1 – 34
Maximum F_p	2,29	34
Minimum F_p	-5,33	11
Single pitch error f_p	-2.29	1

* the counting of the pitch starts between the last and the first tooth

A3. Uncertainty of measurements

A3.1 Profile measurement standard

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
$f_{H\alpha}$	0,255	0,51
$f_{f\alpha}$	0,255	0,51
F_{α}	0,255	0,51

A3.2 Helix measurement standard

	Combined standard uncertainty u in µm			Expanded measurement uncertainty $U_{95\%}$ in µm		
	0°	15°	30°	0°	15°	30°
$f_{H\beta}$	0,455	0,460	0,485	0,91	0,92	0,97
$f_{f\beta}$	0,450	0,455	0,455	0,90	0,91	0,91
F_{β}	0,455	0,465	0,480	0,91	0,93	0,96

A3.3 Pitch measurement standard

	Combined standard uncertainty u in µm	Expanded measurement uncertainty $U_{95\%}$ in µm
F_p	0,320	0,64
f_p	0,265	0,53