Physikalisch–Technische Bundesanstalt

EURAMET Intercomparison

Involute Gear Artifacts

Technical Protocol

Rev 3

1 Introduction

1.1.1 The metrological equivalence of national measurement standards will be determined by a set of comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.1.2 At its meeting in 2007, the EURAMET TC Length decided to run an intercomparison of involute gear artifacts as regional comparison with non-European involvement. PTB was identified as pilot and organizer.

1.1.3 The procedures outlined in this document cover the technical procedure to be followed during measurement of the artifacts. The procedure follows the guidelines established by the BIPM[1].

[1] T.J. Quinn, Guidelines for key comparisons carried out by Consultative Committees, BIPM, Paris

2 Organization

2.1 Participants

2.1.1 A list of National Metrology Institutes (NMIs) or designated institutes considering participation was compiles in the EURAMET TC.

2.1.2 The participating laboratories shall be able to calibrate:

2.1.3 A involute profile artifact with a base circle diameter of 49,9977 mm in following measurement categories: profile slope deviation $f_{H\alpha}$, profile form deviation $f_{f\alpha}$ and profile total deviation F_{α};

2.1.4 A helix slope artifact with 0°, 15°, 30° and 45° left- and right-hand right flanks and a measurement cylinder diameter of 204 mm in following measurement categories: helix slope deviation $f_{H\beta}$, helix form deviation $f_{f\beta}$ and helix total deviation F_{β};

2.1.5 A pitch artifact with a number of teeth of 37 a diameter of the measurement circle of 148 mm in following measurement categories: total pitch error F_p and single pitch error f_p.

2.1.6 All participants must be able to demonstrate independent traceability to the realization of the meter.

2.1.7 After agreeing on a final version of this protocol, each nominated participant must reconfirm its participation and approval of protocol. If for any of the above technical reasons a nominated laboratory is not able to participate, it must notify the pilot laboratory as soon as possible to reschedule the comparison and, eventually invite other possible participants.

2.1.8 By their declared intention to participate in this comparison, the laboratories accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

2.1.9 Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

2.2 Partner

No.	COUNTRY	CONTACT PERSON / ADDRESS
1	GERMANY (Pilot) PTB	Karin Kniel Department Coordinate Metrology Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany Fon +49-531-592-5388 Fax +49-531-592-695388 Karin.Kniel@ptb.de
2	JAPAN AIST	Sonko Osawa National Metrology Institute of JAPAN, AIST 1-1-1 Umezono Tsukuba Ibaraki, 305-8563, Japan Fon +81-29-861-4368 Sonko.Osawa@aist.go.jp
3	Thailand NIMT	Narin Chanthawong National Institute of Metrology of Thailand 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand narin@nimt.or.th
4	UNITED KINGDOM NPL, University of Newcastle	Rob Frazer National Gear Metrology Laboratory Design Unit, Newcastle University Stephenson Building Claremont Road Newcastle upon Tyne NE1 7RU United Kingdom Fon +44-191-222-6217 R.C.Frazer@ncl.ac.uk
5	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

6	USA NIST	Bruce Cox Oak Ridge Metrology Center Y- 12 National Security Complex P.O. Box 2009 Oak Ridge, TN 37831 USA Fon +1-865-574-1524 coxbl@y12.doe.gov

2.3 Form of comparison

2.3.1 The calibration suitability of the artifacts has been assessed by measurements at PTB prior to the start of the circulation of the artifacts. PTB will act as the pilot laboratory.

2.3.2 In the following section the timetable of the comparison is presented.

2.3.3 Each laboratory will receive the artifacts according to the pre-agreed timetable.

2.3.4 All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 4 weeks of completion of the measurements by each laboratory.

2.3.5 Each laboratory has eight weeks for customs clearance (if applicable), measurement and shipment to the following participant from the moment it is received at customs in his country till the following participant receives it at customs. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the time allocated to it. It guarantees that the standards arrive in the country of the next participant at the beginning of the next 8 week period.

2.3.6 If for some reasons, the measurement facility is not ready, the laboratory has to contact the pilot laboratory immediately and – according to the arrangement made – eventually to send the standards directly to the next participant before finishing the measurements or even without doing any measurements. If possible the laboratory will be sent the artifacts at the end of the comparison.

2.4 Timetable

Obsolete

Part. #	NMI	Country	Period
1	PTB	Germany	before project start
2	AIST	Japan	2008-07-28 – 2008-09-19
3	NIMT	Thailand	2008-09-22 – 2008-11-14
4	NIST	USA	2008-11-17 – 2009-01-09
5	NPL	United Kingdom	2009-01-12 – 2009-03-06
6	NSC	Ukraine	2009-03-09 – 2009-05-01
7	PTB	Germany	2009-05-04 – 2009-06-26

Part. #	NMI	Country	Period
1	PTB	Germany	before project start
2	AIST	Japan	2008-07-28 – 2008-09-19
3	NIMT	Thailand	2008-09-22 – 2009-01-20
4	NIST	USA	2009-01-21 – 2009-03-20
5	NPL	United Kingdom	2009-03-23 – 2009-05-15
6	NSC	Ukraine	2009-05-18 – 2009-07-10
7	PTB	Germany	2009-07-13 – 2009-09-04

Part.-#	NMI	Country	Period
1	PTB	Germany	before project start
2	AIST	Japan	2008-07-28 – 2008-09-19
3	NIMT	Thailand	2008-09-22 – 2009-01-20
4	NIST	USA	2009-01-21 – 2009-04-03
5	NPL	United Kingdom	2009-04-06 – 2009-05-29
6	NSC	Ukraine	2009-06-01 – 2009-07-24
7	PTB	Germany	2009-07-27 – 2009-09-18

New, valid from 21.07.2009

Part.-#	NMI	Country	Period
1	PTB	Germany	before project start
2	AIST	Japan	2008-07-28 – 2008-09-19
3	NIMT	Thailand	2008-09-22 – 2009-01-20
4	NIST	USA	2009-01-21 – 2009-04-03
5	NPL	United Kingdom	2009-04-06 – 2009-05-29
6	NSC	Ukraine	2009-06-01 – 2009-08-20
7	PTB	Germany	2009-07-27 – 2009-09-18

2.5 Handling of Artifacts

2.5.1 Upon reception, the laboratory shall confirm it to the pilot laboratory as well as to the sender laboratory by sending the form of Appendix A1. The artifacts shall be examined immediately upon receipt. The condition of the artifacts shall also be noted in the form.

2.5.2 The artifacts shall only be handled by authorized persons and stored in such a way as to prevent damage.

2.5.3 The artifacts shall be examined before dispatch and any change in condition during the measurement at each laboratory shall be communicated to the pilot laboratory.

2.5.4 Please inform the pilot laboratory and the next laboratory via fax or e-mail when the artifacts are about to be sent to the next recipient.

2.5.5 Before the measurements, the artifacts must be cleaned. Before shipment and, if necessary, after the measurements the artifacts must be greased for corrosion protection. Ensure that the content of the package is complete before shipment. Always use the original packaging.

2.6 Transport of Artifacts

2.6.1 It is of utmost importance that the artifacts be transported in a manner in which they will not be lost, damaged or handled by unauthorized persons.

2.6.2 Packaging for the artifacts has been made suitably robust to protect the artifacts from being deformed or damaged during transit. Notices in the boxes will state handling instructions in case the boxes have to be opened at customs. Notify to the airport personnel that the cases shall be towed on a palette in order to minimize the risk of damage.

2.6.3 The artifacts shall be sent via courier or delivery company. They shall be marked as ‘Fragile’.

2.6.4 The artifacts shall be sent with enough time in advance as to have the following laboratory receive them at the nearest port or airport on the date that their period starts.

2.6.5 Until the return of the artifacts to PTB (April 2009), the artifacts are accompanied by an ATA – Carnet. Although this only needed by non EU participants, its presence shall be checked.

2.6.6 Transportation and insurance to the following participant is each laboratory’s responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges upon receipt as well as for any damages that may have occurred within its country. The overall costs for the organization and for the devices are covered by the organizing pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

3 Description of the Artifacts

3.1 Artifacts

3.1.1 PROFILE ARTIFACT

Profile artifact (Involute artifact), d_b = 49,99770 mm

Explanatory Note:
As an alternative to entering the base circle, gearing parameters may be entered. It must be pointed out here that the gearing parameters must be entered with the accuracy stated in the calibration certificate so as to avoid deviations due to rounding errors.

Gearing parameter: Pressure angle α_0 20°
Helix angle $ß_0$ 0°
Module m_n 2,9559134 mm
Number of teeth z 18

3.1.2 HELIX SLOPE ARTIFACT

0° und 15°, 30°, 45° left- and right-hand, right flanks

Helix slope artifact d = 200 mm, b = 75 mm

Helix angle β	0°	15° l+r	30° l+r	45° l+r
Modul m_t	4.0 mm	4.0 mm	4.0 mm	4.0 mm
Number of teeth z	50	50	50	50
Pressure angle α_n	20°	20°	20°	20°

3.1.3 PITCH ARTIFACT

Pitch artifact z = 37

Gearing parameter: Module m_n 4 mm
Number of teeth z 37
Tip diameter d_a 156 mm
Facewidth b 32 mm
Pressure angle a_n 20°

4 Measurement instructions

4.1 Traceability

Length measurements shall be independently traceable to the latest realization of the *mètre* as set out in the current ”*Mise en Pratique*”. This means that the length unit is 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 shall be traceable to the definition of the length unit through calibrations performed in house. Temperature measurements shall be made using the International Temperature Scale of 1990 (ITS-90).

4.2 Measurands

The below mentioned measurands shall be evaluated according to:

- ISO 21771:2007; Gears -- Cylindrical involute gears and gear pairs -- Concepts and geometry
- VDI/VDE 2612:2000-05 Profile and helix checking of involute cylindrical gears

4.2.1 PROFILE ARTIFACT

Measurands

• 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 left flank profile shall be measured in the centre of the tooth flank. The measurement points shall be distributed equidistant spaced over the length of roll. The stylus sphere shall be close to 8 mm in diameter. The evaluation refers to the following parameters.
Length of roll foot *LMf*: 1 mm
Length of roll heat *LMa*: 18 mm

References

The datum face of the artifact bears the green test device mark. The reference axis of the artifact shall be numerically determined. For this purpose, the reference bands (diameter approx. 50 mm) of the gear artifact shall be probed in the centre. In each of these transversal planes at least 36 points, which are distributed equally spaced over the circumference, shall be recorded. Through the points, a circle shall be fitted in accordance with the least squares method and the centre was defined. The axis of the gear artifact shall be defined from the centres of the two circles. The reference point for the height of the profile measurement shall be determined on top of the tooth, 2 mm from the tip circle in the direction of the reference axis. During the measurement, the temperature shall be amounted to 20°C.

4.2.2 HELIX SLOPE ARTIFACT

Measurands

- 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 slope measurements shall be performed in the centre of the artifact on a measurement cylinder with d_M = 204 mm. The stylus sphere shall be close to 8.0 mm in diameter. The evaluation range is L_{β} = 70 mm (centric on the gear ring).

References

The datum face of the artifact is marked by the engravings. The reference axis of the artifact shall be numerically determined. For this purpose, the two reference cylinders of the gear artifact shall be probed. The measurement points shall be arranged in two end face planes. The end face planes shall be located at a distance of 43 mm from the lateral surface of the cylinders with 30 mm in diameter. In each of these transversal planes at least 36 points, which are distributed equally spaced over the circumference, shall be recorded. Through the points, a circle shall be fitted in accordance with the least squares method. The axis of the gear artifact shall be defined from the centres of the two circles.
During the measurement, the temperature shall be amounted to 20 °C.

4.2.3 PITCH ARTIFACT

Measurands

- Total pitch error F_P in µm (left- and right flank)
- Single pitch error f_P in µm (left- and right flank)

Measurement procedure

The artifact shall be fixed with an internal three-jaw chuck at the inside hollow shaft. The pitch shall be measured in the single-flank facility. The stylus sphere shall be close to 3.0 mm in diameter. The diameter of the measurement circle is *dm* = 148 mm.

References

The reference side of the artifact is marked by the engravings.
The reference axis of the artifact shall be numerically determined. For this purpose, two circles in the boring, one 10 mm from the reference surface (upper side) of the gear standard, the other one 40 mm from it, shall be probed. In each case at least 36 points, which are distributed equally spaced over the circumference, shall be recorded. Through theses points, a circle shall be fitted in accordance with the least squares method and the centre shall be determined. The axis of the gear artifact shall be defined from the centres of the two circles.
During the measurement, the temperature shall be amounted to 20 °C.

4.2.4 TEMPERATURE

Laboratories shall report the temperatures at which the length measurements were made.
Laboratories shall measure the artifacts at a temperature of (20 ± 0,3) °C.

4.3 Measurement instructions

4.3.1. Each laboratory is free to use his own measuring method. However, measurements shall be reported in the object reference coordinate system described in 4.2. Before measurement, the artifacts must be inspected for damage. Special attention shall be paid to the measurement and reference surfaces. Any scratches or other damages have to be documented. Appendix A1 contains a form that shall be filled and sent upon reception quoting the state of the artifacts as received.

4.3.2. Before measurement, the artifacts must be cleaned. The measurement surfaces have to be cleaned with special care individually as well as the reference surfaces.

4.3.3. No other measurements are to be attempted by the participants and the artifacts shall not be used for any purpose other than described in this document. The artifacts may not be given to any party other than the participants in the comparison.

4.3.4. If for any reason a laboratory is not able to make all the measurements of all artifacts, it is still encouraged to report the rest of the results.

5 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. Due to differences of equipment, methods and procedures applied between laboratories, a complete list of uncertainty sources to be taken in account may not be drawn.

6 Reporting of results

Results shall be communicated to the pilot laboratory as soon as possible and within four weeks after the end of the corresponding laboratory allocated time period.

Appendix A2 shall be filled quoting the state of the measurement surfaces of the artifacts; describing the measurement instrument, measuring technique, traceability chain, temperature variation and temperature measurement method.

Appendix A3 shall be filled with the measurement results.

Finally the uncertainty must be stated by filling the form of Appendix A4. The uncertainty shall be stated as combined standard uncertainty with no coverage factor applied at the end.

The three forms shall be filled and sent by mail service as well as by electronic mail to the pilot laboratory. The later means is to allow the pilot laboratory to collect the results as soon as possible. **In any case, the signed report must also be sent in paper form.** In case of any differences between the two messages, the paper forms are the ones considered to be valid.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyze the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in the BIPM Key Comparison Guidelines will be followed.

A1. Receipt confirmation

FAX

To: **Dr. Karin Kniel**
PTB
Department "Coordinate Metrology"
Bundesallee 100
38116 Braunschweig

Fax: +49-531-592-695388 **Tel.: +49-531-592-5388**

e-mail: karin.kniel@ptb.de

From:

We confirm having received the standards of the EURAMET *comparison on gear artifacts* .

After visual inspection

- no damage has been noticed;
- the following damage must be reported:
  .....
  .....
  .....
  .....

A2. Measurement results

A2.1 Inspection of the measurement surfaces

Notes:

A2.2 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.)

Traceability path

Description of measuring technique

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

A3. Measurement results

A3.1 Measurements results of the profile artefact

- Number of data points

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

Profile slope deviation $f_{H\alpha}$ in µm	
Profile form deviation $f_{f\alpha}$ in µm	
Profile total deviation F_{α} in µm	

A3.2 Measurements results of the helix slope artefact

- Number of data points

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

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			
15° l R			
15° r R			
30° l R			
30° r R			
45° l R			
45° r R			

A3.3 Measurements results of the pitch artifact

Pitch No. *	Left flank		Right flank	
	F_P in µm	f_P in µm	F_P in µm	f_P in µm
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				

Left flank		
	Result	**Pitch No.***
Total pitch error F_P		
Maximum F_P		
Minimum F_P		
Single pitch error f_P		

Right flank		
	Result	**Pitch No.***
Total pitch error F_P		
Maximum F_P		
Minimum F_P		
Single pitch error f_P		

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

A4. Uncertainty of measurements

A4.1 Profile artifact

	Combined standard uncertainty u_c in µm
$f_{H\alpha}$	
$f_{f\alpha}$	
F_{α}	

A4.2 Helix slope artifact

	Combined standard uncertainty u_c in µm
$f_{H\beta}$	
$f_{f\beta}$	
F_{β}	

A4.3 Pitch artifact

	Combined standard uncertainty u_c in µm
F_p	
f_p	