Metrology Institute of the Republic of
Slovenia

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EUROMET Key Comparison, EUROMET.L-K7

(EUROMET Project 882)

Calibration of line scales

Final Report

Contents

1 Introduction

1.1 At its meeting in October 2005, the TC for Length identified several EUROMET key comparisons in the field of dimensional metrology. In particular, it decided that a key comparison on line standards shall be carried out. This comparison follows the Nano3 comparison (WGDM-7 preliminary comparison on nanometrology).

1.2 Due to the large number of the participants, it has been decided to have 2 groups in the project. The participants for the 2 groups were chosen in accordance with their geographical position (in order to minimize travel times and expenses for the transportation of the standards). Linking laboratories between the groups were chosen among participants in Nano3 project.

1.3 The standards for the comparison were defined at the TCL meeting in October 2005. It was decided that only one line scale of 100 mm with line distance of 0,1 mm would be measured. The 2 groups have got equal standards offered (and produced) by NPL.

1.4 The pilot laboratory for both loops of the comparison was Metrology Istitute of the Republic of Slovenia (MIRS/UM-FS). In addition, METAS (CH) and NPL (UK) were appointed as linking laboratories between the 2 groups.

1.5 A goal of the EUROMET key comparisons for topics in dimensional metrology is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA) [BIPM, 1999]. Therefore, participants in this comparison agreed to use the same apparatus and methods as routinely applied to client artefacts.

2 Organisation

2.1 Participants

The project began with 31 participants – 22 from EURAMET, 4 from SIM (3 NORAMET, 1 SURAMET), 2 from COOMET and 3 from APMP. Due to the large number of participants they were divided into two groups (Table 1 and Table 2). During the project, Norwegian Metrology Service (JV) and FPS Economy - DG Quality and Safety Metrology Division (SMD) from Belgium cancel their participation due to problems with equipment. In year 2006 Thailand sent a request to participate and the request was approved at the TCL meeting in October 2006. Thailand was placed in group 2.

Table 1: Participants in the group 1

Laboratory	Address	Contact person/tel/fax/e-mail
BEV	Bundesamt für Eich – und Vermessungswesen Arltgasse 35 AT-1160 Wien Austria	Michael Matus +43 1 49 110 540 +43 1 49 20 875 michael.matus@bev.gv.at
DZM-FSB	University of Zagreb Faculty of Mechanical Eng. and Naval Architecture Ivana Lucica 5 HR-10000 Zagreb Croatia	Vedran Mudronja +385 1 616 83 35 +385 1 616 85 99 vedran.mudronja@fsb.hr
GUM	Central Office of Measures ul. Elektoralna 2 PL-00950 Warszawa Poland	Zbigniew Ramotowski +48 22 581 9543 +48 22 620 8378 length@gum.gov.pl
INM	National Institute of Metrology Sos. Vitan-Barzesti 11 Sector 4 Bucharesti 042122-RO Romania	Alexandru Duta +40 21 334 55 20 +40 21 334 55 33 alexandru.duta@inm.ro
JV	Norwegian Metrology Service Fetvejen 99 NO-2007 Kjeller Norway	Helge Karlsson +47 64 84 84 84 +47 64 84 84 85 helge.karlsson@justervesenet.no
LNMC	Latvian National Metrology Centre 157, K. Valdemara Str. LV-1013 Riga Latvia	Edite Turka +371 7 362 086 +371 7 362 805 edite.turka@lnmc.lv
METAS	Bundesamt für Metrologie Lindenweg 50 CH-3084 Wabern Switzerland	Felix Meli +41 31 32 33 346 +41 31 32 33 210 felix.meli@metas.ch
MIKES	Centre for Metrology and Accreditation Tekniikantie 1 P.O. Box 9 FI-02151 Espoo Finland	Antti Lassila +358 10 6054 413 +358 10 6054 499 antti.lassila@mikes.fi
MIRS	University of Maribor Faculty of Mechancal Engineering Smetanova 17 SI-2000 Maribor Slovenia	Bojan Acko +386 2 220 7581 +386 2 220 7990 bojan.acko@uni-mb.si

Laboratory	Address	Contact person/tel/fax/e-mail
NCM	National Centre of Metrology 52B G.M. Dimitrov Blvd. BG-1040 Sofia Bulgaria	Veselin Gavalyugov +359 2 97 02 760 +359 2 97 02 719 v.gavalyugov@bim.government.bg
NML	National Metrology Laboratory Enterprice Ireland Campus Glasnevin IE-Dublin 9 Ireland	Howard McQuoid +353 1 808 2657 +353 1 808 2026 howard.mcquoid@enterprise-ireland.com
NPL	National Physical Laboratory Hampton Road Teddington, Middlesex TW 11 OLW United Kingdom	Michael McCarthy +44 20 8943 6655 +44 20 8614 0453 michael.mccarthy@npl.co.uk
NSCIM	National Scientific Center "Institute of metrology" Myronosytskaja st., 42, Kharkov, 61002, Ukraine	Valentin Solovyov +380 57 704-98-77 +380 57 700-34-47 solovyov@metrology.kharkov.ua
OMH	National Office of Measures Németvölgyi út 37-39 H-1124 Budapest XII. Hungary	Edit Banreti +36 1 458 59 97 +36 1 458 59 27 e.banreti@omh.hu
PTB	Physikalisch-Technische Bundesanstalt Department 5.2, Length and Angle Metrology Bundesallee 100 DE-38116 Braunschweig Germany	Harald Bosse +49 531 5925200 +49 531 5925205 harald.bosse@ptb.de
SMU	Slovak Institute of Metrology Karloveská 63 SK-842 55 Bratislava Slovakia	Roman Fira +421 2 602 94 321 +421 2 654 29 592 fira@smu.gov.sk
ZMDM	Bureau of Measures and Precious Metals Mike Alasa 14 YU - 11 000 Beograd Serbia	Slobodan Zelenika +381 11 20 24 418 +381 11 21 81 668 zelenika@szmdm.sv.gov.yu

Changes in group 1 during the project:

JV	Norwegian Metrology Service Fetvejen 99 NO-2007 Kjeller Norway	Participation cancelled
CMI	Czech Metrology Institute V Botanice 4 CZ 150 72 Praha 5 Czech Republic	After measuring in Group 2 (October 06) they improved measurement capabilities. New measurements in Group 1 were approved by Euromet TCL. Results in group 2 were cancelled.

Table 2: Participants in the group 2

Laboratory	Address	Contact person/tel/fax/e-mail
CEM	Centro Espanol de Metrologia Alfar, 2 ES-28760 Tres Cantos (Madrid) Spain	Emilio Prieto +34 91 807 47 16 +34 91 807 48 07/809 eprieto@mfom.es
CENAM	CENAM-Centro Nacional de Metrologia Division de Metrologia Dimensional Km 4,5 Carretera a Los Cues, El Marqués 76241 Queretaro Mexico	Carlos Colin Miguel Viliesid Alonso +52 442 211 05 74 +52 442 211 05 77 ccolin@cenam.mx mviliesi@cenam.mx
CMI	Czech Metrology Institute V Botanice 4 CZ 150 72 Praha 5 Czech Republic	Petr Balling +420 257 288 326 +420 257 328 077 pballing@cmi.cz
EIM	Hellenic Institute of Metrology Industrial Area of Thessaloniki Block 45 GR-57 022 Sindos Thessaloniki Greece	Christos Bandis +30 2310 56 99 99 +30 2310 56 99 96 bandis@eim.org.gr
INMETRO	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial Laboratório de Metrologia Dimensional - Lamin - Prédio 3 Av. Nossa Senhora das Graças, 50 Xerém - 25250-020 Duque de Caxias Rio de Janeiro, Brazil	João Antônio Pires Alves +55 21 2679 9107 +55 21 2679 1505 jaalves@inmetro.gov.br
INRIM	Instituto Nazionale di Ricerca Metrologica (INRIM) Strada delle Cacce, 73 IT-10135 Torino Italy	Gian Bartolo Picotto +39 011 3977 469/473 +39 011 3977 459 g.picotto@inrim.it
METAS	Bundesamt für Metrologie Lindenweg 50 CH-3084 Wabern Switzerland	Felix Meli +41 31 32 33 346 +41 31 32 33 210 felix.meli@metas.ch
NIM	National Institute of Metrology Length Division Beisanhuandonglu 18 100013 Beijing China	Sitian Gao Tel: +86 10 84251574 Fax: +86 10 64218703 gaost@nim.ac.cn
NIST	National Institute of Standards and Technology Manufacturing Engineering Laboratory Precision Engineering Division Nano-Scale Metrology Group 100 Bureau Drive, Stop 8212 Bldg. 220, Rm A117 Gaithersburg, Maryland 20899-8212 USA	William B. Penzes +301 975 3477 +301 869 0822 william.penzes@nist.gov
NMi-VSL BV	NMi Van Swinden Laboratorium B.V. Thijsseweg 11 P.O. Box 654 NL-2600 AR Delft The Netherlands	Gerard Kotte +31 15 269 16 01 +31 15 261 29 71 gkotte@nmi.nl

Laboratory	Address	Contact person/tel/fax/e-mail
NPL	National Physical Laboratory Hampton Road Teddington, Middlesex TW 11 OLW United Kingdom	Michael McCarthy +44 20 8943 6655 +44 20 8614 0453 michael.mccarthy@npl.co.uk
NPLI	National Physical Laboratory Physico-Mechanical Standards Length & Dimension Standards New Delhi -110012 India	R.P. Singhal +91-11-25732965 +91-11-25732965 singhal@mail.nplindia.ernet.in
NRC	Institute for National Measurement Standards (INMS) National Research Council Canada (NRC) 1200 Montreal Road Ottawa, ON, Canada K1A OR6	Jim Pekelsky +613 993 7578 +613 952 1394 jim.pekelsky@nrc.ca
SMD	FPS Economy DG Quality and Safety Metrology Division (SMD) Boulevard du Roi Albert II, 16 BE 1000 Brussels Belgium	Hugo Piree +32 2 277 7610 +32 2 277 5405 hugo.piree@mineco.fgov.be
A*Star - NMC	National Metrology Centre A*Star 1 Science Park Drive Singapore 118221	Siew Leng Tan +65 6279 1938 +65 6279 1994 tan_siew_leng@nmc.a-star.edu.sg
VNIIM	VNIIM - All-Russian Institute for Metrology 19 Moscovsky prosp. RU - 198005 St. Petersburg Russia	Konstantin V.Chekirda +7 812 323 9664 +7 812 713 0114 K.V.Chekirda@vniim.ru

Changes in group 2 during the project:

SMD	FPS Economy DG Quality and Safety Metrology Division (SMD) Boulevard du Roi Albert II, 16 BE 1000 Brussels Belgium	Participation cancelled
CMI	Czech Metrology Institute V Botanice 4 CZ 150 72 Praha 5 Czech Republic	Results in group 2 were cancelled New measurements in group 1
NIMT	National Institute of Metrology Thailand Department of Dimensional Metrology 3/5 Moo 3, Klong 5, Klongluang, Pathumthani 12120 Thailand	NEW PARTICIPANT (approved at Euromet TCL meeting 2006) Contact: Anusorn Tonmueanwai +662 577 5100 ext 1216 +662 577 3658 / 662 5773659 anusorn@nimt.or.th

2.2 Linking laboratories

Linking laboratories between the two groups were METAS – CH and NPL – UK. The linking laboratories measured both artefacts in the beginning and at the end of the loop. Their measurements were also used for evaluating the stability of the artefacts.

2.3 Form of comparison

2.3.1 The comparison was performed in a 'circular' form in both groups. The artefact was circulated within a group of laboratories. Before sending it to the non-EU participants (in the end of each loop), they were returned to the pilot laboratory in order to prepare the necessary ATA Carnet and other forms for the custom formalities.

2.3.2 All results were communicated directly to the pilot laboratory.

2.4 Circulation of the artefact and performance of the measurements

2.4.1 The participating laboratories were asked to specify a preferred timetable slot for their measurements of the artefact - the timetables given below have been drawn up taking these preferences into account.

Table 3: Time schedule for the group 1

Laboratory	Country	Date
MIRS	Slovenia	July 2006
METAS	Switzerland	August 2006
NPL	United kingdom	September 2006
OMH	Hungary	October 2006
BEV	Austria	November 2006
SMU	Slovakia	December 2006
PTB	Germany	January 2007
GUM	Poland	February 2007
MIKES	Finland	March 2007
JV	Norway	April 2007
LNMC	Latvia	May 2007
NML	Ireland	June 2007
NCM	Bulgaria	July 2007
INM	Romania	August 2007
ZMDM	Serbia	September 2007
DZM-FSB	Croatia	October 2007
NSCIM	Ukraine	November 2007
METAS	Switzerland	December 2007
NPL	United kingdom	January 2008

Table 4: Time schedule for the group 2

Laboratory	Country	Date
METAS	Switzerland	August 2006
NPL	United kingdom	September 2006
CMI	Czech Republic	October 2006
EIM	Greece	November 2006
INRIM	Italy	December 2006
NMi-VSL	Netherlands	January 2007
CEM	Spain	February 2007
SMD	Belgium	March 2007
INMETRO	Brazil	April 2007
CENAM	Mexico	May 2007
NIST	USA	June 2007
NRC	Canada	July 2007
A*Star–NMC	Singapore	August 2007
NIM	China	September 2007
NPLI	India	October 2007
NPL	United kingdom	November 2007
METAS	Switzerland	December 2007
VNIIM	Russia	January 2008

2.4.2 Each laboratory had one month for calibration and transportation. With its confirmation to participate, each laboratory has confirmed that it was capable to perform the measurements in the time allocated to it. In this way it was assured, that the artefact arrived in the country of the next participant at the beginning of the next month. However, due to many customs problems (ATA not stamped, ATA lost, substitutional ATA, special arrangements – temporary imports for countries without ATA agreement, …), cancellation of participation, new laboratory, additional measurement in another group, some measurements were not performed in the original time schedule. Changes are indicated in Table 5 and 6.

Table 5: Changes in measurement schedule in group 1

Laboratory	Country	Date
ZMDM	Serbia	October 2007
DZM-FSB	Croatia	December 2007
NSCIM	Ukraine	January 2007
CMI	Czech Republic	March 2008
METAS	Switzerland	July 2008
NPL	United kingdom	June 2008

Table 6: Changes in measurement schedule in group 2

Laboratory	Country	Date
INMETRO	Brazil	May 2007
CENAM	Mexico	June 2007
NIST	USA	July – August 2007
NRC	Canada	July 2008
A*Star–NMC	Singapore	August – September 2007
NIM	China	September – October 2007
NPLI	India	Oct 2007 – Feb.2008
NIMT	Thailand	March – April 2008
NPL	United kingdom	September 2008
METAS	Switzerland	June 2008
VNIIM	Russia	December 2008

2.5 Transport of the artefacts

Transport of the artefacts was critical in some cases outside Europe. In most cases fast courier services were used. The ATA carnet, which was used for the majority of laboratories outside EU, was mostly handled correctly. Sometimes it was not stamped correctly and once it was lost in Asia. But a substitutional ATA was issued and the problem was successfully solved. Special customs arrangements (temporary import) were necessary for some countries.

Packaging for the artefact was robust to protect the artefacts from being deformed or damaged during transit. The artefact was in an original NPL wooden box, which was put into a robust transport box (See Fig. 1). The outer transport box was wrapped in a cardboard box, which was replaced each time when it was worn out.

Fig. 1: Scale containers

3 The artefact

3.1 Description of the artefact

At the Euromet TCL meeting in October 2005 in Bucharest it has been decided to measure a 100 mm quarz scale with 0.1 mm pitch. The artefact has been produced by NPL. Its basic purpose is to serve as a standard in precise industrial calibrations. The artefact is shown in Fig. 2.

Fig. 2: NPL line scale

The width of the scale lines is approx. 10 µm. The scale is provided by two parallel horizontal lines at the beginning and at the end of the scale. The distance between those 2 lines is approx. 50 µm. Some details of the scale can be seen in Fig. 3.

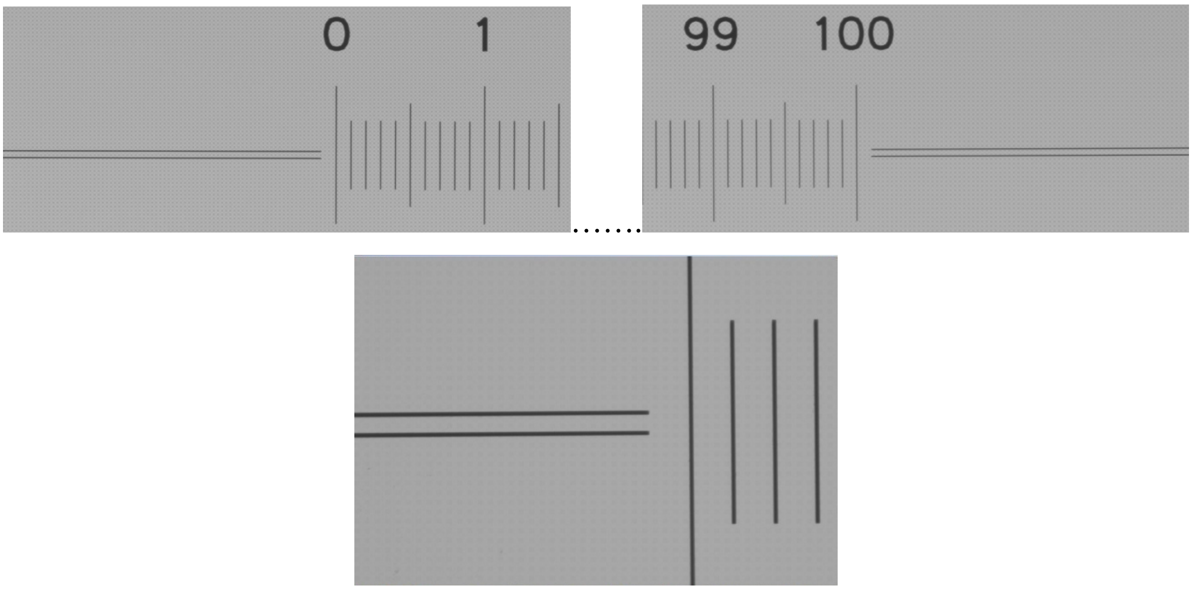

Fig. 3: Details of the scale

Equal artefacts were used in both groups. The artefact for group 1 was marked with engraved letter “A” and the artefact for group 2 with “B”. The boxes were marked in the same manner with stickers.

Dimensions of the artefact are presented in Fig. 4.

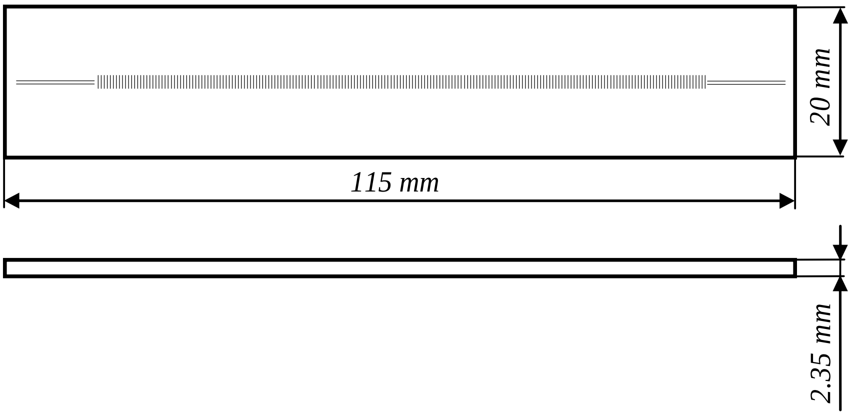

Fig. 4: Dimensions of the artefact

3.2 Fixing the artefact

The artefact was shipped without any special mounting fixtures. It was recommended to support the measurement objects at the Airy points (distance of x = 0.2113·L from both ends), held only by their gravity forces. It was not allowed to use any type of glue or wax for mounting the scale. If additional clamping of the scale was required during measurement, e.g. because of a fast moving carriage, it was recommended to lightly pinch the scale on the sides at one of the Airy support points. If other support or clamping conditions were applied during measurement, it was the responsibility of the participant to refer his results to the Airy point support conditions.

4 Measurement instructions

4.1 Traceability

4.1.1 Length measurements should be traceable to the latest realisation of the metre as set out in the current “*Mise en Pratique*”.

4.1.2 Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

4.2 Measurand

Measurand was the distance between the centre line position of the reference line (position “0”) and the centre line position of the measured line (Fig. 5). To increase comparability of the results, all measurements were performed over the section between the two horizontal lines (at the beginning and at the end of the scale) with a width of approx. 50 µm. That is, it had to be tried to apply an effective slit height or CCD image window **height of 50 µm** for the analysis of measurements. If the effective height could not be set exactly to 50 µm, a value close to it should have been chosen.

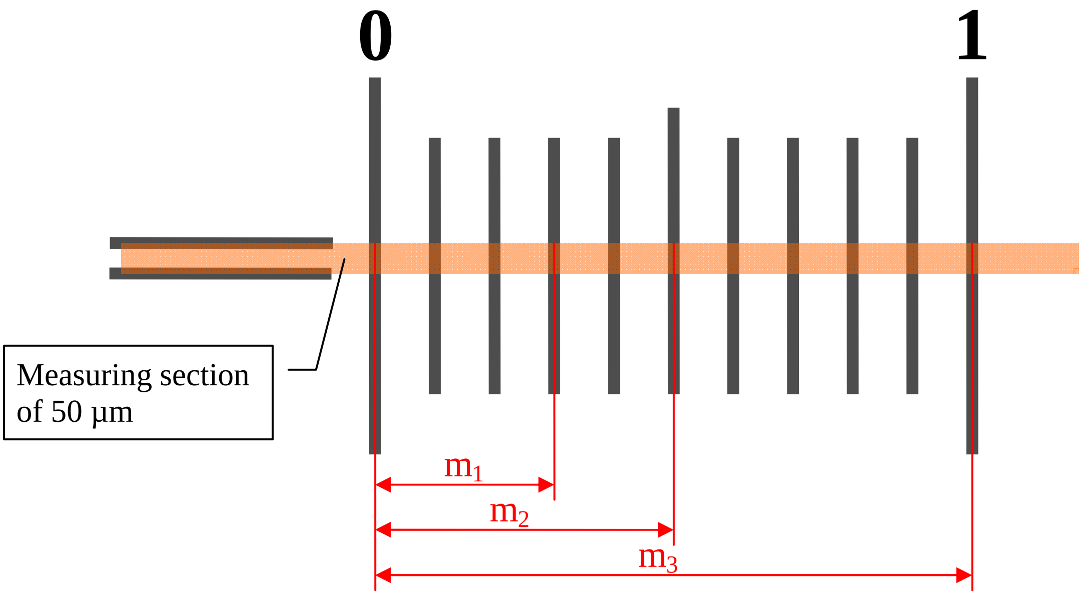

Fig. 5: Measurand (m_1, m_2, m_3) and measuring section

Table 7: The lines (distances) that were measured:

Nominal lengths in mm									
0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5	10	15	20	25	30	35	40	45	50
55	60	65	70	75	80	85	90	95	100

Measurement conditions:

The positions of the lines had to be determined as the **centre line positions**[1] of every line, while the scale was lying on the Airy points (see 3.2). The participants were asked to describe the way the position of the line was determined.

For alignment purposes of the graduation lines the upper horizontal lines at the beginning and at the end of the scale should be used.

The measured values had to be referred to the following reference conditions:

- temperature of 20 °C (ITS-90),
- pressure of 1013,25 hPa (1013,25 mbar).

If necessary, corrections had to be applied based upon the following parameters:

Quartz:

- Thermal expansion coefficient: .... $\alpha = 5 \cdot 10^{-7}\ K^{-1}$
- Length compressibility: .... $\kappa = - 8.9 \cdot 10^{-7}\ bar^{-1}$

4.3 Measurement instructions

4.3.1 The calibration had to be carried out as for a normal customer. The participants were free to choose their own method of measurement. However, under the assumption that the value of the measurand is a true property of the material measure of length, only one result for a measurand had to be given irrespective of the number of different measurement methods used. For each method applied, a complete description of the method had to be given. A detailed estimation of the measurement uncertainty according to the *ISO Guide to the Expression of Uncertainty in Measurement (GUM)* had to be supplied.

4.3.2 The measurements had to be reported for measuring conditions, given in 4.2.

4.3.3 Before calibration, the scale had to be inspected for damages. Any scratches, dirty spots or other damages had to be documented

4.3.4 The measurement results (appropriately corrected to the reference conditions) had to be reported using forms, given in the protocol.

4.4 Measurement uncertainty

The uncertainty of measurement had to be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. In order to achieve a better comparability, some possible influence parameters and notations were given. The participants were encouraged to use all known and significant influence parameters for their applied methods. The following list could have been used as an indication of possible influence parameters:

Possible contributions from **line position sensing** technique:

δ_{Eres} Resolution of edge detection

s_E Repeatability of edge detection

[1] The key comparison guideline states, that the methods usually applied by the participants for calibrations should also be used within the comparison. Because different line center extraction algorithms will normally be used by the participants, it is essential that the different procedures are well described and that edge detection influences are accounted for in the uncertainty estimation. A possible edge detection algorithm e.g. is the arithmetic mean of left and right edge positions if those are explicitly measured (e.g. at 50% threshold) or the centroid of 2D image intensity data.

δ_{Edef} Edge geometry influence (roughness, parallelism)

δ_{lpos} Influence of adjustment of measurement line

δ_{lwin} Influence of adjustment of measurement window or slit length

δ_{Efoc} Influence of focal length variation

$\delta_{E\lambda}$ Influence of detection light wavelength

δ_{Epol} Influence of detection light polarization

δ_{Ecoh} Influence of detection light coherence

Mag Microscope magnification (or other position deviation sensing device)

δ_{Enon} Nonlinearities of position sensing technique

δ_{Ealig} Microscope axis alignment

δ_{Ealg} Influence of line edge detection algorithm, possible asymmetry of line profiles, line shape

δ_{Erev} Influence of measurement in reversed orientation

Possible contributions from interferometric **displacement measurement** technique:

λ_o vacuum wavelength of light source used for displacement measurement

n_{air} Index of refraction of air[2]

t_{air} Air temperature

p_{air} Air pressure

RH_{air} Air humidity

c_{CO2} Air CO_2 concentration

δl_{Res} Interferometer resolution

δl_{NL} Interferometer nonlinearity (polarisation mixing, etc.)

δl_{DP} Interferometer dead path influences (temperature variation, etc.)

δl_{MP} Variation of measurement path in one orientation (normal, meander, random, ..)

δl_{Drift} Drift influence (forward, backward measurement)

δl_{Rev} Influence of measurement in reversed orientation

δl_{Ai} Errors due to Abbe offsets and pitch and yaw of translation stages

δl_{Si} Errors of scale alignment

δl_{Ii} Cosine errors of interferometer alignment

Possible contributions from **scale properties**:

$\alpha_{Z,\,Cr}$ Linear coefficient of thermal expansion of scale material

Δt_s = (t_s - 20) is the difference of the scale temperature t_s in °C during the measurement from the reference temperature of 20 °C

$\kappa_{Z,\,Cr}$ Linear coefficient of compressibility of scale material

δh Flatness deviation of scale graduation surface

δ_{supp} Influence of support conditions

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[2] If the index of refraction is determined by the parameter method according to Edlen, the updated version of the formula should be applied as published in: G. Bönsch, E. Potulski, Metrologia, 1998, **35**, 133-139. The estimated combined standard uncertainty of the quoted formula itself is $1*10^{-8}$.

The deviations dL from nominal length had to be measured and expressed as a function of input quantities x_i

$$dL = f(x_i)\,, \tag{1}$$

The combined standard uncertainty $u_c(dl)$ is the quadratic sum of the standard uncertainties of the input quantities $u(x_i)$ each weighted by a sensitivity coefficient c_i

$$u_c^{\,2}(dL) = \sum_i c_i^{\,2} u^2(x_i), \quad \text{with } c_i = \frac{\partial dL}{\partial x_i}. \tag{2}$$

The participants were required to report their measurement uncertainty budget in a prepared table (in Appendix A.2 of the technical protocol) with the format according to the scheme below. "Distrib." is the type of distribution of the input quantity (N=normal, R=rectangular, T=triangular, etc.), ν_i is the number of degrees of freedom of $u(x_i)$.

Example scheme:

Input quantity x_i	Distrib.	$u(x_i)$	ν_i	$c_i = \partial dL / \partial x_i$	$u_i\,(dL)$ / nm
Edge detection reproduc. s_E	N	3 nm	10	1	3
Cosine error scale alignment	R	140 µrad	>100	-	$10^{-8}\,L$
...	...	...	...	...	...

5 Measurement equipment and methods used by the participants

Detailed information on the equipment and method used by the participants is in Appendix B.2. Short summary is presented in Table 8.

Table 8: Overview of instrumentation used by the participants

Laboratory	Measuring instrument	Line detection
MIRS	Zeiss ULM 01-600 C 1D measurement machine by using laser interferometer HP 5528A, fixed microscope, moving scale, hand driven	CCD microscope, in-house software
BEV	SIP 3002 length measuring machine with a standard HP 5529A laser interferometer; fixed scale, moving microscope, hand driven	Incident light CCD-microscope; two parallel reference lines
CMI	Interferometric comparator IK-1 (CMI design), fixed microscope, moving scale; motor driven	CCD microscope; in-house software
DZM-FSB	500 mm 1D machine, in-house design and construction, Renishaw ML 10 laser interferometer, fixed microscope, moving scale, hand driven	CCD microscope, in-house software
GUM	1000 mm 1D SIP measuring bench, laser interferometer HP-5528A, fixed microscope, moving scale, motor driven + precision piezo-electric actuator	CCD-microscope; two parallel reference lines
INM	Longitudinal comparator, He – Ne frequency stabilized laser interferometer, fixed microscope, moving scale, motor driven	Optical microscope
LNMC	Horizontal comparator IZA-7, longitudinal comparison, fixed scale, hand driven	2 microscopes
METAS	2D photomask measuring system 400 mm x 300 mm, differential two axis plane mirror interferometer (HP), fixed microscope, moving scale, motor driven, fully automated	CCD microscope, motorised focusing, in-house software
MIKES	MIKES‘ line scale interferometer, Michelson interferometer utilising a calibrated 633 nm Zeeman-stabilised He-Ne laser, dynamic method, moving microscope, motor driven	CCD microscope, synchronous data sampling
NCM	Comparator, HP 5529A laser interferometer, fixed scale, moving microscope, hand driven	Photoelectric microscope
NML	SIP horizontal measuring machine, Agilent 5519A laser, fixed microscope, moving scale, hand driven	Optical microscope

Laboratory	Measuring instrument	Line detection
NPL	NPL 400mm range air-bearing stage (interferometrically monitored), two co-linear independent laser interferometers, (NPL differential Jamin type, HP Michelson), fixed microscope, moving scale (different conditions in 2006 and 2008), motor driven	NPL NanoVision image processing system
NSCIM	Horizontal comparator with Michelson dynamic laser interferometer, primary standard DETU 01-03-98, fixed scale, moving microscope, hand driven	Photoelectric microscope (PEM)
OMH	3 m Zeiss universal length measuring machine, HP 5528 laser interferometer, hand driven	CCD microscope, reference screen lines
PTB	PTB Nanometer Comparator, vacuum interferometer (iodine-stabilized, frequency doubled Nd:YAG laser, fixed microscope, moving scale, motor driven	PTB optical microscope with CCD camera, in-house software
SMU	1-D machine Abbe Zeiss (range up to 200 mm), laser interferometer HP 5529B, fixed microscope, moving scale, hand driven	Optical microscope
ZMDM	Zeiss ULM 3000 1-D measuring machine, laser interferometer HP 5526 A, fixed scale, moving microscope, hand driven	Zeiss optical microscope
CEM	Custom-built length comparator CEM-TEK 1200, laser-interferometer (Stabilized Laser Source HP 5517C)	In-house software
CENAM	Optical microscope brand Leitz Libra 200, moving scale, hand driven	CCD microscope, manual edge observation, Micro/Measure Microscope Software
EIM	Leitz universal measuring microscope, laser interferometer Renishaw, moving scale, hand driven	CCD microscope, analysis of digital images
INMETRO	Optical CMM SIP Trioptic, laser interferometer, fixed microscope, moving scale, hand driven	CCD microscope
INRIM	Moore Measuring Machine, laser interferometer HP 5518 fixed microscope, moving scale, motor driven	CCD microscope, in-house software
NIM	NIM comparator, , He-Ne laser interferometer	Optical-electronic microscope dual slit line position detection
NIST	N1ST Line Scale lnterferometer (LSI) - heterodyne interferometer, He-Ne laser, fixed microscope, moving scale, motor driven	Scanning electro-optical line detector, in-house software
NMi-VSL BV	SIP 400 measuring machine, laser interferometer HP, fixed microscope, moving scale, hand driven	CCD microscope, in-house software

Laboratory	Measuring instrument	Line detection
NPLI	Universal measuring machine SIP UMM – MUL -214 B, heterodyne laser interferometer HP 5529A, fixed microscope moving scale, hand driven	Optical microscope
NRC	NRC 4-metre Line Scale Comparator, HP heterodyne laser interferometer, fixed scale, moving microscope, motor driven	CCD microscope, in-house software
A*Star - NMC	Laser line width measurement system (base with two working stages, motor drives, He-Ne laser interferometer), fixed microscope moving scale, motor driven	Photoelectric microscope with single slit
NIMT	Line scale interferometer (stabilized He-Ne laser, fixed scale, moving edge sensor, motor (?) driven	Edge sensor using triple slits system
VNIIM	VNIIM comparator (carriage, laser polarization interferometer, refractometer) fixed scale, moving microscope, motor driven, measurements in dynamic mode	Microscope with laser diodes and photodiode

6 Stability of the standards

The standards used for this comparison were made of quartz with expected good long term stability. However, no historical data were available, since the standards were new. The material properties (chapter 4) were not exactly determined, the values were obtained from general knowledge about the used material.

In order to check the long-term stability, measurements of two linking laboratories (METAS and NPL) were performed in the beginning of the project (year 2006) and close to the end of the project (2008).

The stability checks comprised the total length change during 2 years, as well as possible line centre shifts due to damages and dirtiness of single lines.

6.1 Stability of the total line scale length

Stability of the total line scale length (over 100 mm) is demonstrated in Figures 6 (Scale “A”, Group 1) and 7 (Scale “B”, Group 2). Deviations from nominal length, measured by the linking laboratories in years 2006 and 2008 are represented together with the standard uncertainties.

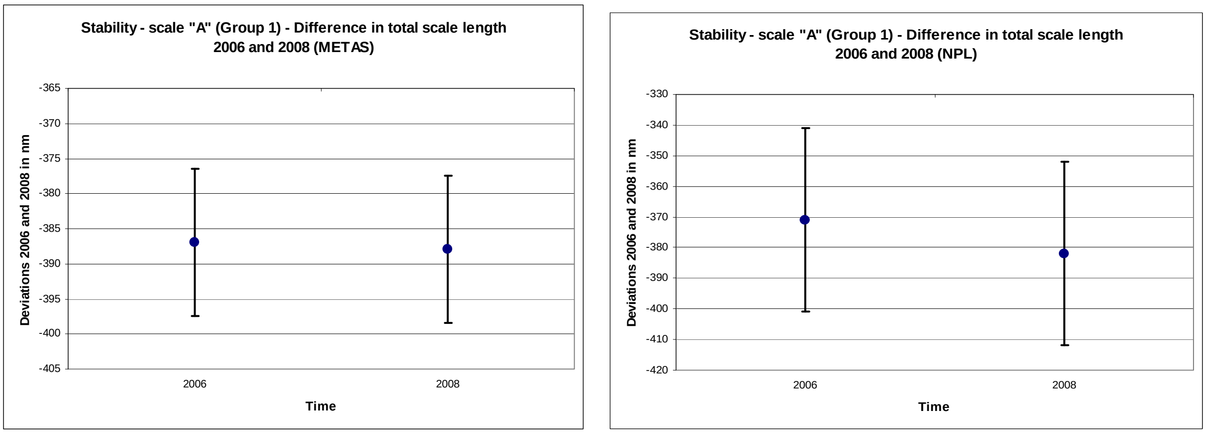


Fig. 6: Measured deviations of the scale “A” in years 2006 and 2008

The result for scale A in Fig. 6 shows a slight drift in negative direction, which is however much smaller than the standard uncertainties of both laboratories. Therefore, no drift correction was applied to the measurement values.

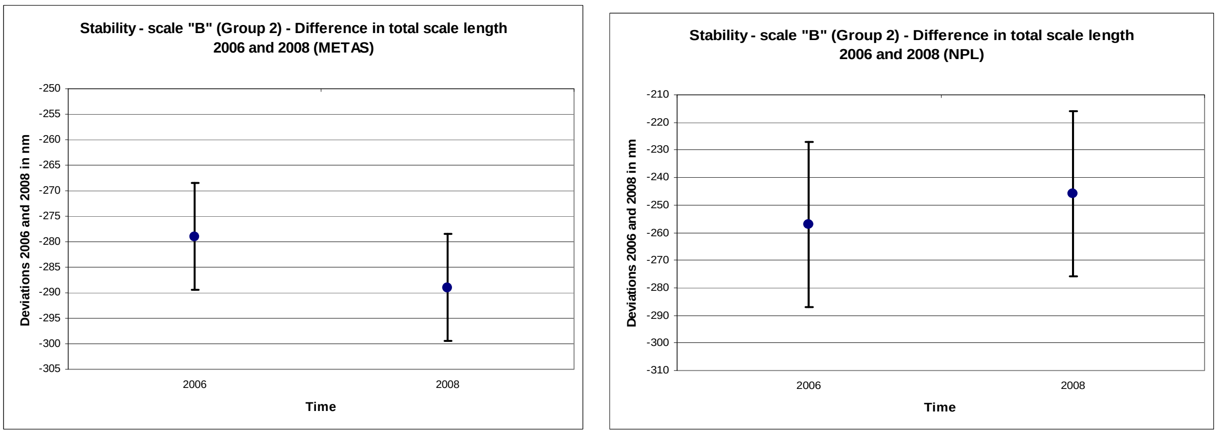


Fig. 7: Measured deviations of the scale “B” in years 2006 and 2008

The result for scale B in Fig. 7 shows drifts in different directions. Because no systematic drift was identified, no corrections were applied to the measurement values to compensate for drift.

6.2 Stability of single line centres

The participating laboratories were instructed how to clean the scale before measurement and to report possible damages. The following damages and dirt spots were reported:

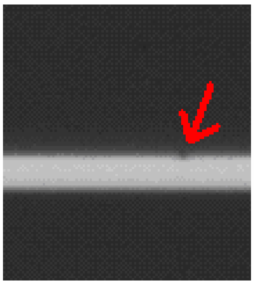
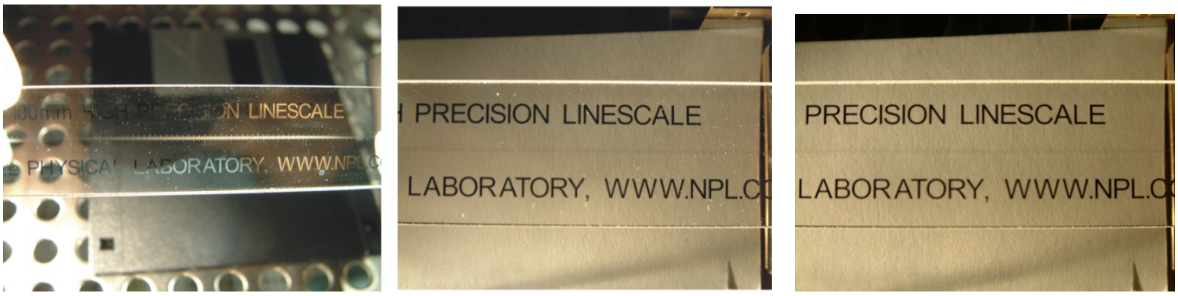
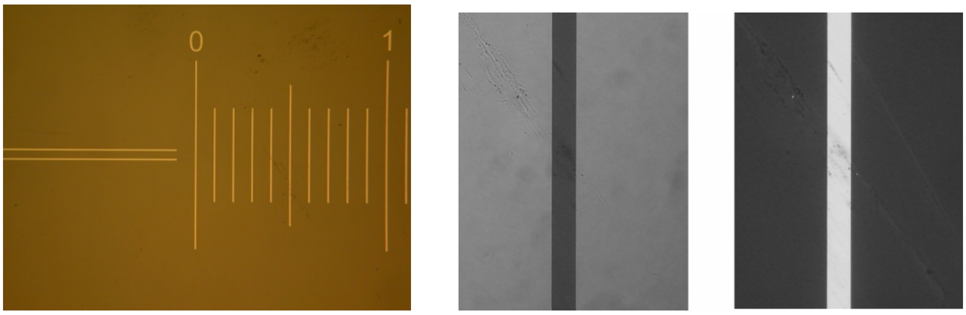


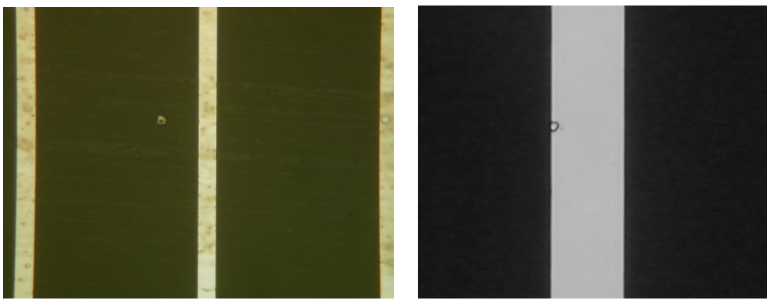
Fig. 8: MIKES reported small damage on the reference line (Scale "A")



Dust on scale before and after cleaning



Spots on glass



Spots on a line

Fig. 9: Dirt and damages reported by PTB (scale "A")

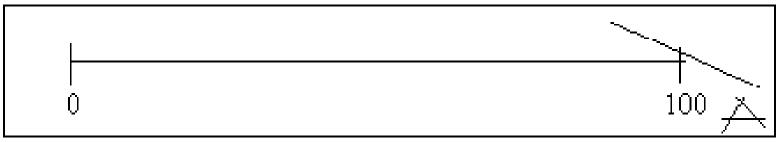


Fig. 10: Scratches reported by NCM (scale “A”)

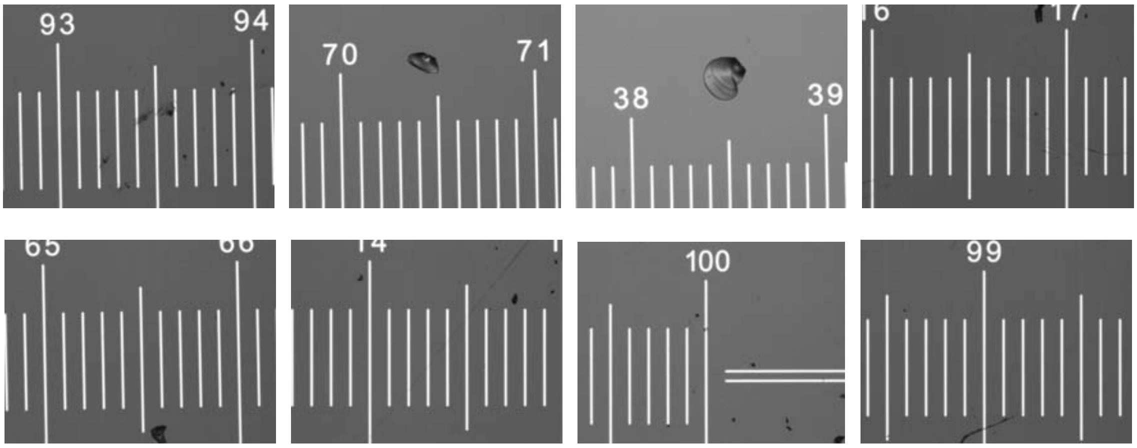


Fig. 11: Dirt and damages reported by A*Star–NMC Singapore (scale “B”)

After discussion between the pilot laboratory and both linking laboratories it was agreed that reported damages would not impact the majority of results and their uncertainties. The laboratories were also instructed in the technical protocol to perform the measurements as for their clients. So it was in their responsibility to consider disturbances in their uncertainty budget.

Single line centre shifts due to changes on lines can be evaluated from the diagrams in Figures 12 to 16. Results are presented in three different ways:

- as a comparison of measurements in 2006 and 2008 – Fig. 12 and 13
- as an absolute difference of two results (2008 – 2006) – Fig. 14
- as deviations of two measurements from calculated arithmetic mean (2006 and 2008) – Fig. 15 and 16

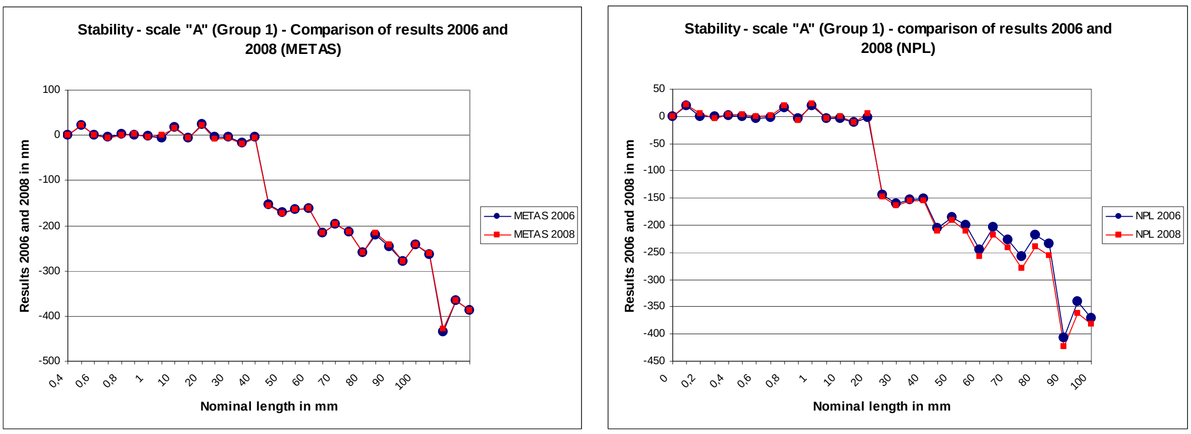


Fig. 12: Comparison of measurements, performed by METAS and NPL in 2006 and in 2008 on scale “A”

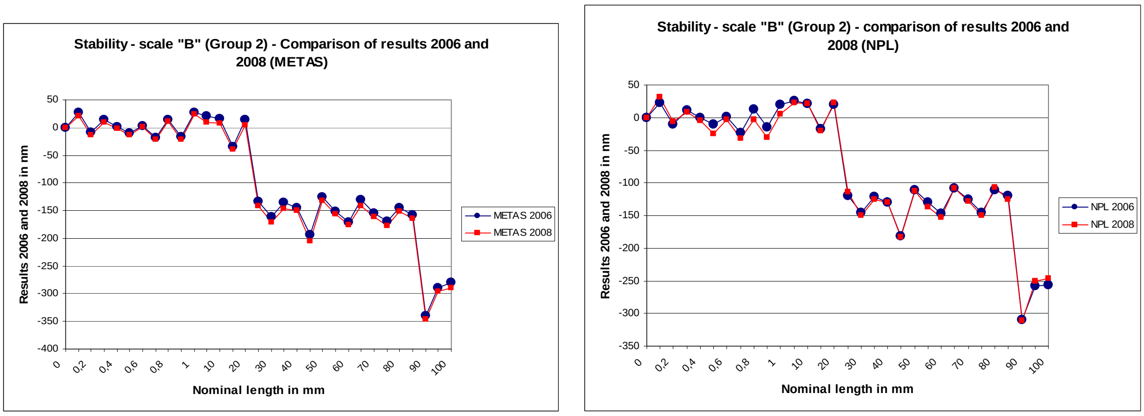


Fig. 13: Comparison of measurements, performed by METAS and NPL in 2006 and in 2008 on scale "B"

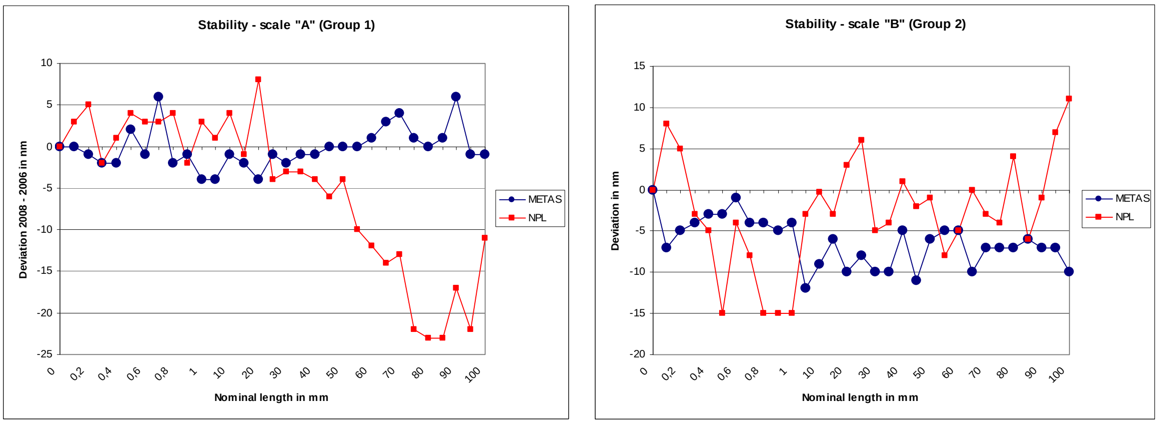


Fig. 14: Absolute difference of the results from 2006 and 2008 for scales "A" and "B"

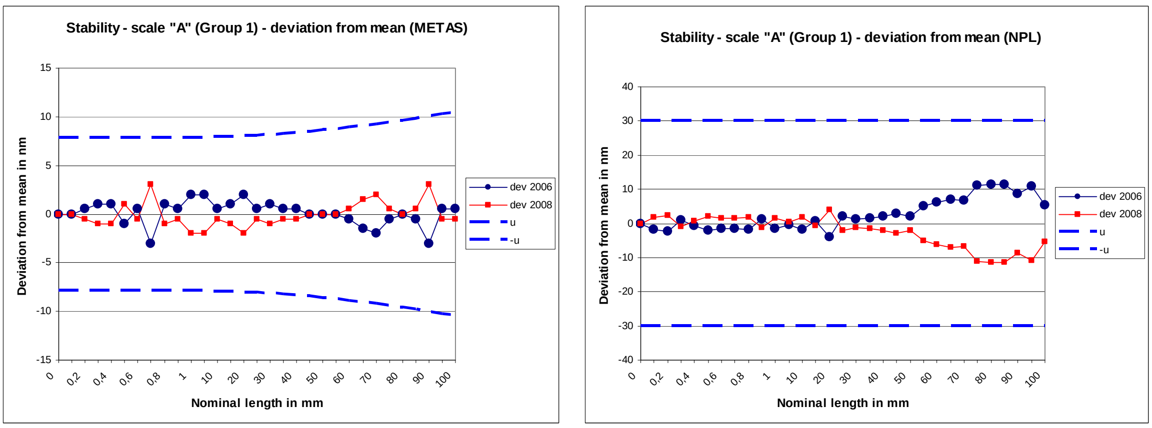


Fig. 15: Deviations of 2006 and 2008 measurements from the mean value (scale A) with indicated standard uncertainties

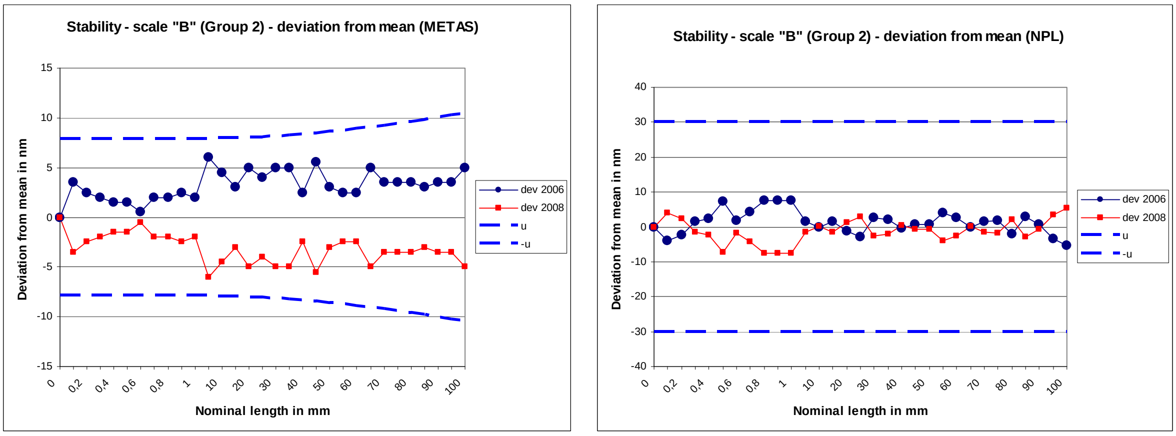


Fig. 16: Deviations of 2006 and 2008 measurements from the mean value (scale B) with indicated standard uncertainties

Figures 12 and 13 showing the deviations from the nominal values are not very useful, since the differences can hardly be seen. Fig. 14 shows for scale "A" the biggest difference of 23 nm measured by NPL, while the biggest difference in METAS results is 6 nm. For scale "B", the biggest difference measured by NPL was 15 nm, while the biggest difference measured by METAS was 12 nm. Fig. 15 and 16 show, that all measured differences were within the standard uncertainty boundaries.

6.3 Impact of line scale instability

Although no systematic change in line scale length was detected, there are possible influences on measured results by random influences like dirt, damages, different cleaning approaches etc. These influences were taken into account by adding an additional uncertainty component before calculating the reference values and their uncertainties and consistency of the results (E_n). This uncertainty component derived from the stability measurements made by the linking laboratories. They measured the scale at the beginning and at the end of the comparison.
A time dependent contribution (stability uncertainty) has to be added to a calibration value because the value is used at a time considerably later than the measurement. So adding the stability contribution makes the calibration valid over the full time span of the comparison (which lasted more than 2 years).

7 Analysis of the results

The reference values (x_{ref}) were calculated as the weighted mean of all measurements (x_i), the weight factors being $u^{-2}(x_i)$. For each measurement point the reference value was calculated. In the second step, for the calculation of reference values from the largest consistent subset of measurements, some of the values with $|E_n| > 1$ were omitted one by one, beginning with the largest $|E_n|$, until the Birge criterion was met.

Reference value:

$$x_{ref} = \frac{\sum_{i=1}^{n} u^{-2}(x_i) \cdot x_i}{\sum_{i=1}^{n} u^{-2}(x_i)} \tag{3}$$

Combined standard uncertainty:

$$u_c(x_{ref}) = \frac{1}{\sqrt{\sum_{i=1}^{n} u^{-2}(x_i)}} \tag{4}$$

E_n-value:

$$E_n = \frac{x_{lab} - x_{ref}}{k \cdot \sqrt{u^2(x_{lab}) - u^2(x_{ref})}} \; ; \; k = 2 \tag{5}$$

The Birge ratio:

$$R_B = \frac{u_{ext}}{u_{\text{int}}} \tag{6}$$

$$u_{ext} = \sqrt{\frac{\left[\sum_{i=1}^{n} (x_i - x_{ref}) / u(x_i)\right]^2}{(n-1)\sum_{i=1}^{n} u^{-2}(x_i)}} \tag{7}$$

$$u_{\text{int}} = 1/\sqrt{\sum_{i=1}^{n} u^{-2}(x_i)} \tag{8}$$

The Birge criterion:

$$R_B < \sqrt{1 + \sqrt{\frac{8}{n-1}}} \tag{9}$$

8 Measurement results

8.1 Measurement results - Group 1

Measurement results of Group 1 are presented in Table 9. The first set of NPL measurements and the last set of METAS measurements were used only for scale stability evaluation. They were excluded from final evaluation of the participants.

Table 9: Measurement results – Group 1

Meas. point	0,1 mm		0,2 mm		0,3 mm		0,4 mm		0,5 mm		0,6 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
MIRS-SI	20,0	61,1	0,0	61,2	0,0	61,4	20,0	61,5	30,0	61,6	30,0	61,7
METAS-CH	21,0	7,9	1,0	7,9	-4,0	7,9	3,0	7,9	0,0	7,9	-2,0	7,9
NPL-GB	18,6	30,0	-0,6	30,0	-1,3	30,0	2,3	30,0	-1,0	30,0	-3,6	30,0
OMH-HU	-119,0	100,0	-117,0	100,0	-14,0	100,0	-5,0	100,0	12,0	100,0	1,0	100,0
BEV-AT	14,0	23,0	10,0	23,0	10,0	23,0	20,0	23,0	14,0	23,0	12,0	23,0
SMU-SK	2,0	46,0	-34,0	46,0	-10,0	46,0	-13,0	46,0	-4,0	46,0	4,0	46,0
PTB-DE	35,2	13,0	5,4	32,0	9,0	13,0	55,5	32,0	32,0	32,0	10,5	13,0
GUM-PL	58,0	134,0	4,0	134,0	24,0	134,0	66,0	134,0	14,0	134,0	14,0	134,0
MIKES-FI	20,0	25,0	1,0	11,3	-4,0	11,3	45,0	25,0	10,0	11,3	-2,0	11,3
LNMC-LV	-200,0	823,0	-200,0	823,0	-200,0	823,0	0,0	823,0	200,0	823,0	400,0	823,0
NML-IE	-80,0	739,6	-46,0	739,6	-186,0	739,6	40,0	739,6	-360,0	739,6	-120,0	739,6
NCM-BG	24,0	78,0	0,0	78,0	1,0	78,0	2,0	78,0	41,0	78,0	-2,0	78,0
INM-RO	40,0	101,0	60,0	101,0	60,0	101,0	40,0	101,0	10,0	101,0	10,0	101,0
ZMDM-SR	-17,3	101,0	-5,3	101,0	1,4	101,0	23,1	101,0	13,9	101,0	-24,7	101,0
DZM-HR	3,0	75,1	-1,0	75,1	3,0	75,2	14,0	75,2	26,0	75,3	8,0	75,3
NSCIM-UA	36,0	20,0	12,0	20,0	-1,0	20,0	23,0	20,0	17,0	20,0	-204,0	20,0
CMI-CZ	28,0	14,0	1,0	14,0	-4,0	14,0	3,0	14,0	8,0	14,0	4,0	14,0
METAS-CH	21,0	7,9	0,0	7,9	-6,0	7,9	1,0	7,9	2,0	7,9	-3,0	7,9
NPL-GB	22,0	30,0	4,1	30,0	-3,2	30,0	3,4	30,0	3,0	30,0	-0,3	30,0

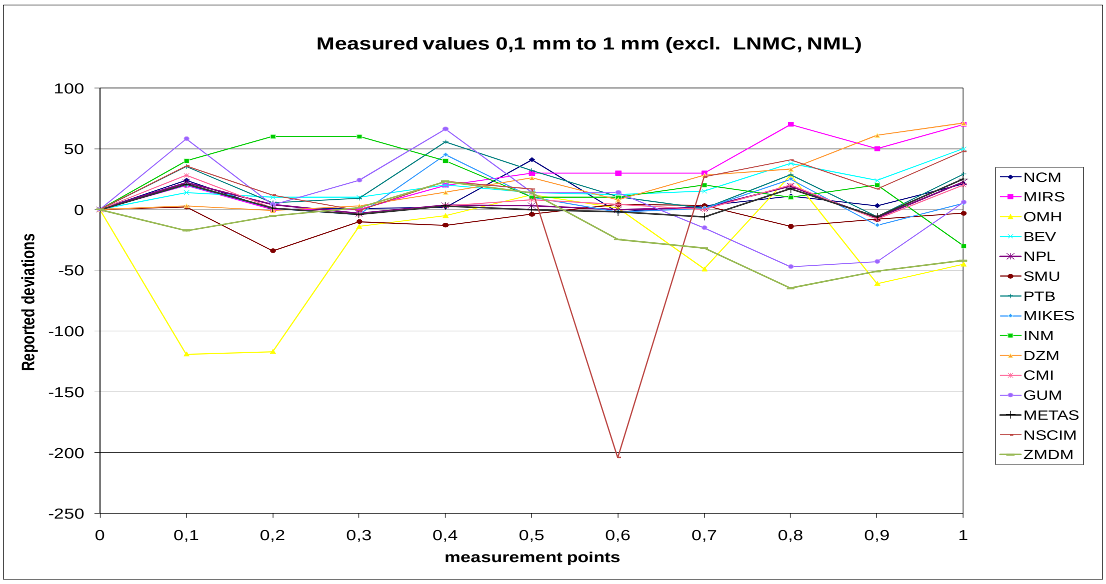
Meas. point	0,7 mm		0,8 mm		0,9 mm		1,0 mm		5,0 mm		10,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
MIRS-SI	30,0	61,8	70,0	62,0	50,0	62,1	70,0	62,2	20,0	67,0	0,0	73,0
METAS-CH	-6,0	7,9	17,0	7,9	-6,0	7,9	25,0	7,9	-4,0	7,9	-5,0	7,9
NPL-GB	-1,4	30,0	15,2	30,0	-4,5	30,0	19,4	30,0	-4,0	30,0	-4,1	30,0
OMH-HU	-49,0	100,0	28,0	100,0	-61,0	100,0	-45,0	100,0	-57,0	100,0	-91,0	100,0
BEV-AT	15,0	23,0	38,0	23,0	24,0	23,0	50,0	23,0	-16,0	111,0	-11,0	111,0
SMU-SK	3,0	46,0	-14,0	46,0	-8,0	46,0	-3,0	46,0	-26,0	46,0	-30,0	46,0
PTB-DE	0,8	32,0	28,6	13,0	-6,1	13,0	29,1	13,0	5,4	13,0	6,0	13,0
GUM-PL	-15,0	134,0	-47,0	134,0	-43,0	134,0	6,0	134,0	135,0	134,1	135,0	134,4
MIKES-FI	1,0	11,3	25,0	11,3	-13,0	11,3	5,0	11,3	-4,0	11,3	-6,0	11,3
LNMC-LV	300,0	823,0	100,0	823,0	100,0	823,0	50,0	823,0	420,0	823,0	360,0	823,0
NML-IE	-60,0	739,6	140,0	739,6	340,0	739,6	320,0	739,6	240,0	739,6	200,0	739,6
NCM-BG	3,0	78,0	11,0	78,0	3,0	78,0	21,0	78,0	-3,0	78,0	1,0	78,1
INM-RO	20,0	101,0	10,0	101,0	20,0	101,0	-30,0	101,0	30,0	101,0	30,0	101,0
ZMDM-SR	-31,8	101,0	-64,8	101,0	-50,9	101,0	-42,0	101,0	-3639,2	101,0	-8219,0	101,0
DZM-HR	28,0	75,4	33,0	75,4	61,0	75,5	71,0	75,5	36,0	77,5	25,0	80,0
NSCIM-UA	27,0	20,0	41,0	20,0	17,0	20,0	48,0	20,0	68,0	20,0	92,0	20,1
CMI-CZ	0,0	14,0	20,0	14,0	-8,0	14,0	20,0	14,0	-5,0	14,0	-6,0	14,1
METAS-CH	0,0	7,9	15,0	7,9	-7,0	7,9	21,0	7,9	-8,0	7,9	-6,0	7,9
NPL-GB	1,5	30,0	19,0	30,0	-6,9	30,0	22,5	30,0	-3,3	30,0	-0,3	30,0

Meas. point	15,0 mm		20,0 mm		25,0 mm		30,0 mm		35,0 mm		40,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
MIRS-SI	0,0	79,0	0,0	85,0	-140,0	91,0	-180,0	97,0	-200,0	103,0	-210,0	109,0
METAS-CH	-17,0	8,0	-3,0	8,0	-154,0	8,1	-171,0	8,2	-164,0	8,3	-162,0	8,4
NPL-GB	-10,5	30,0	-2,6	30,0	-143,4	30,0	-160,6	30,0	-152,8	30,0	-150,9	30,0
OMH-HU	-50,0	100,0	-28,0	100,0	-263,0	100,0	-159,0	100,0	-89,0	100,1	-322,0	100,1
BEV-AT	-64,0	111,0	-48,0	111,0	-180,0	111,0	-247,0	111,0	-255,0	111,0	-272,0	111,0
SMU-SK	-21,0	46,0	-34,0	46,0	-83,0	46,1	-87,0	46,1	-90,0	46,1	-102,0	46,2
PTB-DE	17,6	13,0	5,7	13,0	-134,1	13,0	-158,5	13,0	-149,7	13,0	-149,1	13,0
GUM-PL	174,0	134,8	81,0	135,5	-66,0	136,3	-15,0	137,3	-126,0	138,5	-45,0	139,8
MIKES-FI	-1,0	11,3	-9,0	11,3	-144,0	11,4	-171,0	11,4	-161,0	11,4	-159,0	11,4
LNMC-LV	270,0	823,0	510,0	823,0	230,0	823,0	970,0	823,0	-150,0	823,0	320,0	823,0
NML-IE	480,0	739,6	400,0	739,6	760,0	739,6	340,0	739,6	680,0	739,6	900,0	739,6
NCM-BG	-21,0	78,2	-13,0	78,3	-154,0	78,5	-176,0	78,7	-150,0	78,9	-179,0	79,2
INM-RO	10,0	101,1	-10,0	101,1	-40,0	101,2	-20,0	101,3	-20,0	101,4	-10,0	101,6
ZMDM-SR	-10837,1	101,0	-14582,3	101,1	-18716,9	101,1	-22493,0	101,2	-25864,6	101,2	-29161,2	101,3
DZM-HR	-7,0	82,5	14,0	85,0	-238,0	87,5	-276,0	90,0	-299,0	92,5	-167,0	95,0
NSCIM-UA	116,0	20,2	162,0	20,3	62,0	20,4	124,0	20,6	134,0	20,9	162,0	21,1
CMI-CZ	-12,0	14,3	-3,0	14,5	-153,0	14,8	-174,0	15,1	-161,0	15,5	-168,0	16,0
METAS-CH	-19,0	8,0	-7,0	8,0	-155,0	8,1	-173,0	8,2	-165,0	8,3	-163,0	8,4
NPL-GB	-11,9	30,0	5,7	30,0	-147,2	30,0	-163,2	30,0	-155,7	30,0	-155,0	30,0

Meas. point	45,0 mm		50,0 mm		55,0 mm		60,0 mm		65,0 mm		70,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
MIRS-SI	-290,0	115,0	-220,0	121,0	-270,0	127,0	-310,0	133,0	-250,0	139,0	-280,0	145,0
METAS-CH	-216,0	8,5	-196,0	8,6	-214,0	8,8	-260,0	8,9	-220,0	9,1	-246,0	9,3
NPL-GB	-205,0	30,0	-186,4	30,0	-200,1	30,0	-245,1	30,0	-203,9	30,0	-227,5	30,0
OMH-HU	-282,0	100,1	-261,0	100,1	-351,0	100,1	-318,0	100,2	-232,0	100,2	-329,0	100,2
BEV-AT	-351,0	111,0	-290,0	111,0	-342,0	111,0	-418,0	111,0	-377,0	111,0	-444,0	111,0
SMU-SK	-109,0	46,2	-107,0	46,2	-124,0	46,3	-142,0	46,3	-144,0	46,4	-162,0	46,5
PTB-DE	-200,9	13,0	-180,6	13,0	-201,5	13,0	-244,2	13,0	-200,4	13,0	-236,4	13,0
GUM-PL	-236,0	141,4	-259,0	143,0	-312,0	144,8	-422,0	146,8	-335,0	148,9	-479,0	151,2
MIKES-FI	-220,0	11,5	-195,0	11,5	-210,0	11,6	-257,0	11,6	-213,0	11,7	-245,0	11,7
LNMC-LV	140,0	823,0	670,0	823,0	120,0	823,0	580,0	823,0	-220,0	823,0	-110,0	823,0
NML-IE	760,0	739,6	920,0	739,6	880,0	739,6	1600,0	739,6	1860,0	739,6	1780,0	739,6
NCM-BG	-231,0	79,5	-225,0	79,8	-243,0	80,2	-294,0	80,6	-249,0	81,1	-282,0	81,6
INM-RO	-50,0	101,7	-50,0	101,9	-20,0	102,1	-20,0	102,3	-40,0	102,5	-40,0	102,8
ZMDM-SR	-33155,7	101,4	-37149,2	101,4	-40400,0	101,5	-43905,1	101,6	-48228,9	101,8	-50952,6	101,9
DZM-HR	-200,0	97,5	-168,0	100,0	-222,0	102,5	-266,0	105,0	-201,0	107,5	-255,0	110,0
NSCIM-UA	-69,0	21,4	221,0	21,7	214,0	22,1	209,0	22,5	236,0	22,8	230,0	23,3
CMI-CZ	-229,0	16,5	-213,0	17,0	-218,0	17,5	-276,0	18,1	-224,0	18,8	-259,0	19,4
METAS-CH	-216,0	8,5	-196,0	8,6	-214,0	8,8	-259,0	8,9	-217,0	9,1	-242,0	9,3
NPL-GB	-210,7	30,0	-190,6	30,0	-210,5	30,0	-257,5	30,0	-217,9	30,0	-240,9	30,0

Meas. point	75,0 mm		80,0 mm		85,0 mm		90,0 mm		95,0 mm		100,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
MIRS-SI	-290,0	151,0	-280,0	157,0	-320,0	163,0	-510,0	169,0	-420,0	175,0	-440,0	181,0
METAS-CH	-280,0	9,4	-242,0	9,6	-263,0	9,8	-434,0	10,0	-365,0	10,3	-387,0	10,5
NPL-GB	-257,0	30,0	-217,4	30,0	-234,0	30,0	-406,3	30,0	-340,6	30,0	-371,0	30,0
OMH-HU	-559,0	100,2	-456,0	100,3	-531,0	100,3	-639,0	100,4	-466,0	100,4	-486,0	100,4
BEV-AT	-465,0	111,0	-475,0	111,0	-516,0	111,0	-657,0	111,0	-615,0	111,0	-709,0	111,0
SMU-SK	-191,0	46,5	-201,0	46,6	-197,0	46,7	-222,0	46,8	-211,0	46,9	-250,0	47,0
PTB-DE	-273,6	13,0	-231,1	13,0	-230,7	13,0	-410,3	13,0	-352,8	13,0	-387,9	13,0
GUM-PL	-451,0	153,6	-533,0	156,1	-562,0	158,7	-605,0	161,4	-551,0	164,3	-588,0	167,2
MIKES-FI	-284,0	11,8	-235,0	11,9	-292,0	25,0	-399,0	25,0	-342,0	25,0	-388,0	12,2
LNMC-LV	250,0	823,0	-230,0	823,0	-950,0	823,0	-1420,0	823,0	-1210,0	823,0	-1720,0	823,0
NML-IE	2500,0	739,6	2020,0	739,6	2060,0	739,6	2340,0	739,6	2840,0	739,6	2840,0	739,6
NCM-BG	-324,0	82,1	-289,0	82,6	-313,0	83,2	-485,0	83,8	-423,0	84,4	-443,0	85,1
INM-RO	-50,0	103,0	-40,0	103,3	-20,0	103,6	-30,0	103,9	-60,0	104,3	-30,0	104,6
ZMDM-SR	-55368,7	102,0	-58869,3	102,1	-62248,0	102,3	-66038,9	102,4	-69011,4	102,6	-73278,6	102,8
DZM-HR	-310,0	112,5	-262,0	115,0	-310,0	117,5	-391,0	120,0	-321,0	122,5	-312,0	125,0
NSCIM-UA	187,0	23,7	235,0	24,2	226,0	24,7	74,0	25,2	182,0	25,7	135,0	26,2
CMI-CZ	-295,0	20,1	-259,0	20,8	-280,0	21,5	-459,0	22,2	-382,0	23,0	-412,0	23,8
METAS-CH	-279,0	9,4	-242,0	9,6	-262,0	9,8	-428,0	10,0	-366,0	10,3	-388,0	10,5
NPL-GB	-279,3	30,0	-240,0	30,0	-256,6	30,0	-423,7	30,0	-362,4	30,0	-381,6	30,0

Figure 17 presents measurement results (deviations from nominal values) for measurement ranges 0,1 mm to 1 mm and 1 mm to 100 mm.



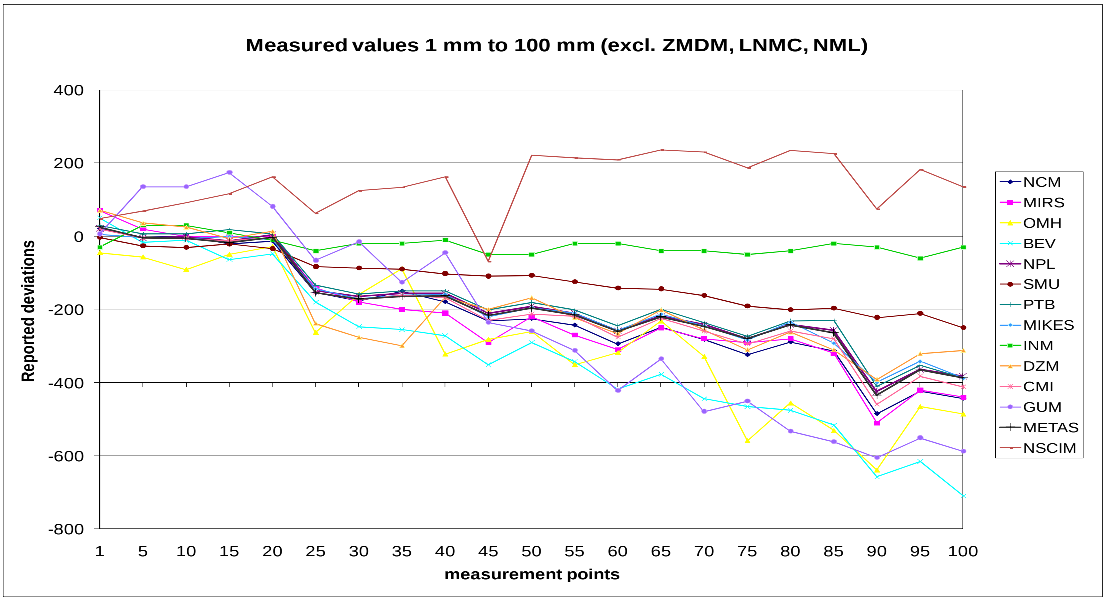


Figure 17: Deviations from nominal values - group 1

Graphical illustration of deviations from the reference values, which were calculated separately for group 1 (without linking the groups) are presented in Appendix B.1.

8.2 Measurement results – Group 2

Measurement results of Group 2 are presented in Table 10. The first set of NPL measurements and the last set of METAS measurements were used only for scale stability evaluation. They were excluded from final evaluation of the participants.

Table 10: Measurement results – Group 2

Meas. point	0,1 mm		0,2 mm		0,3 mm		0,4 mm		0,5 mm		0,6 mm	
	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm
METAS-CH	28,0	7,9	-8,0	7,9	14,0	7,9	1,0	7,9	-10,0	7,9	3,0	7,9
NPL-GB	22,9	30,0	-10,7	30,0	11,4	30,0	-0,5	30,0	-9,9	30,0	0,6	30,0
EIM-GR	29,0	566,0	22,0	566,0	48,0	566,0	34,0	566,0	20,0	566,0	17,0	566,0
INRIM-IT	31,0	45,0	-4,0	45,0	21,0	45,0	7,0	45,0	-2,0	45,0	6,0	45,0
Nmi-VSL-NL	22,0	21,0	-13,0	21,0	10,0	21,0	-8,0	21,0	-15,0	21,0	-40,0	21,1
CEM-ES	35,0	28,4	-12,0	28,4	15,0	28,4	9,0	28,4	-7,0	28,4	3,0	28,4
INMETRO-BR	30,0	63,0	42,0	63,0	62,0	63,0	21,0	63,0	11,0	63,0	23,0	63,0
CENAM-MX	0,0	137,8	0,0	137,8	0,0	137,8	0,0	137,8	0,0	137,8	-100,0	137,8
NIST-US	36,0	3,1	1,2	3,1	16,7	3,1	4,4	3,1	-11,2	3,1	4,9	3,1
NRC-CA	26,8	40,0	-11,3	40,0	13,6	40,0	2,3	40,0	-13,7	40,0	5,3	40,0
A*Star-NMC-SG	50,0	115,0	0,0	115,0	0,0	115,0	25,0	115,0	0,0	115,0	0,0	115,0
NIM-CN	11,0	49,0	-28,0	49,0	-12,0	49,0	-26,0	49,0	-33,0	49,0	-16,0	49,0
NPLI-IN	26,0	236,0	-32,0	236,0	92,0	236,0	-144,0	236,0	-76,0	236,0	-114,0	236,0
NIMT-THA	25,8	20,5	-8,8	20,5	18,7	20,5	20,5	20,5	5,1	20,5	4,0	20,5
NPL-GB	30,9	30,0	-5,8	30,0	8,6	30,0	-5,1	30,0	-24,6	30,0	-3,3	30,0
METAS-CH	21,0	7,9	-13,0	7,9	10,0	7,9	-2,0	7,9	-13,0	7,9	2,0	7,9
VNIIM-RU	27,0	10,0	-13,0	10,0	10,0	10,0	-5,0	10,1	-16,0	10,1	-1,0	10,1

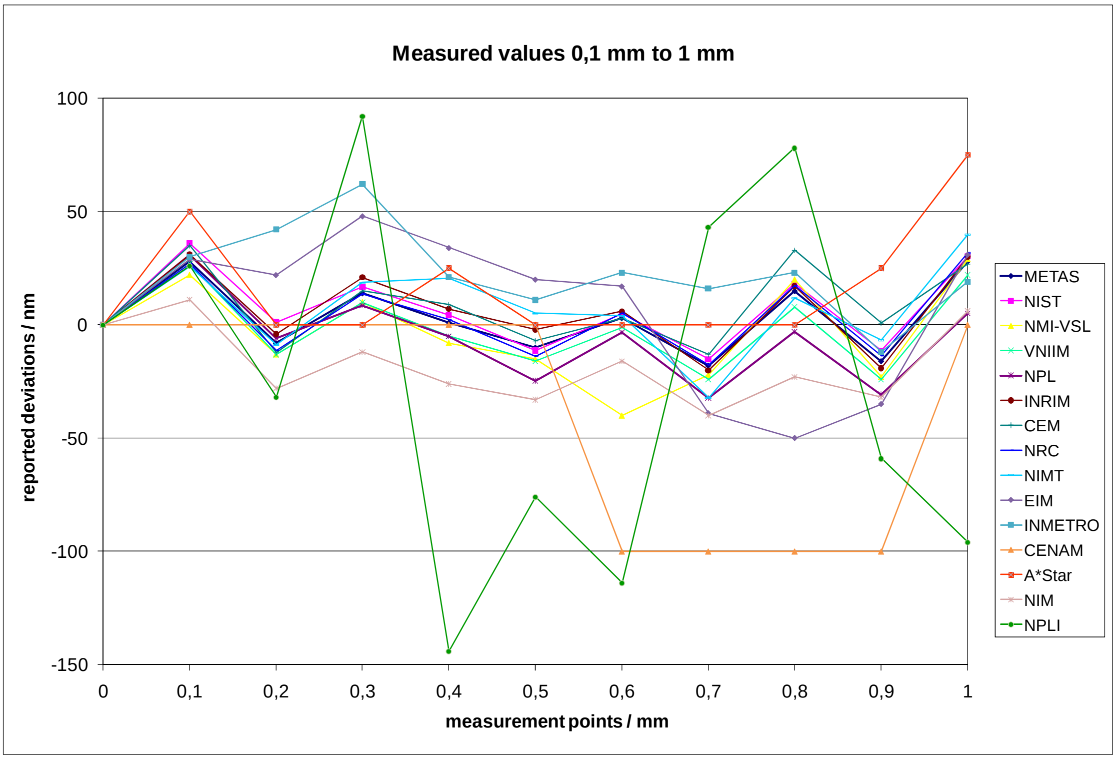
Meas. point	0,7 mm		0,8 mm		0,9 mm		1,0 mm		5,0 mm		10,0 mm	
	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm
METAS-CH	-18,0	7,9	15,0	7,9	-16,0	7,9	28,0	7,9	21,0	7,9	16,0	7,9
NPL-GB	-23,9	30,0	12,2	30,0	-15,5	30,0	20,3	30,0	24,9	30,0	20,9	30,0
EIM-GR	-39,0	566,0	-50,0	566,0	-35,0	566,0	31,0	566,0	-29,0	566,0	-37,0	566,1
INRIM-IT	-20,0	45,0	17,0	45,0	-19,0	45,0	30,0	45,0	21,0	45,0	23,0	45,0
Nmi-VSL-NL	-22,0	21,1	20,0	21,1	-23,0	21,1	29,0	21,1	16,0	21,5	12,0	21,9
CEM-ES	-13,0	28,4	33,0	28,4	1,0	28,4	27,0	28,4	40,0	28,4	60,0	28,5
INMETRO-BR	16,0	63,0	23,0	63,0	-12,0	63,0	19,0	63,0	-4,0	63,0	-4,0	63,0
CENAM-MX	-100,0	137,8	-100,0	137,8	-100,0	137,8	0,0	137,8	-100,0	138,2	0,0	139,2
NIST-US	-15,1	3,1	18,2	3,1	-11,3	3,1	30,3	3,1	20,7	3,7	24,9	3,7
NRC-CA	-17,6	40,0	17,4	40,0	-13,6	40,0	31,8	40,0	21,5	40,0	22,9	40,0
A*Star-NMC-SG	0,0	115,0	0,0	115,0	25,0	115,0	75,0	115,0	-25,0	115,0	-50,0	115,1
NIM-CN	-40,0	49,0	-23,0	49,0	-32,0	49,0	6,0	49,0	9,0	49,0	1,0	49,0
NPLI-IN	43,0	236,0	78,0	236,0	-59,0	236,0	-96,0	236,0	12,0	236,0	-76,0	236,0
NIMT-THA	-32,2	20,5	11,8	20,5	-6,7	20,5	40,0	20,5	20,8	20,7	16,1	21,1
NPL-GB	-32,3	30,0	-2,9	30,0	-30,7	30,0	5,2	30,0	22,0	30,0	21,2	30,0
METAS-CH	-22,0	7,9	11,0	7,9	-21,0	7,9	24,0	7,9	9,0	7,9	7,0	7,9
VNIIM-RU	-24,0	10,1	8,0	10,1	-24,0	10,1	22,0	10,2	8,0	10,8	10,0	11,5

Meas. point	15,0 mm		20,0 mm		25,0 mm		30,0 mm		35,0 mm		40,0 mm	
	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm	dL / nm	u_c / nm
METAS-CH	-34,0	8,0	15,0	8,0	-133,0	8,1	-161,0	8,2	-136,0	8,3	-145,0	8,4
NPL-GB	-17,9	30,0	20,0	30,0	-119,4	30,0	-145,6	30,0	-121,8	30,0	-130,5	30,0
EIM-GR	-75,0	566,2	-126,0	566,4	-269,0	566,6	-422,0	566,8	-396,0	567,1	-522,0	567,4
INRIM-IT	-23,0	45,1	22,0	45,2	-126,0	45,3	-154,0	45,4	-131,0	45,5	-136,0	45,7
Nmi-VSL-NL	-29,0	22,4	28,0	22,8	-101,0	23,3	-142,0	23,7	-128,0	24,2	-112,0	24,6
CEM-ES	16,0	28,5	43,0	28,6	-79,0	28,7	-131,0	28,8	-77,0	28,9	-79,0	29,1
INMETRO-BR	-23,0	63,0	16,0	63,0	-69,0	63,0	-95,0	63,0	-84,0	63,0	-80,0	63,0
CENAM-MX	0,0	140,9	-100,0	143,2	-300,0	146,2	0,0	149,7	-200,0	153,8	0,0	158,3
NIST-US	-19,4	3,8	27,3	3,8	-116,6	3,9	-145,8	4,0	-119,3	4,1	-119,3	4,2
NRC-CA	-24,2	40,1	23,1	40,2	-115,0	40,3	-139,9	40,4	-120,8	40,6	-121,1	40,8
A*Star-NMC-SG	-75,0	115,1	0,0	115,2	-150,0	115,3	-150,0	115,5	-150,0	115,7	-150,0	115,8
NIM-CN	-12,0	49,0	28,0	49,0	-91,0	49,0	-97,0	49,0	-75,0	49,0	-73,0	49,0
NPLI-IN	-68,0	236,0	-23,0	236,1	-344,0	236,1	-261,0	236,2	-176,0	236,3	-212,0	236,3
NIMT-THA	-19,7	21,9	1,2	23,0	-119,6	24,2	-151,3	25,7	-137,1	27,3	-127,9	29,1
NPL-GB	-20,7	30,0	22,7	30,0	-113,3	30,0	-150,7	30,0	-126,2	30,0	-129,5	30,0
METAS-CH	-40,0	8,0	5,0	8,0	-141,0	8,1	-171,0	8,2	-146,0	8,3	-150,0	8,4
VNIIM-RU	-38,0	12,3	6,0	13,0	-140,0	13,8	-167,0	14,5	-146,0	15,3	-151,0	16,0

Meas. point	45,0 mm		50,0 mm		55,0 mm		60,0 mm		65,0 mm		70,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
METAS-CH	-194,0	8,5	-126,0	8,6	-151,0	8,8	-171,0	8,9	-131,0	9,1	-155,0	9,3
NPL-GB	-181,4	30,0	-110,9	30,0	-129,4	30,0	-147,5	30,0	-107,8	30,0	-125,3	30,0
EIM-GR	-582,0	567,8	-561,0	568,2	-547,0	568,7	-547,0	569,2	-474,0	569,7	-520,0	570,3
INRIM-IT	-180,0	45,9	-106,0	46,1	-138,0	46,3	-156,0	46,6	-117,0	46,8	-143,0	47,1
Nmi-VSL-NL	-159,0	25,1	-59,0	25,5	-101,0	26,0	-124,0	26,4	-84,0	26,9	-89,0	27,3
CEM-ES	-151,0	29,2	-101,0	29,4	-128,0	29,6	-134,0	29,8	-113,0	30,1	-128,0	30,3
INMETRO-BR	-98,0	63,0	-84,0	63,0	-87,0	63,0	-77,0	92,0	-140,0	92,0	-77,0	92,0
CENAM-MX	100,0	163,4	-100,0	168,8	-100,0	174,6	-100,0	180,8	-200,0	187,2	-300,0	193,9
NIST-US	-183,1	4,3	-110,8	4,5	-131,7	4,6	-153,1	4,8	-111,2	4,9	-129,0	5,1
NRC-CA	-171,5	41,0	-99,7	41,2	-127,5	41,5	-145,6	41,8	-106,9	42,1	-133,0	42,4
A*Star-NMC-SG	-200,0	116,1	-150,0	116,3	-175,0	116,6	-200,0	116,9	-175,0	117,2	-175,0	117,6
NIM-CN	-116,0	49,0	-32,0	49,0	-53,0	49,0	-48,0	49,0	-5,0	49,0	-27,0	49,0
NPLI-IN	-238,0	236,4	-163,0	236,5	-252,0	236,7	-271,0	236,8	-129,0	236,9	-56,0	237,1
NIMT-THA	-192,0	31,0	-121,9	33,0	-147,7	35,1	-150,9	37,2	-131,1	39,4	-206,0	41,6
NPL-GB	-183,0	30,0	-112,3	30,0	-137,5	30,0	-152,5	30,0	-107,8	30,0	-128,5	30,0
METAS-CH	-205,0	8,5	-132,0	8,6	-156,0	8,8	-176,0	8,9	-141,0	9,1	-162,0	9,3
VNIIM-RU	-202,0	16,8	-133,0	17,5	-157,0	18,3	-177,0	19,0	-138,0	19,8	-161,0	20,5

Meas. point	75,0 mm		80,0 mm		85,0 mm		90,0 mm		95,0 mm		100,0 mm	
	dL / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm	*dL* / nm	u_c / nm
METAS-CH	-170,0	9,4	-145,0	9,6	-158,0	9,8	-340,0	10,0	-289,0	10,3	-279,0	10,5
NPL-GB	-146,3	30,0	-110,6	30,0	-120,5	30,0	-310,3	30,0	-258,1	30,0	-256,7	30,0
EIM-GR	-541,0	570,9	-505,0	571,6	-570,0	572,3	-641,0	573,1	-562,0	573,9	-497,0	574,8
INRIM-IT	-151,0	47,4	-123,0	47,8	-139,0	48,1	-315,0	48,5	-262,0	48,8	-255,0	49,2
Nmi-VSL-NL	-112,0	27,8	-99,0	28,2	-109,0	28,7	-273,0	29,1	-216,0	29,6	-187,0	30,0
CEM-ES	-156,0	30,6	-105,0	30,9	-144,0	31,2	-307,0	31,5	-257,0	31,8	-261,0	32,1
INMETRO-BR	-80,0	92,0	9,0	92,0	-59,0	92,0	-308,0	92,0	-263,0	92,0	-342,0	92,0
CENAM-MX	-400,0	200,9	-400,0	208,1	-400,0	215,5	-500,0	223,1	-500,0	230,8	-500,0	238,7
NIST-US	-146,2	5,3	-125,3	5,4	-125,4	5,6	-313,4	5,8	-266,3	6,0	-249,6	6,2
NRC-CA	-143,6	42,7	-118,2	43,1	-125,4	43,5	-312,9	43,9	-261,8	44,3	-256,8	44,7
A*Star-NMC-SG	-225,0	118,0	-150,0	118,4	-162,0	118,8	-338,0	119,2	-238,0	119,7	-212,0	120,2
NIM-CN	-31,0	49,0	8,0	49,0	-2,0	49,0	-167,0	49,0	-115,0	49,0	-101,0	49,0
NPLI-IN	-106,0	237,2	-190,0	237,4	-294,0	237,6	-364,0	237,8	-592,0	237,9	-713,0	238,2
NIMT-THA	-158,0	43,9	-124,5	46,2	-151,7	48,5	-314,1	50,8	-279,4	53,2	-259,4	55,6
NPL-GB	-149,8	30,0	-106,3	30,0	-126,2	30,0	-311,5	30,0	-251,2	30,0	-246,2	30,0
METAS-CH	-177,0	9,4	-152,0	9,6	-164,0	9,8	-347,0	10,0	-296,0	10,3	-289,0	10,5
VNIIM-RU	-179,0	21,3	-147,0	22,0	-161,0	22,8	-345,0	23,5	-292,0	24,3	-286,0	25,0

Figure 18 presents measurement results (deviations from nominal values) for measurement ranges 0,1 mm to 1 mm and 1 mm to 100 mm.



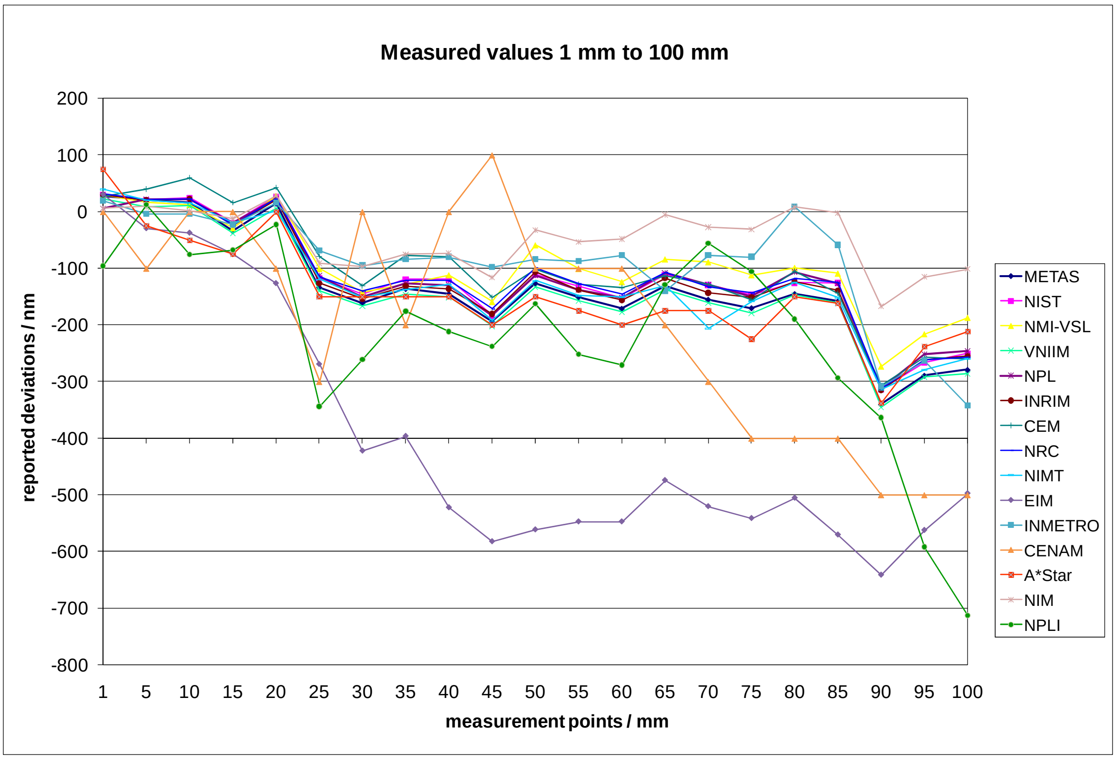


Figure 18: Deviations from nominal values – group 2

Graphical illustration of deviations from the reference values, which were calculated separately for group 2 (without linking the groups) are presented in Appendix B.1.

8.3 Correction of the original results

After issuing draft A report, one laboratory (SMU from Group 1) requested to correct its results due to wrong thermal expansion correction, and one laboratory (A*Star from group 2) requested to correct its uncertainty budget due to obvious error in calculating standard uncertainties of input quantities.

After the two laboratories had sent their technical explanations, the requested changes were approved, because clear mistakes were shown. The explanations are attached below:

SMU Slovakia:

"*SMU used Abbe Zeiss length measuring machine combined with HP 5529B laser interferometer. The computer was working permanently during the measurement period (December 2006), i.e. it ran approximately 3 weeks without switch off. The external sensors have been used and the actualized values of the line measure temperature and atmosphere parameters were being inserted into the system before each measurement cycle (10 lines within each measurement cycle). Of course, the thermal dilatation coefficient (in the form x.xxx ppm/°C) was inserted once at the beginning of SMU measurements and thus its value remained untouched during the whole measurement period.*

The most frequently used values while measuring steel or glass artifacts are therefore 11.500 ppm/°C or 8.500 ppm/°C respectively. Unfortunately, only after receipt of the first draft I realized that the value I saw displayed was 5.000 ppm/°C (instead of 0.500 ppm/°C). Nevertheless, I must admit that after almost 3 years I am not quite sure (i.e. 100%) what I actually saw on the display, but it is much more probable that 0.5 ppm was not displayed there.

The average temperature corresponding to the larger nominal lengths was 19,63 °C, therefore the temperature compensation according to the value of $5x10^{-6}$ K^{-1} *was 10 times larger and hence it shifted the measured values towards the nominal ones (of course, just those lying below the nominal, but in fact it seems that for entirely all larger values it is the case). For example, in the corrected set of SMU results, the deviation corresponding to 100 mm has changed from –84 nm to –250 nm, etc.*

Paradoxically, I always kept in mind that the thermal expansion coefficient of quartz is low and thus I did not care for the temperature as usually, not in terms of the temperature measurement itself, but in terms of the communication with the air condition centre. The air conditioning system of the institute is old, expensive and not as effective as in many other institutes, therefore we have always problem to keep the temperature close to 20 °C, even if it is relatively stable. It was December and thus the temperature in lab was below 20 °C. Just three weeks I had for measurements (we have obliged holiday from Christmas to New Year at the SMU) and there was not enough time to wait until the ambient temperature is closer to 20 °C.

The microscope magnification I used was 125x and the line edge was of high quality; according to my experience, I can hardly believe that I could be wrong by roughly 0.5 μm as it looks from the first submitted set of measurements.
I am aware that some people could take the explanation given above as the clear speculation, because of the subjective feeling of "what I saw on the display 2.5 years ago" can be hardly taken as the rigid proof in this case."

A*Star Singapore:

*"A*Star-NMC-SG has requested a change in two uncertainty components being the errors due to horizontal and vertical Abbe offsets. The initial values of the two components were given at 2 sigma level with rectangular distribution and should be divided by SQRT(3) for the conversion to standard uncertainty. The miss-calculations were corrected and updated in the uncertainty budget table."*

8.4 Link between the groups

The results in the previous chapter were shown for each group separately. This chapter is presenting the results after linking the groups by using Bayesian statistics [2].

In order to make statistical formulas more clear, Group 1 is indexed with “A” and Group 2 with “B” as shown in Figure 19. Index “C” is assigned to the intersection of sets “A” and “B” , which contains 2 elements (linking laboratories NPL and METAS).

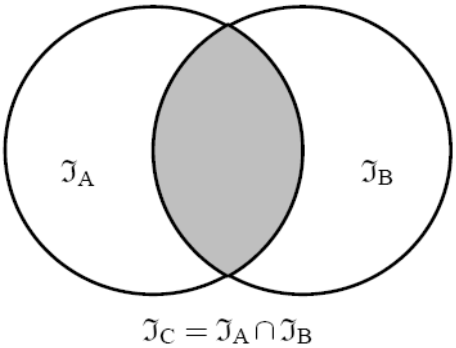


Figure 19: Group 1 and Group 2 are presented by 2 sets of elements “A” and “B”

The results are calculated by the following formulas:

Reference values:

$$y_A = \frac{bS_1 + cS_2}{ab - c^2} \tag{10}$$

$$y_B = \frac{cS_1 + aS_2}{ab - c^2} \tag{11}$$

Standard uncertainties of the reference values:

$$u(y_A) = \sqrt{\frac{b}{ab - c^2}} \tag{12}$$

$$u(y_B) = \sqrt{\frac{a}{ab - c^2}} \tag{13}$$

Covariance:

$$u(y_A, y_B) = \frac{c}{ab - c^2} \tag{14}$$

Where:

$$a = \sum_{i \in (\Im_A \setminus \Im_B)} \frac{1}{u^2(x_{A,i})} + \sum_{i \in (\Im_A \cap \Im_B)} \frac{u^2(x_{B,i})}{u^2(x_{A,i})u^2(x_{B,i}) - u^2(x_{A,i}, x_{B,i})} \tag{15}$$

$$b = \sum_{i \in (\Im_B \setminus \Im_A)} \frac{1}{u^2(x_{B,i})} + \sum_{i \in (\Im_A \cap \Im_B)} \frac{u^2(x_{A,i})}{u^2(x_{A,i})u^2(x_{B,i}) - u^2(x_{A,i}, x_{B,i})} \tag{16}$$

$$c = \sum_{i \in (\Im_A \cap \Im_B)} \frac{u(x_{A,i}, x_{B,i})}{u^2(x_{A,i})u^2(x_{B,i}) - u^2(x_{A,i}, x_{B,i})} \tag{17}$$

$$S_1 = \sum_{i \in (\Im_A \setminus \Im_B)} \frac{x_{A,i}}{u^2(x_{A,i})} + \sum_{i \in (\Im_A \cap \Im_B)} \frac{u^2(x_{B,i})x_{A,i} - u(x_{A,i}, x_{B,i})x_{B,i}}{u^2(x_{A,i})u^2(x_{B,i}) - u^2(x_{A,i}, x_{B,i})} \tag{18}$$

$$S_2 = \sum_{i \in (\Im_A \setminus \Im_B)} \frac{x_{B,i}}{u^2(x_{B,i})} + \sum_{i \in (\Im_A \cap \Im_B)} \frac{u^2(x_{A,i})x_{B,i} - u(x_{A,i}, x_{B,i})x_{A,i}}{u^2(x_{A,i})u^2(x_{B,i}) - u^2(x_{A,i}, x_{B,i})} \tag{19}$$

Values x are reported results of participating laboratories ($x_{A,i}$ for Group 1 and $x_{B,i}$ for Group 2), while $u(x)$ are reported standard uncertainties.

8.5 Intercomparison results for linked groups considering line scale stability

The results are shown in Table 12. Linking laboratories are in the middle of the table and are marked with green colour. Above them are laboratories from Group 1, while the laboratories from Group 2 are in the bottom part of the table.

The results given in Table 12 were calculated from the largest consistent subset. This subset was created by eliminating laboratories with the greatest E_n values until the Birge criterion (Ch. 7) was met and Chi-test passed. E_n values $|E_n| > 1$ are marked with yellow colour. Eliminated laboratories for single measurement points are shown in Table 11.

Table 11: Laboratories that were excluded from calculation of the reference values:

Measuring point (mm)	No. of excl. labs	Excluded laboratories	Measuring point (mm)	No. of excl. labs	Excluded laboratories
0,6	1	NSCIM-UA	55	2	ZMDM-SR, NSCIM-UA
5	1	ZMDM-SR	60	3	ZMDM-SR, NSCIM-UA, NML-IE
10	1	ZMDM-SR	65	2	ZMDM-SR, NSCIM-UA
15	2	ZMDM-SR, NSCIM-UA	70	2	ZMDM-SR, NSCIM-UA
20	2	ZMDM-SR, NSCIM-UA	75	3	ZMDM-SR, NSCIM-UA, NML-IE
25	2	ZMDM-SR, NSCIM-UA	80	3	ZMDM-SR, NSCIM-UA, NML-IE
30	2	ZMDM-SR, NSCIM-UA	85	5	ZMDM-SR, NSCIM-UA, NML-IE, OMH-HU, BEV-AT, NIM-CN
35	2	ZMDM-SR, NSCIM-UA	90	5	ZMDM-SR, NSCIM-UA, NML-IE, SMU-SK, INM-RO
40	2	ZMDM-SR, NSCIM-UA	95	4	ZMDM-SR, NSCIM-UA, NML-IE, SMU-SK
45	2	ZMDM-SR, NSCIM-UA	100	5	ZMDM-SR, NSCIM-UA, NML-IE, BEV-AT, INM-RO, NIM-CN
50	2	ZMDM-SR, NSCIM-UA			

Table 12: Reference values and uncertainties for all lines of scale A and scale B. Additionally, the deviations and the consistency with the reference values (E_n) are given for each participant

Meas. Point	0,1 mm		0,2 mm		0,3 mm		0,4 mm		0,5 mm		0,6 mm	
$x_{ref,\ scale\ A}$	24,3 nm		2,0 nm		-0,4 nm		13,4 nm		8,8 nm		2,9 nm	
$x_{ref,\ scale\ B}$	29,9 nm		-6,4 nm		14,2 nm		1,7 nm		-11,3 nm		-0,6 nm	
$u_{c(xref),\ scale\ A}$	7,2 nm		7,1 nm		6,7 nm		7,7 nm		7,1 nm		7,0 nm	
$u_{c(xref),\ scale\ B}$	6,2 nm		6,2 nm		6,2 nm		6,2 nm		6,2 nm		6,2 nm	
	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n
MIRS-SI	-4,3	0,03	-2,0	0,02	0,4	0,00	6,6	0,05	21,2	0,17	27,1	0,22
OMH-HU	-143,3	0,71	-119,0	0,59	-13,6	0,07	-18,4	0,09	3,2	0,02	-1,9	0,01
BEV-AT	-10,3	0,21	8,0	0,16	10,4	0,21	6,6	0,14	5,2	0,11	9,1	0,19
SMU-SK	-22,3	0,24	-36,0	0,39	-9,6	0,10	-26,4	0,28	-12,8	0,14	1,1	0,01
PTB-DE	10,9	0,36	3,4	0,05	9,4	0,30	42,1	0,64	23,2	0,35	7,6	0,25
GUM-PL	33,7	0,13	2,0	0,01	24,4	0,09	52,6	0,20	5,2	0,02	11,1	0,04
MIKES-FI	-4,3	0,08	-1,0	0,03	-3,6	0,13	31,6	0,60	1,2	0,04	-4,9	0,18
LNMC-LV	-224,3	0,14	-202,0	0,12	-199,6	0,12	-13,4	0,01	191,2	0,12	397,1	0,24
NML-IE	-104,3	0,07	-48,0	0,03	-185,6	0,13	26,6	0,02	-368,8	0,25	-122,9	0,08
NCM-BG	-0,3	0,00	-2,0	0,01	1,4	0,01	-11,4	0,07	32,2	0,21	-4,9	0,03
INM-RO	15,7	0,08	58,0	0,29	60,4	0,30	26,6	0,13	1,2	0,01	7,1	0,03
ZMDM-SR	-41,6	0,21	-7,3	0,04	1,8	0,01	9,7	0,05	5,1	0,03	-27,6	0,14
DZM-HR	-21,3	0,14	-3,0	0,02	3,4	0,02	0,6	0,00	17,2	0,11	5,1	0,03
NSCIM-UA	11,7	0,27	10,0	0,23	-0,6	0,01	9,6	0,22	8,2	0,19	-206,9	4,35
CMI-CZ	3,7	0,11	-1,0	0,03	-3,6	0,11	-10,4	0,33	-0,8	0,03	1,1	0,03
NPL-GB	-2,3	0,04	2,2	0,03	-2,8	0,05	-10,0	0,16	-5,8	0,09	-3,2	0,05
METAS-CH	-3,3	0,15	-1,0	0,04	-3,6	0,16	-10,4	0,47	-8,8	0,39	-4,9	0,22
NPL-GB	1,0	0,02	0,5	0,01	-5,6	0,09	-6,8	0,11	-13,2	0,21	-2,6	0,04
METAS-CH	-1,9	0,08	-1,6	0,07	-0,2	0,01	-0,7	0,03	1,3	0,06	3,6	0,15
EIM-GR	-0,9	0,00	28,4	0,03	33,8	0,03	32,3	0,03	31,3	0,03	17,6	0,02
INRIM-IT	1,1	0,01	2,4	0,03	6,8	0,07	5,3	0,06	9,3	0,10	6,6	0,07
Nmi-VSL-NL	-7,9	0,17	-6,6	0,15	-4,2	0,09	-9,7	0,21	-3,7	0,08	-39,4	0,86
CEM-ES	5,1	0,09	-5,6	0,09	0,8	0,01	7,3	0,12	4,3	0,07	3,6	0,06
INMETRO-BR	0,1	0,00	48,4	0,38	47,8	0,38	19,3	0,15	22,3	0,18	23,6	0,19
CENAM-MX	-29,9	0,11	6,4	0,02	-14,2	0,05	-1,7	0,01	11,3	0,04	-99,4	0,36
NIST-US	6,1	0,33	7,6	0,40	2,5	0,14	2,7	0,14	0,1	0,01	5,5	0,29
NRC-CA	-3,1	0,04	-4,9	0,06	-0,5	0,01	0,6	0,01	-2,4	0,03	5,9	0,07
A*Star-NMC-SG	20,1	0,09	6,4	0,03	-14,2	0,06	23,3	0,10	11,3	0,05	0,6	0,00
NIM-CN	-18,9	0,19	-21,6	0,22	-26,2	0,26	-27,7	0,28	-21,7	0,22	-15,4	0,15
NPLI-IN	-3,9	0,01	-25,6	0,05	77,8	0,16	-145,7	0,31	-64,7	0,14	-113,4	0,24
NIMT-THA	-4,1	0,09	-2,4	0,05	4,5	0,10	18,7	0,42	16,4	0,37	4,6	0,10
VNIIM-RU	-2,9	0,11	-6,6	0,25	-4,2	0,16	-6,7	0,25	-4,7	0,17	-0,4	0,01

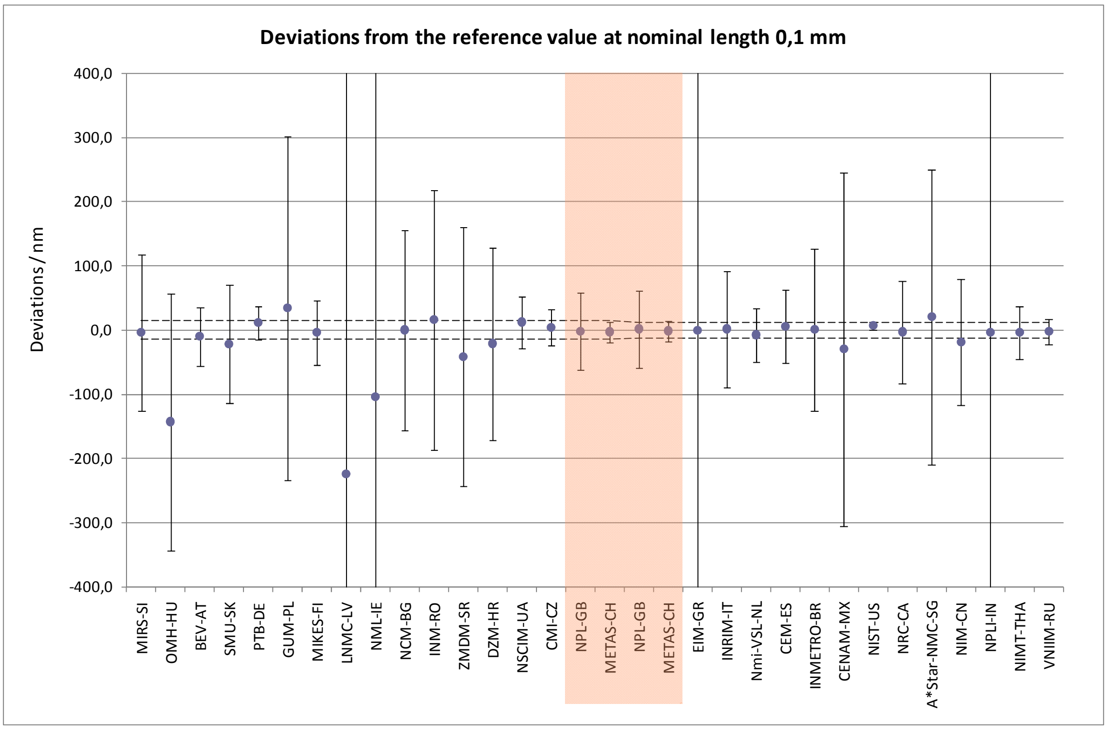
Meas. Point	0,7 mm		0,8 mm		0,9 mm		1 mm		5 mm		10 mm	
$x_{ref,\ scale\ A}$	2,9 nm		23,9 nm		-2,7 nm		24,3 nm		4,6 nm		5,8 nm	
$x_{ref,\ scale\ B}$	-20,2 nm		14,2 nm		-15,9 nm		27,3 nm		18,3 nm		19,3 nm	
$u_{c(xref),\ scale\ A}$	7,1 nm		6,7 nm		6,7 nm		6,7 nm		7,0 nm		7,0 nm	
$u_{c(xref),\ scale\ B}$	6,2 nm		6,2 nm		6,2 nm		6,2 nm		6,3 nm		6,4 nm	
	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n
MIRS-SI	27,1	0,22	46,1	0,37	52,7	0,42	45,7	0,36	15,4	0,11	-5,8	0,04
OMH-HU	-51,9	0,26	4,1	0,02	-58,3	0,29	-69,3	0,35	-61,6	0,31	-96,8	0,48
BEV-AT	12,1	0,25	14,1	0,29	26,7	0,55	25,7	0,52	-20,6	0,09	-16,8	0,08
SMU-SK	0,1	0,00	-37,9	0,41	-5,3	0,06	-27,3	0,29	-30,6	0,33	-35,8	0,38
PTB-DE	-2,1	0,03	4,7	0,15	-3,4	0,11	4,8	0,16	0,8	0,03	0,2	0,01
GUM-PL	-17,9	0,07	-70,9	0,26	-40,3	0,15	-18,3	0,07	130,4	0,49	129,2	0,48
MIKES-FI	-1,9	0,07	1,1	0,04	-10,3	0,36	-19,3	0,68	-8,6	0,31	-11,8	0,42
LNMC-LV	297,1	0,18	76,1	0,05	102,7	0,06	25,7	0,02	415,4	0,25	354,2	0,22
NML-IE	-62,9	0,04	116,1	0,08	342,7	0,23	295,7	0,20	235,4	0,16	194,2	0,13
NCM-BG	0,1	0,00	-12,9	0,08	5,7	0,04	-3,3	0,02	-7,6	0,05	-4,8	0,03
INM-RO	17,1	0,08	-13,9	0,07	22,7	0,11	-54,3	0,27	25,4	0,13	24,2	0,12
ZMDM-SR	-34,7	0,17	-88,7	0,44	-48,2	0,24	-66,3	0,33	-3643,8	17,89	-8224,8	40,38
DZM-HR	25,1	0,17	9,1	0,06	63,7	0,42	46,7	0,31	31,4	0,20	19,2	0,12
NSCIM-UA	24,1	0,56	17,1	0,39	19,7	0,45	23,7	0,55	63,4	1,46	86,2	1,98
CMI-CZ	-2,9	0,09	-3,9	0,12	-5,3	0,16	-4,3	0,13	-9,6	0,30	-11,8	0,36
NPL-GB	-1,4	0,02	-5,0	0,08	-4,2	0,07	-1,8	0,03	-7,9	0,13	-6,1	0,10
METAS-CH	-8,9	0,39	-6,9	0,30	-3,3	0,14	0,7	0,03	-8,6	0,38	-10,8	0,47
NPL-GB	-12,0	0,19	-17,1	0,27	-14,8	0,24	-22,2	0,35	3,7	0,06	1,9	0,03
METAS-CH	2,2	0,09	0,8	0,03	-0,1	0,00	0,7	0,03	2,7	0,11	-3,3	0,14
EIM-GR	-18,8	0,02	-64,2	0,06	-19,1	0,02	3,7	0,00	-47,3	0,04	-56,3	0,05
INRIM-IT	0,2	0,00	2,8	0,03	-3,1	0,03	2,7	0,03	2,7	0,03	3,7	0,04
Nmi-VSL-NL	-1,8	0,04	5,8	0,13	-7,1	0,16	1,7	0,04	-2,3	0,05	-7,3	0,15
CEM-ES	7,2	0,12	18,8	0,32	16,9	0,28	-0,3	0,01	21,7	0,36	40,7	0,68
INMETRO-BR	36,2	0,28	8,8	0,07	3,9	0,03	-8,3	0,07	-22,3	0,18	-23,3	0,18
CENAM-MX	-79,8	0,29	-114,2	0,41	-84,1	0,30	-27,3	0,10	-118,3	0,43	-19,3	0,07
NIST-US	5,1	0,27	4,0	0,21	4,6	0,25	3,0	0,16	2,4	0,12	5,6	0,29
NRC-CA	2,6	0,03	3,2	0,04	2,3	0,03	4,5	0,05	3,1	0,04	3,6	0,04
A*Star-NMC-SG	20,2	0,09	-14,2	0,06	40,9	0,18	47,7	0,21	-43,3	0,19	-69,3	0,30
NIM-CN	-19,8	0,20	-37,2	0,37	-16,1	0,16	-21,3	0,21	-9,3	0,09	-18,3	0,18
NPLI-IN	63,2	0,13	63,8	0,14	-43,1	0,09	-123,3	0,26	-6,3	0,01	-95,3	0,20
NIMT-THA	-12,0	0,27	-2,4	0,05	9,2	0,21	12,6	0,28	2,4	0,05	-3,2	0,07
VNIIM-RU	-3,8	0,14	-6,2	0,23	-8,1	0,30	-5,3	0,20	-10,3	0,37	-9,3	0,32

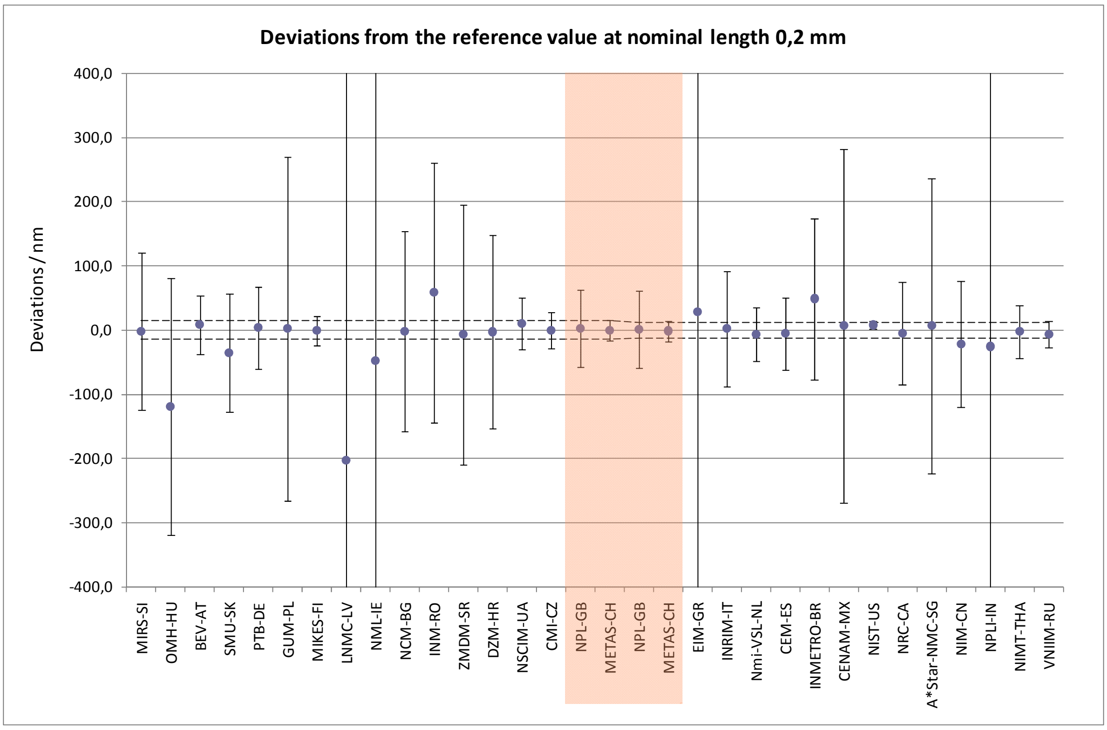
Meas. Point	15 mm		20 mm		25 mm		30 mm		35 mm		40 mm	
$x_{ref,\ scale\ A}$	-5,1 nm		-2,8 nm		-145,3 nm		-165,8 nm		-157,3 nm		-157,5 nm	
$x_{ref,\ scale\ B}$	-24,8 nm		19,4 nm		-120,6 nm		-150,2 nm		-125,9 nm		-127,0 nm	
$u_{c(xref),\ scale\ A}$	7,4 nm		7,4 nm		7,5 nm		7,5 nm		7,6 nm		7,7 nm	
$u_{c(xref),\ scale\ B}$	6,5 nm		6,5 nm		6,6 nm		6,7 nm		6,9 nm		7,0 nm	
	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n
MIRS-SI	5,1	0,03	2,8	0,02	5,3	0,03	-14,2	0,07	-42,7	0,21	-52,5	0,24
OMH-HU	-44,9	0,22	-25,2	0,13	-117,7	0,59	6,8	0,03	68,3	0,34	-164,5	0,82
BEV-AT	-58,9	0,26	-45,2	0,20	-34,7	0,16	-81,2	0,36	-97,7	0,44	-114,5	0,51
SMU-SK	-15,9	0,17	-31,2	0,33	62,3	0,67	78,8	0,84	67,3	0,72	55,5	0,59
PTB-DE	22,7	0,74	8,5	0,28	11,2	0,36	7,3	0,24	7,6	0,25	8,4	0,27
GUM-PL	179,1	0,66	83,8	0,31	79,3	0,29	150,8	0,55	31,3	0,11	112,5	0,40
MIKES-FI	4,1	0,15	-6,2	0,22	1,3	0,05	-5,2	0,18	-3,7	0,13	-1,5	0,05
LNMC-LV	275,1	0,17	512,8	0,31	375,3	0,23	1135,8	0,69	7,3	0,00	477,5	0,29
NML-IE	485,1	0,33	402,8	0,27	905,3	0,61	505,8	0,34	837,3	0,57	1057,5	0,71
NCM-BG	-15,9	0,10	-10,2	0,06	-8,7	0,06	-10,2	0,06	7,3	0,05	-21,5	0,14
INM-RO	15,1	0,07	-7,2	0,04	105,3	0,52	145,8	0,72	137,3	0,67	147,5	0,72
ZMDM-SR	-10832,0	53,15	-14579,5	71,51	-18571,6	91,05	-22327,2	109,39	-25707,3	125,86	-29003,7	141,88
DZM-HR	-1,9	0,01	16,8	0,10	-92,7	0,53	-110,2	0,61	-141,7	0,76	-9,5	0,05
NSCIM-UA	121,1	2,51	164,8	3,40	207,3	4,25	289,8	5,88	291,3	5,85	319,5	6,34
CMI-CZ	-6,9	0,21	-0,2	0,01	-7,7	0,23	-8,2	0,24	-3,7	0,10	-10,5	0,29
NPL-GB	-6,9	0,11	8,5	0,14	-1,9	0,03	2,6	0,04	1,7	0,03	2,5	0,04
METAS-CH	-11,9	0,53	-0,2	0,01	-8,7	0,38	-5,2	0,22	-6,7	0,28	-4,5	0,19
NPL-GB	4,1	0,07	3,3	0,05	7,3	0,12	-0,4	0,01	-0,3	0,00	-2,5	0,04
METAS-CH	-9,2	0,39	-4,4	0,18	-12,4	0,52	-10,8	0,45	-10,1	0,42	-18,0	0,73
EIM-GR	-50,2	0,04	-145,4	0,13	-148,4	0,13	-271,8	0,24	-270,1	0,24	-395,0	0,35
INRIM-IT	1,8	0,02	2,6	0,03	-5,4	0,06	-3,8	0,04	-5,1	0,06	-9,0	0,10
Nmi-VSL-NL	-4,2	0,09	8,6	0,18	19,6	0,39	8,2	0,16	-2,1	0,04	15,0	0,29
CEM-ES	40,8	0,68	23,6	0,40	41,6	0,69	19,2	0,32	48,9	0,81	48,0	0,79
INMETRO-BR	1,8	0,01	-3,4	0,03	51,6	0,41	55,2	0,43	41,9	0,33	47,0	0,37
CENAM-MX	24,8	0,09	-119,4	0,42	-179,4	0,61	150,2	0,50	-74,1	0,24	127,0	0,40
NIST-US	5,4	0,28	7,9	0,41	4,0	0,21	4,4	0,23	6,6	0,33	7,7	0,39
NRC-CA	0,6	0,01	3,7	0,05	5,6	0,07	10,3	0,12	5,1	0,06	5,9	0,07
A*Star-NMC-SG	-50,2	0,22	-19,4	0,08	-29,4	0,13	0,2	0,00	-24,1	0,10	-23,0	0,10
NIM-CN	12,8	0,13	8,6	0,09	29,6	0,30	53,2	0,53	50,9	0,51	54,0	0,54
NPLI-IN	-43,2	0,09	-42,4	0,09	-223,4	0,47	-110,8	0,23	-50,1	0,11	-85,0	0,18
NIMT-THA	5,2	0,11	-18,1	0,37	1,1	0,02	-1,1	0,02	-11,2	0,19	-0,9	0,01
VNIIM-RU	-13,2	0,44	-13,4	0,43	-19,4	0,59	-16,8	0,49	-20,1	0,57	-24,0	0,65

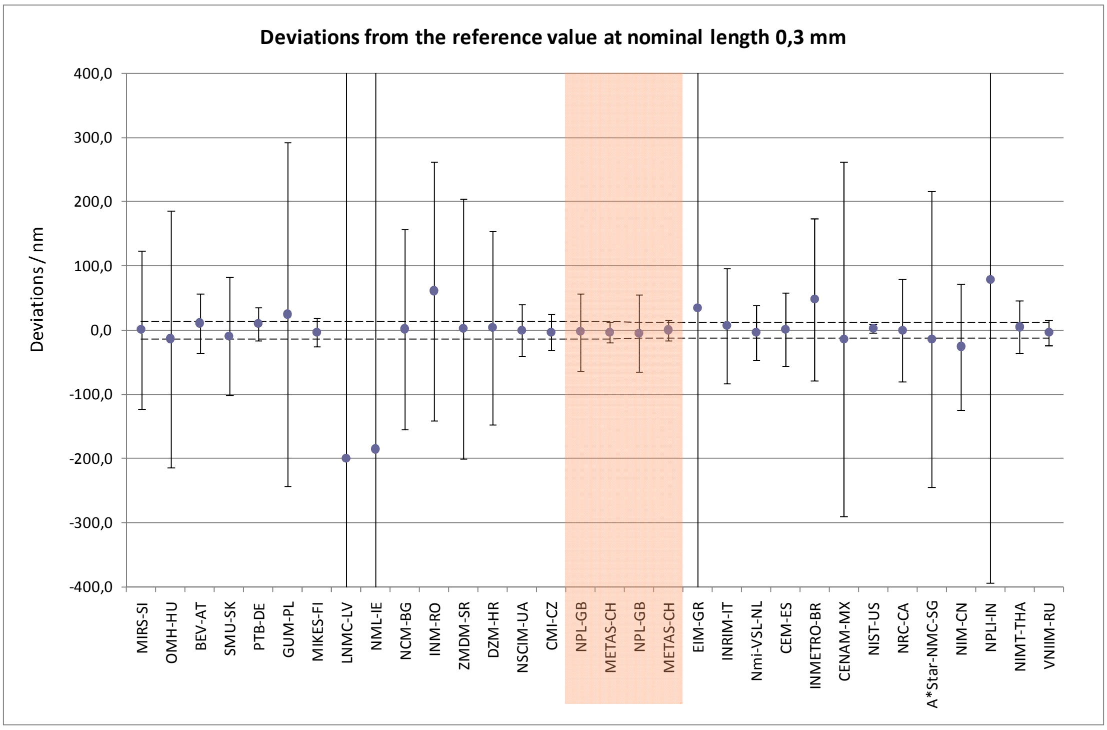
Meas. Point	45 mm		50 mm		55 mm		60 mm		65 mm		70 mm	
$x_{ref,\ scale\ A}$	-212,8 nm		-192,2 nm		-209,1 nm		-255,1 nm		-212,4 nm		-243,2 nm	
$x_{ref,\ scale\ B}$	-182,1 nm		-111,6 nm		-136,1 nm		-154,4 nm		-116,0 nm		-136,8 nm	
$u_{c(xref),\ scale\ A}$	7,8 nm		7,9 nm		8,0 nm		8,1 nm		8,2 nm		8,3 nm	
$u_{c(xref),\ scale\ B}$	7,1 nm		7,2 nm		7,4 nm		7,5 nm		7,7 nm		7,8 nm	
	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n
MIRS-SI	-77,2	0,33	-27,8	0,11	-60,9	0,24	-54,9	0,21	-37,6	0,14	-36,8	0,13
OMH-HU	-69,2	0,34	-68,8	0,34	-141,9	0,71	-62,9	0,31	-19,6	0,10	-85,8	0,43
BEV-AT	-138,2	0,62	-97,8	0,44	-132,9	0,60	-162,9	0,73	-164,6	0,74	-200,8	0,90
SMU-SK	103,8	1,10	85,2	0,91	85,1	0,90	113,1	1,20	68,4	0,72	81,2	0,86
PTB-DE	11,9	0,38	11,6	0,37	7,6	0,24	10,9	0,35	12,0	0,38	6,8	0,21
GUM-PL	-23,2	0,08	-66,8	0,23	-102,9	0,35	-166,9	0,57	-122,6	0,41	-235,8	0,78
MIKES-FI	-7,2	0,25	-2,8	0,10	-0,9	0,03	-1,9	0,06	-0,6	0,02	-1,8	0,06
LNMC-LV	352,8	0,21	862,2	0,52	329,1	0,20	835,1	0,51	-7,6	0,00	133,2	0,08
NML-IE	972,8	0,66	1112,2	0,75	1089,1	0,74	1855,1	1,25	2072,4	1,40	2023,2	1,37
NCM-BG	-18,2	0,11	-32,8	0,20	-33,9	0,21	-38,9	0,24	-36,6	0,22	-38,8	0,24
INM-RO	162,8	0,80	142,2	0,70	189,1	0,92	235,1	1,14	172,4	0,84	203,2	0,98
ZMDM-SR	-32942,9	160,99	-36957,0	180,41	-40190,9	195,97	-43650,0	212,56	-48016,5	233,50	-50709,4	246,23
DZM-HR	12,8	0,07	24,2	0,12	-12,9	0,06	-10,9	0,05	11,4	0,05	-11,8	0,05
NSCIM-UA	143,8	2,81	413,2	7,97	423,1	8,04	464,1	8,67	448,4	8,24	473,2	8,54
CMI-CZ	-16,2	0,44	-20,8	0,55	-8,9	0,23	-20,9	0,52	-11,6	0,28	-15,8	0,37
NPL-GB	2,1	0,03	1,6	0,03	-1,3	0,02	-2,3	0,04	-5,6	0,09	2,2	0,04
METAS-CH	-3,2	0,13	-3,8	0,16	-4,9	0,20	-4,9	0,19	-7,6	0,30	-2,8	0,11
NPL-GB	-0,9	0,01	-0,8	0,01	-1,4	0,02	1,9	0,03	8,2	0,13	8,3	0,13
METAS-CH	-11,9	0,48	-14,4	0,57	-14,9	0,58	-16,6	0,64	-15,0	0,57	-18,2	0,68
EIM-GR	-399,9	0,35	-449,4	0,40	-410,9	0,36	-392,6	0,34	-358,0	0,31	-383,2	0,34
INRIM-IT	2,1	0,02	5,6	0,06	-1,9	0,02	-1,6	0,02	-1,0	0,01	-6,2	0,06
Nmi-VSL-NL	23,1	0,43	52,6	0,97	35,1	0,64	30,4	0,54	32,0	0,56	47,8	0,82
CEM-ES	31,1	0,51	10,6	0,17	8,1	0,13	20,4	0,33	3,0	0,05	8,8	0,14
INMETRO-BR	84,1	0,66	27,6	0,22	49,1	0,39	77,4	0,42	-24,0	0,13	59,8	0,32
CENAM-MX	282,1	0,86	11,6	0,03	36,1	0,10	54,4	0,15	-84,0	0,22	-163,2	0,42
NIST-US	-1,0	0,05	0,8	0,04	4,4	0,21	1,3	0,06	4,8	0,22	7,8	0,35
NRC-CA	10,6	0,13	11,9	0,14	8,6	0,10	8,8	0,10	9,1	0,11	3,8	0,04
A*Star-NMC-SG	-17,9	0,08	-38,4	0,16	-38,9	0,17	-45,6	0,19	-59,0	0,25	-38,2	0,16
NIM-CN	66,1	0,66	79,6	0,80	83,1	0,83	106,4	1,07	111,0	1,11	109,8	1,10
NPLI-IN	-55,9	0,12	-51,4	0,11	-115,9	0,24	-116,6	0,25	-13,0	0,03	80,8	0,17
NIMT-THA	-9,9	0,15	-10,3	0,15	-11,6	0,16	3,5	0,05	-15,1	0,19	-69,2	0,81
VNIIM-RU	-19,9	0,52	-21,4	0,54	-20,9	0,51	-22,6	0,53	-22,0	0,50	-24,2	0,53

Meas. Point	75	mm	80	mm	85	mm	90	mm	95	mm	100	mm
$x_{ref,\ scale\ A}$	-281,2	nm	-241,3	nm	-256,3	nm	-429,0	nm	-362,1	nm	-386,2	nm
$x_{ref,\ scale\ B}$	-151,9	nm	-124,2	nm	-138,7	nm	-316,4	nm	-265,7	nm	-259,0	nm
$u_{c(xref),\ scale\ A}$	8,4	nm	8,6	nm	9,4	nm	9,7	nm	9,9	nm	9,1	nm
$u_{c(xref),\ scale\ B}$	8,0	nm	8,1	nm	8,3	nm	8,4	nm	8,6	nm	8,8	nm
	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n	x_i-x_{ref}	E_n
MIRS-SI	-8,8	0,03	-38,7	0,12	-63,7	0,19	-81,0	0,24	-57,9	0,17	-53,8	0,15
OMH-HU	-277,8	1,38	-214,7	1,07	-274,7	1,35	-210,0	1,04	-103,9	0,52	-99,8	0,49
BEV-AT	-183,8	0,82	-233,7	1,05	-259,7	1,16	-228,0	1,02	-252,9	1,14	-322,8	1,44
SMU-SK	90,2	0,95	40,3	0,42	59,3	0,62	207,0	2,09	151,1	1,52	136,2	1,41
PTB-DE	7,6	0,24	10,2	0,31	25,6	0,80	18,7	0,58	9,3	0,29	-1,7	0,05
GUM-PL	-169,8	0,55	-291,7	0,93	-305,7	0,96	-176,0	0,54	-188,9	0,57	-201,8	0,60
MIKES-FI	-2,8	0,09	6,3	0,21	-35,7	0,67	30,0	0,56	20,1	0,37	-1,8	0,06
LNMC-LV	531,2	0,32	11,3	0,01	-693,7	0,42	-991,0	0,60	-847,9	0,52	-1333,8	0,81
NML-IE	2781,2	1,88	2261,3	1,53	2316,3	1,57	2769,0	1,87	3202,1	2,16	3226,2	2,18
NCM-BG	-42,8	0,26	-47,7	0,29	-56,7	0,34	-56,0	0,33	-60,9	0,36	-56,8	0,33
INM-RO	231,2	1,12	201,3	0,97	236,3	1,14	399,0	1,90	302,1	1,44	356,2	1,68
ZMDM-SR	-55087,5	267,05	-58628,0	283,74	-61991,7	299,29	-65609,9	316,12	-68649,3	330,10	-72892,4	350,03
DZM-HR	-28,8	0,13	-20,7	0,09	-53,7	0,23	38,0	0,16	41,1	0,17	74,2	0,30
NSCIM-UA	468,2	8,30	476,3	8,28	482,3	8,16	503,0	8,34	544,1	8,84	521,2	8,37
CMI-CZ	-13,8	0,31	-17,7	0,38	-23,7	0,51	-30,0	0,62	-19,9	0,40	-25,8	0,50
NPL-GB	1,9	0,03	1,3	0,02	-0,2	0,00	5,3	0,08	-0,4	0,01	4,6	0,07
METAS-CH	1,2	0,05	-0,7	0,02	-6,7	0,25	-5,0	0,18	-2,9	0,10	-0,8	0,03
NPL-GB	2,1	0,03	17,9	0,28	12,6	0,20	4,9	0,08	14,5	0,23	12,9	0,20
METAS-CH	-18,1	0,66	-20,8	0,74	-19,3	0,68	-23,6	0,81	-23,3	0,78	-20,0	0,66
EIM-GR	-389,1	0,34	-380,8	0,33	-431,3	0,38	-324,6	0,28	-296,3	0,26	-238,0	0,21
INRIM-IT	0,9	0,01	1,2	0,01	-0,3	0,00	1,4	0,01	3,7	0,04	4,0	0,04
Nmi-VSL-NL	39,9	0,68	25,2	0,42	29,7	0,49	43,4	0,70	49,7	0,79	72,0	1,13
CEM-ES	-4,1	0,06	19,2	0,30	-5,3	0,08	9,4	0,14	8,7	0,13	-2,0	0,03
INMETRO-BR	71,9	0,39	133,2	0,72	79,7	0,43	8,4	0,05	2,7	0,01	-83,0	0,45
CENAM-MX	-248,1	0,62	-275,8	0,66	-261,3	0,61	-183,6	0,41	-234,3	0,51	-241,0	0,50
NIST-US	5,7	0,25	-1,1	0,05	13,3	0,57	3,0	0,13	-0,6	0,02	9,4	0,38
NRC-CA	8,3	0,09	6,1	0,07	13,4	0,15	3,6	0,04	3,9	0,04	2,2	0,02
A*Star-NMC-SG	-73,1	0,31	-25,8	0,11	-23,3	0,10	-21,6	0,09	27,7	0,12	47,0	0,19
NIM-CN	120,9	1,21	132,2	1,32	136,7	1,33	149,4	1,49	150,7	1,50	158,0	1,53
NPLI-IN	45,9	0,10	-65,8	0,14	-155,3	0,33	-47,6	0,10	-326,3	0,68	-454,0	0,95
NIMT-THA	-6,1	0,07	-0,3	0,00	-13,0	0,13	2,4	0,02	-13,7	0,13	-0,3	0,00
VNIIM-RU	-27,1	0,58	-22,8	0,47	-22,3	0,45	-28,6	0,55	-26,3	0,50	-27,0	0,49

Graphical presentations of measured results indicated as deviations from calculated reference values follow in the next 30 diagrams. The dotted lines indicate the uncertainties of the reference values. Uncertainty bars in the diagrams represent expanded uncertainty U (k = 2).




Deviations from the reference value at nominal length 0,2 mm
Deviations / nm
400,0
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,3 mm
Deviations / nm
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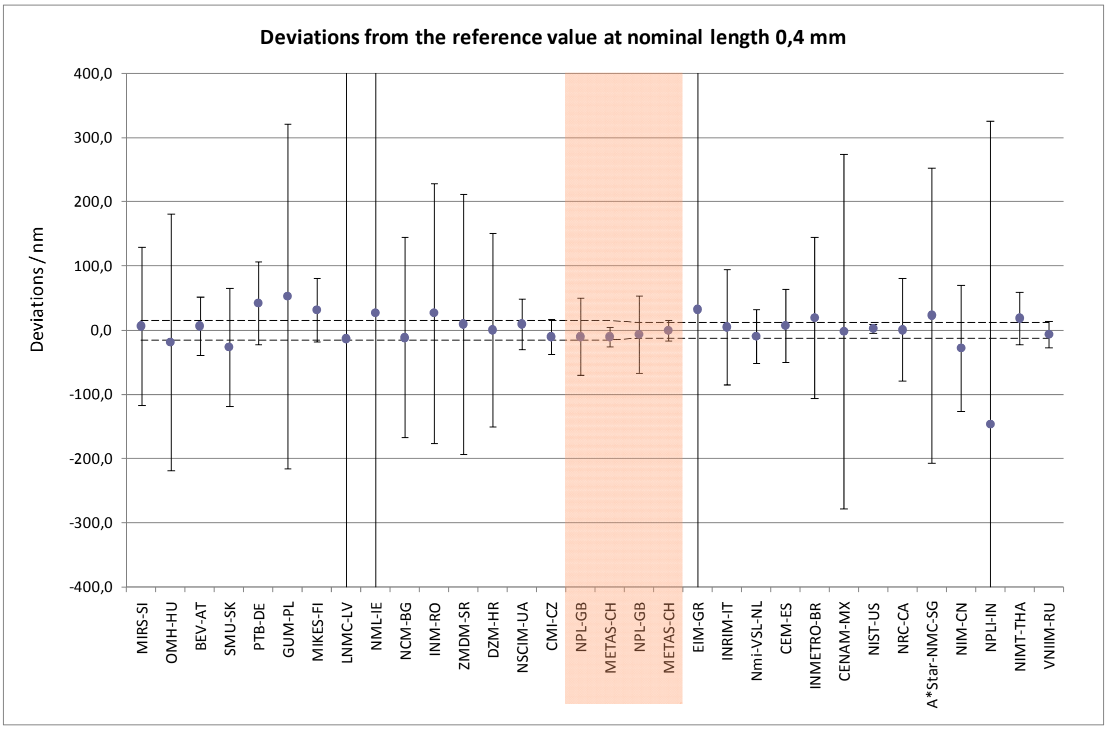
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,4 mm
Deviations / nm
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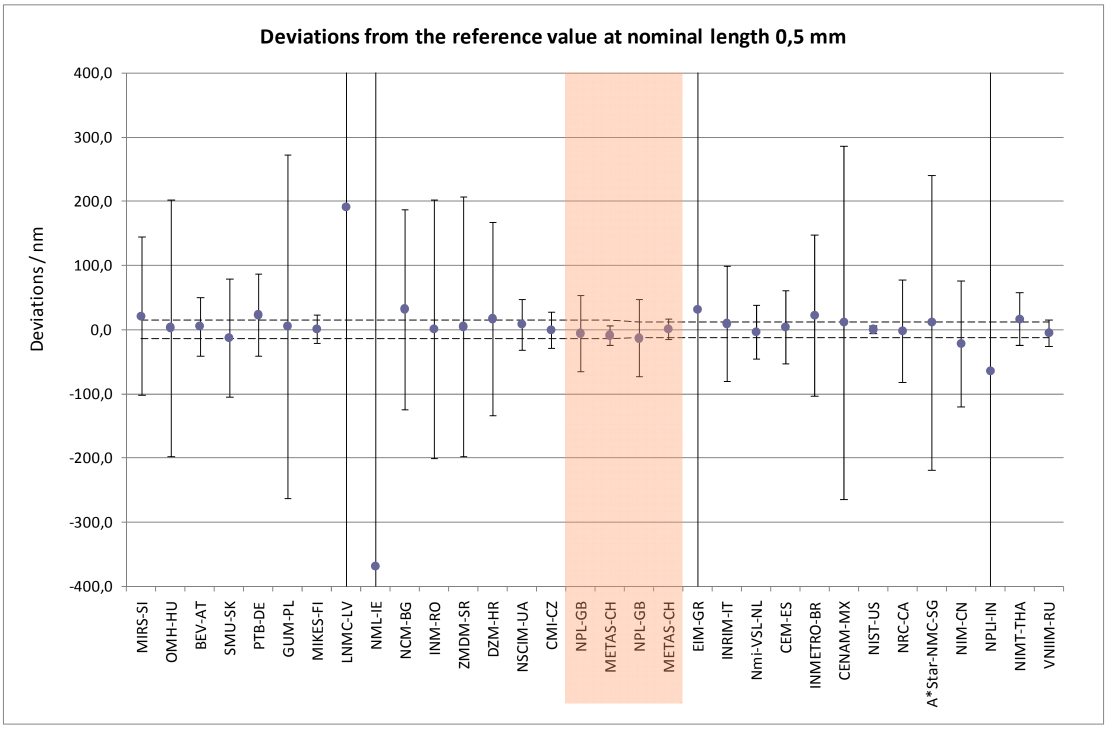
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,5 mm
Deviations / nm
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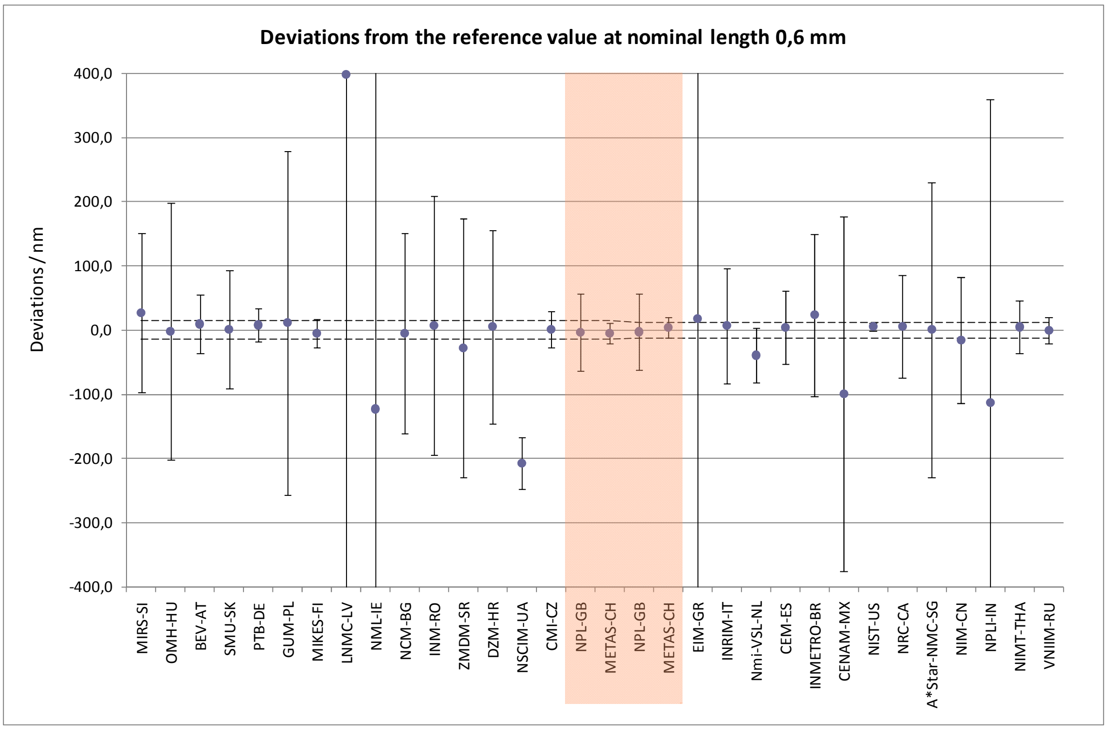
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,6 mm
Deviations / nm
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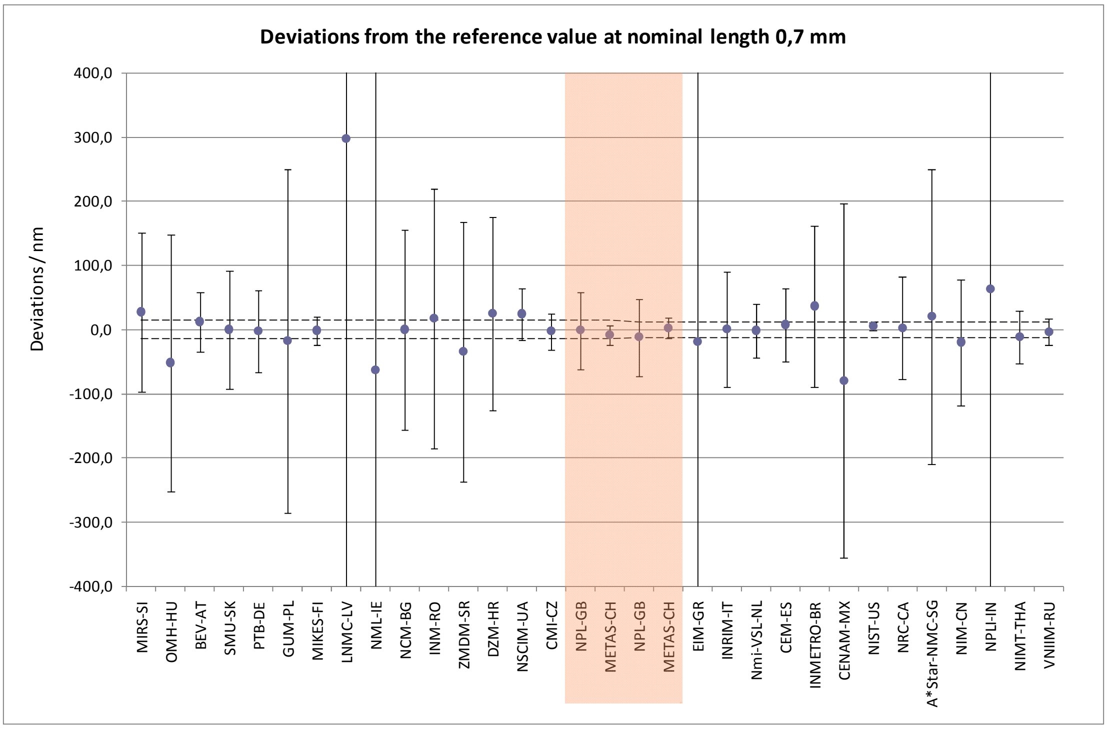
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,7 mm
Deviations / nm
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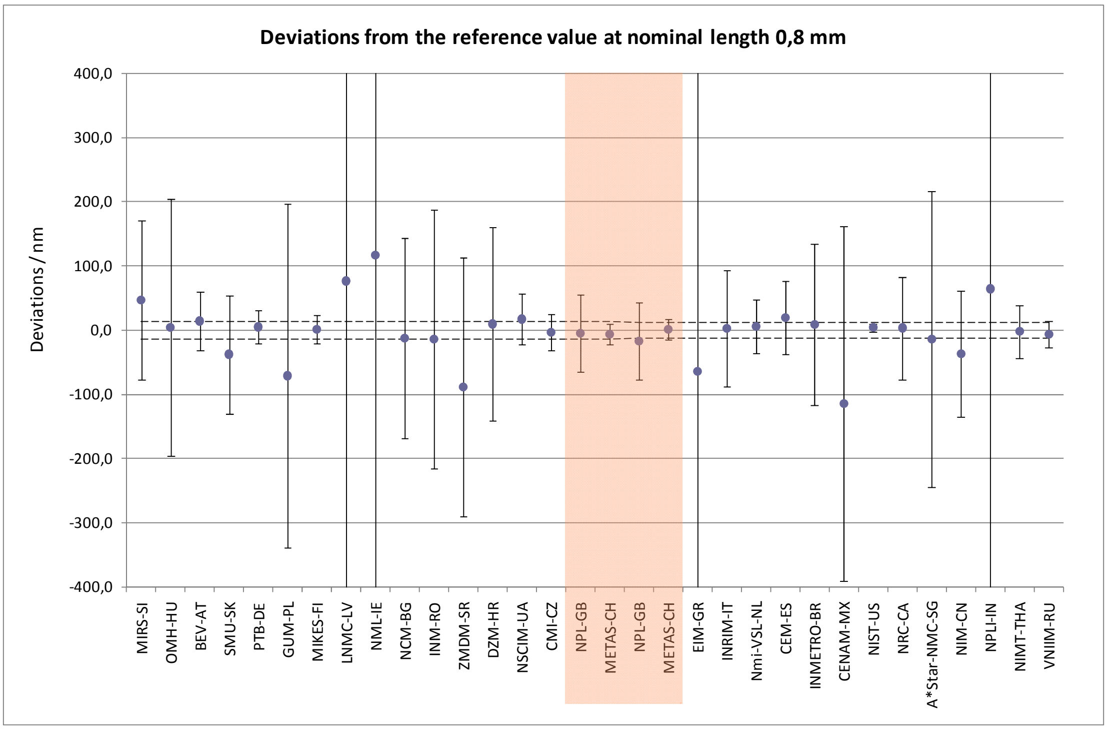
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,8 mm
Deviations / nm
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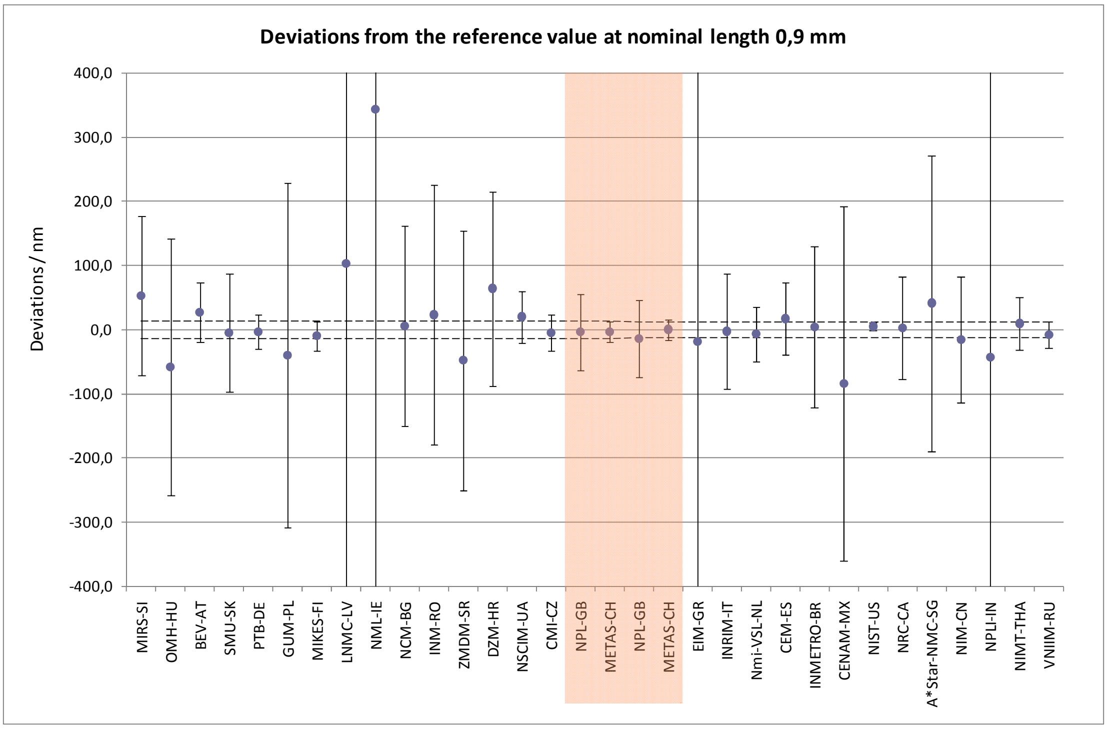
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 0,9 mm
Deviations / nm
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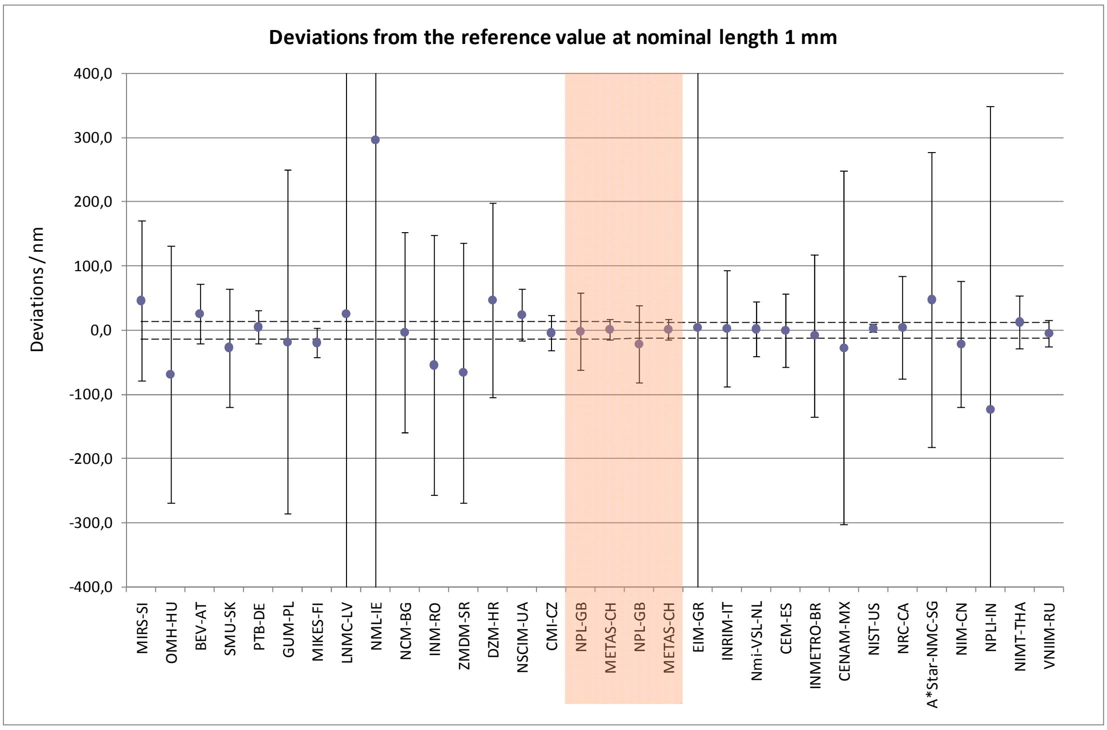
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU


Deviations from the reference value at nominal length 1 mm
Deviations / nm
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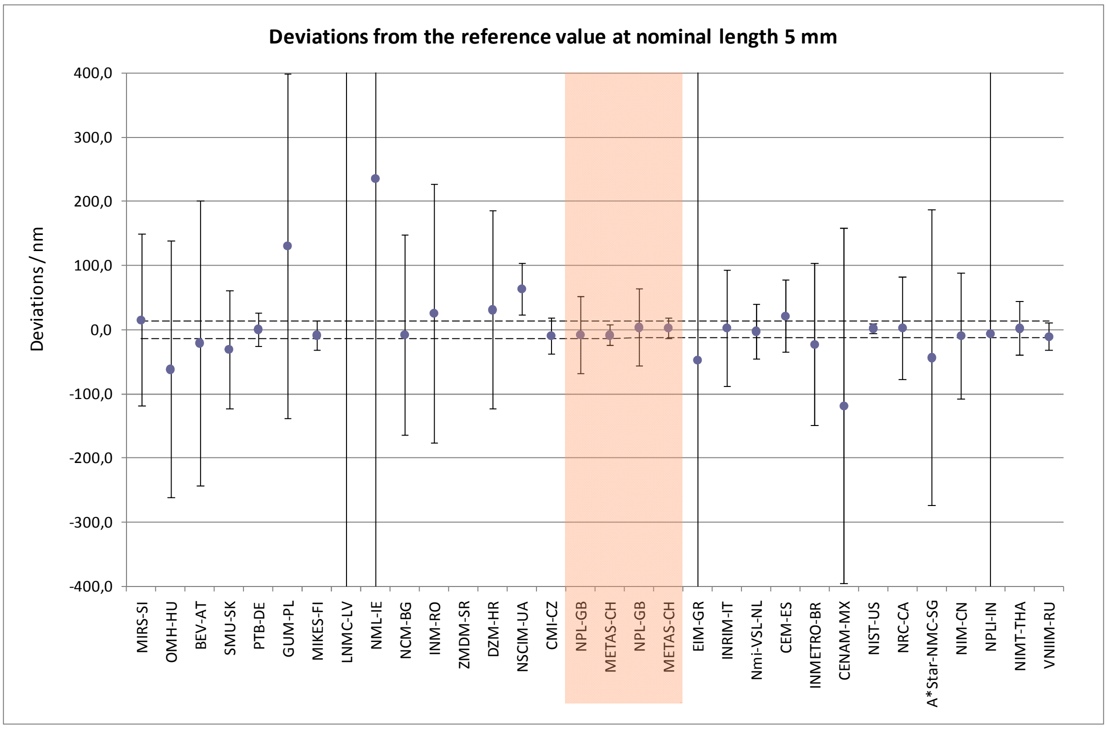
300,0
200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
ZMDM-SR
DZM-HR
NSCIM-UA
CMI-CZ
NPL-GB
METAS-CH
NPL-GB
METAS-CH
EIM-GR
INRIM-IT
Nmi-VSL-NL
CEM-ES
INMETRO-BR
CENAM-MX
NIST-US
NRC-CA
A*Star-NMC-SG
NIM-CN
NPLI-IN
NIMT-THA
VNIIM-RU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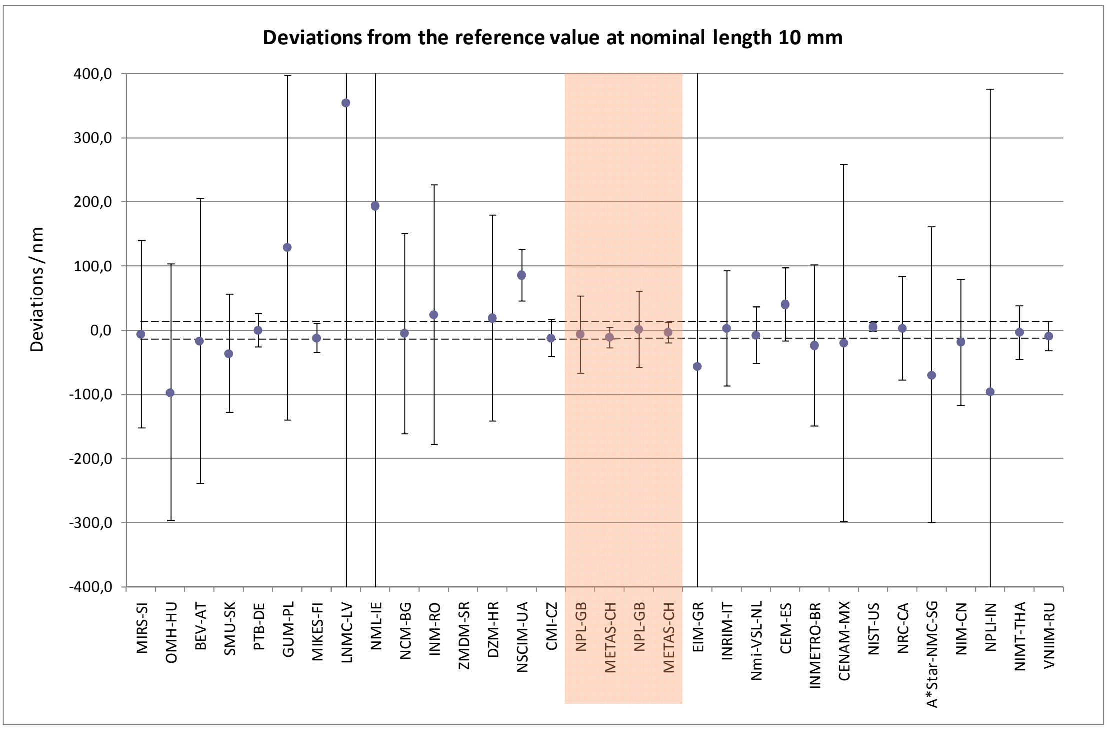
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Deviations / nm
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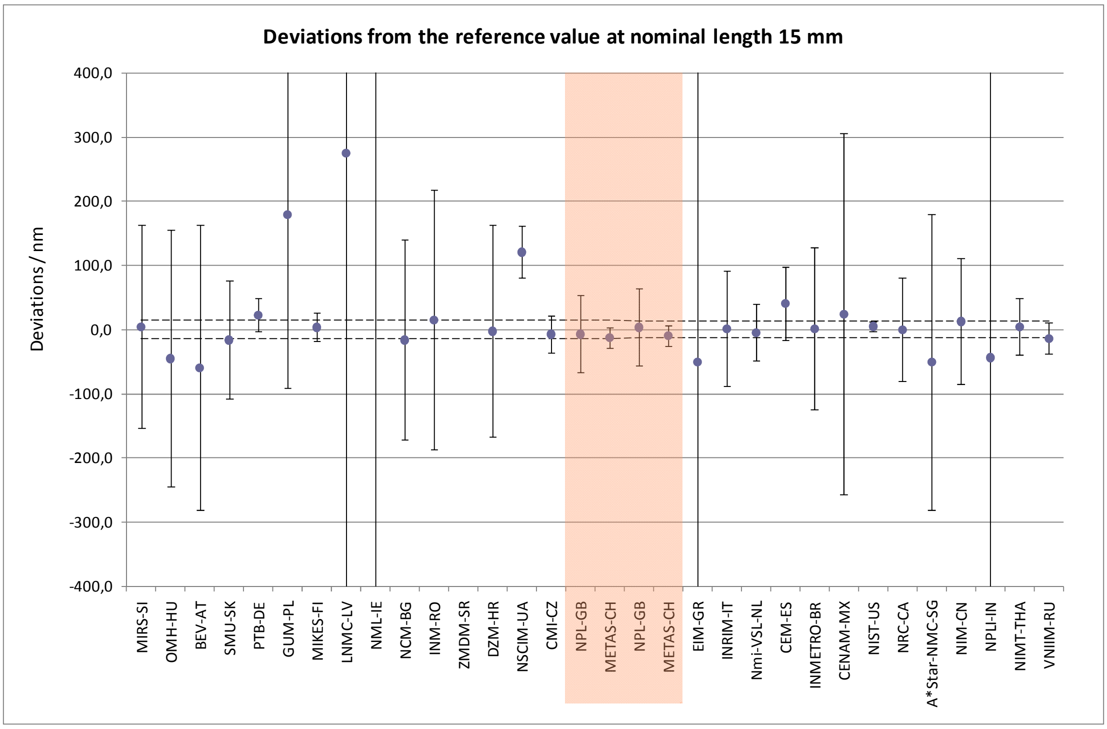
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Deviations / nm
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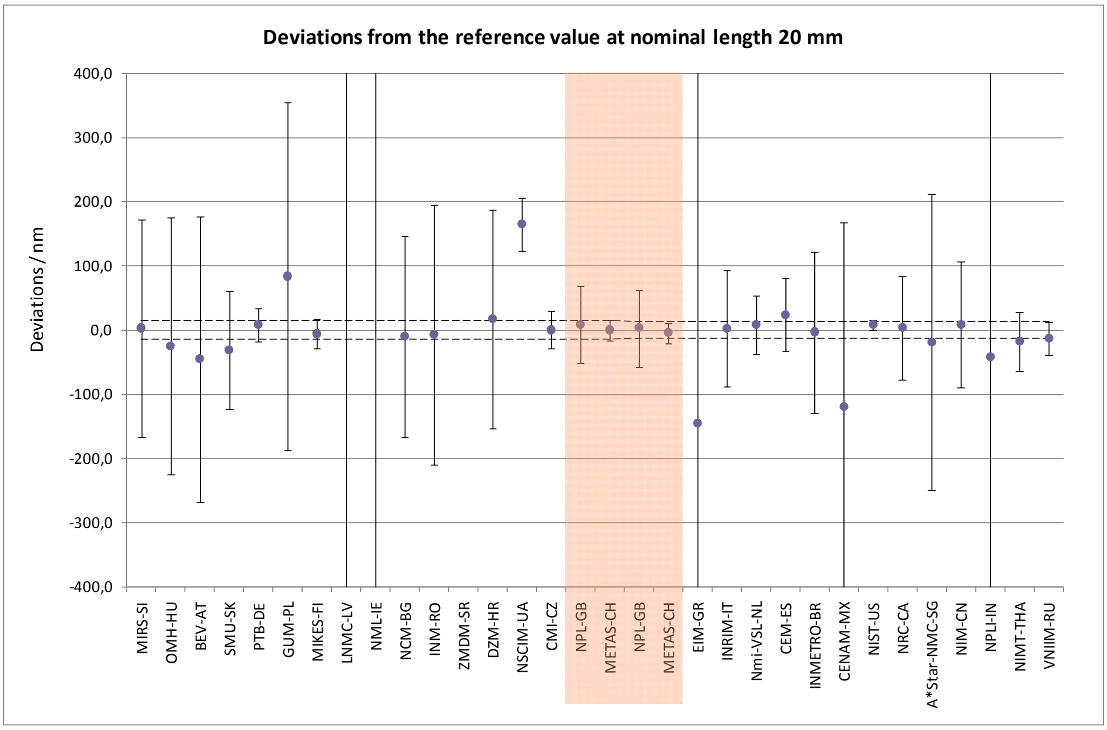
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Deviations / nm
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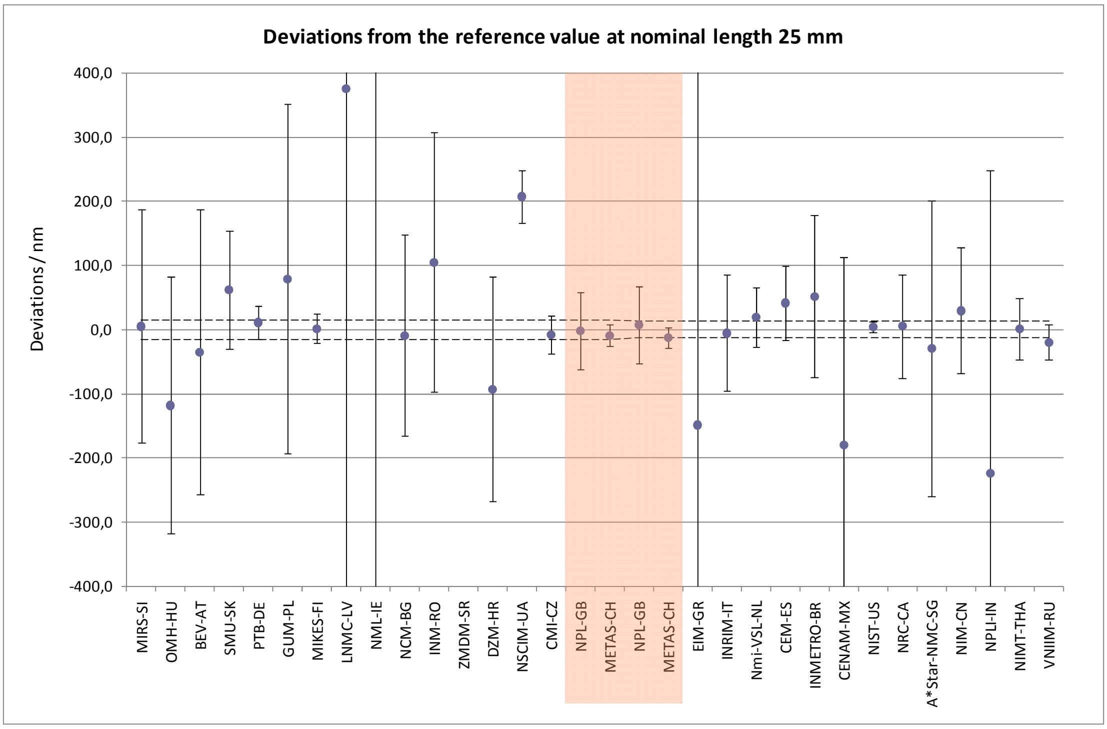
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Deviations / nm
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-200,0
-300,0
-400,0
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SMU-SK
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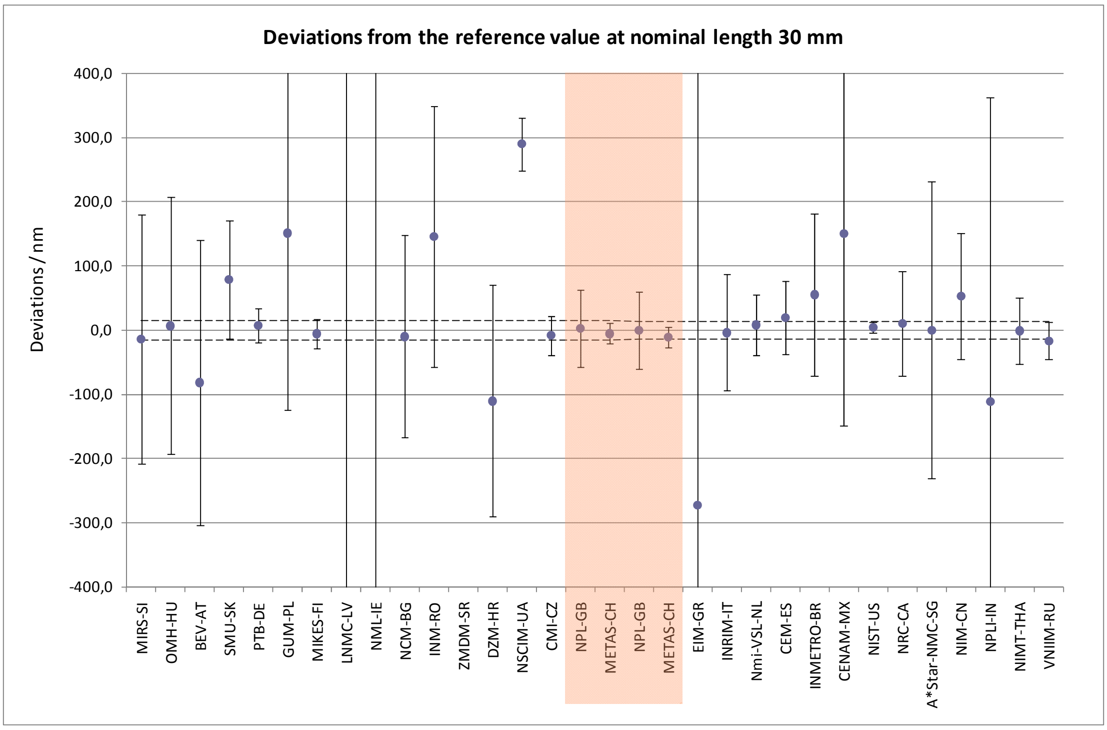
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Deviations / nm
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0,0
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-200,0
-300,0
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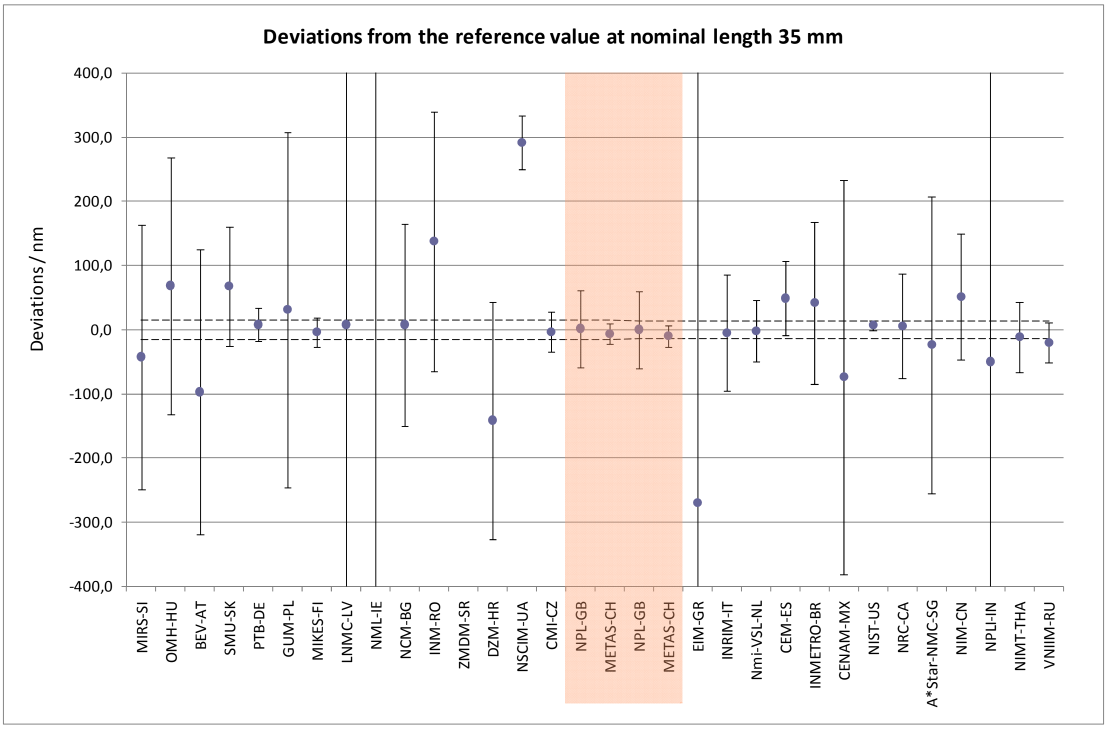
Deviations from the reference value at nominal length 35 mm
Deviations / nm
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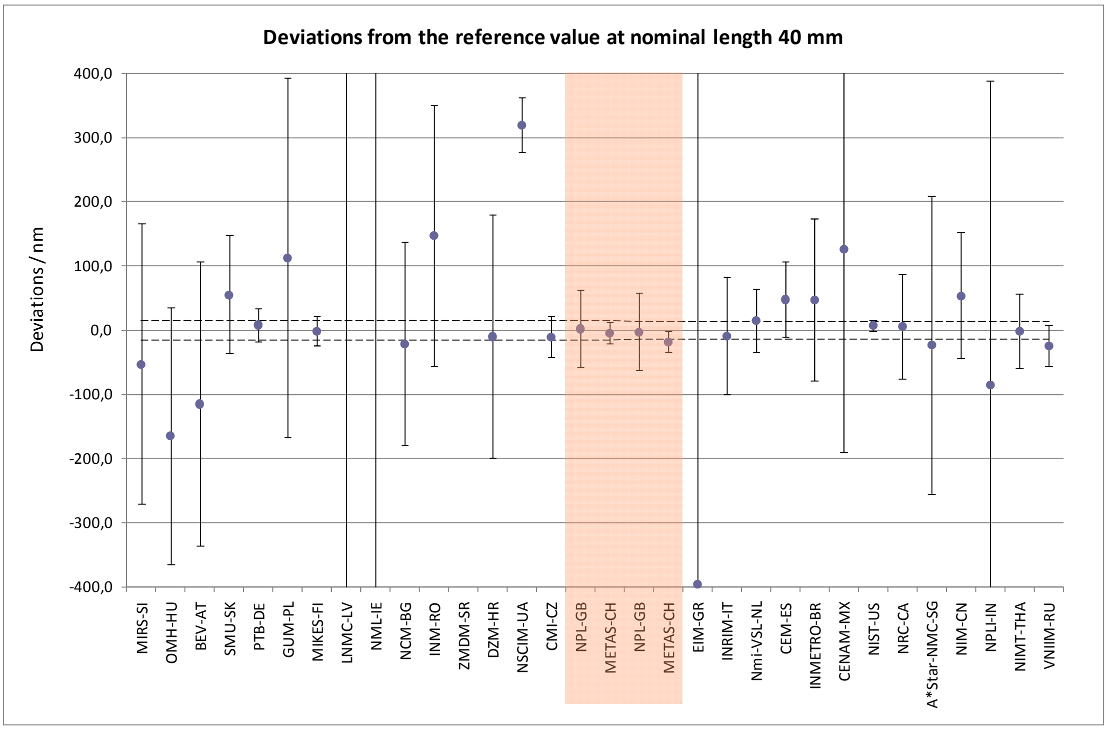
Deviations from the reference value at nominal length 40 mm
Deviations / nm
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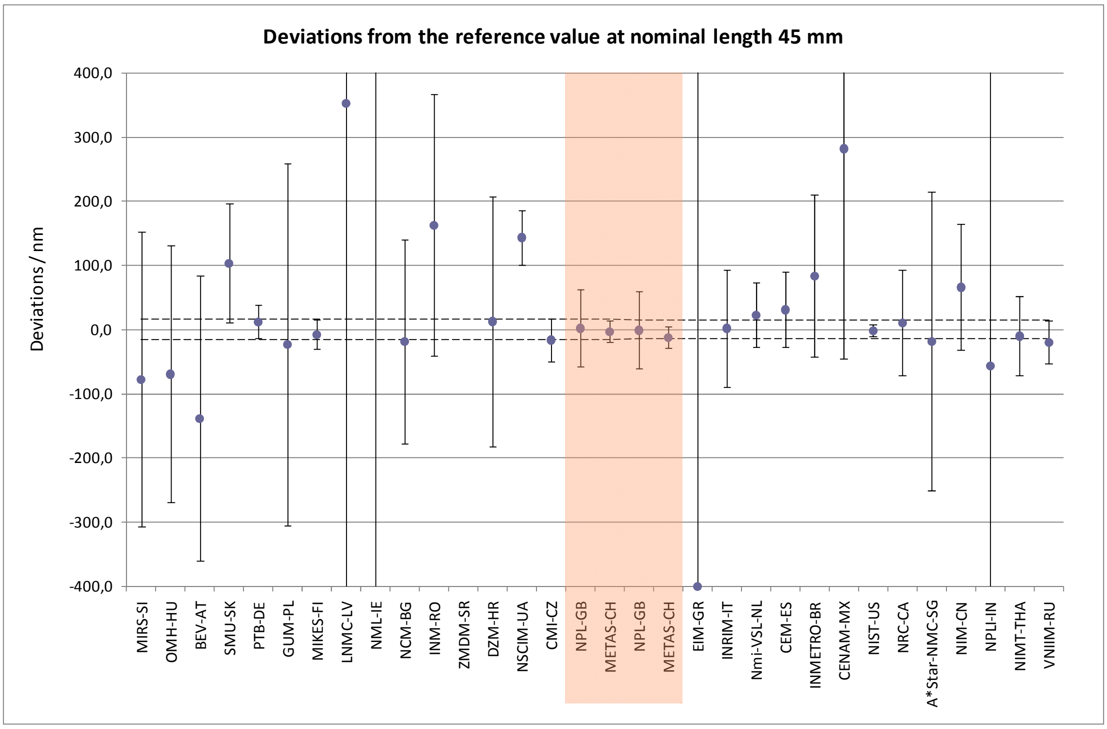
Deviations from the reference value at nominal length 45 mm
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-300,0
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OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
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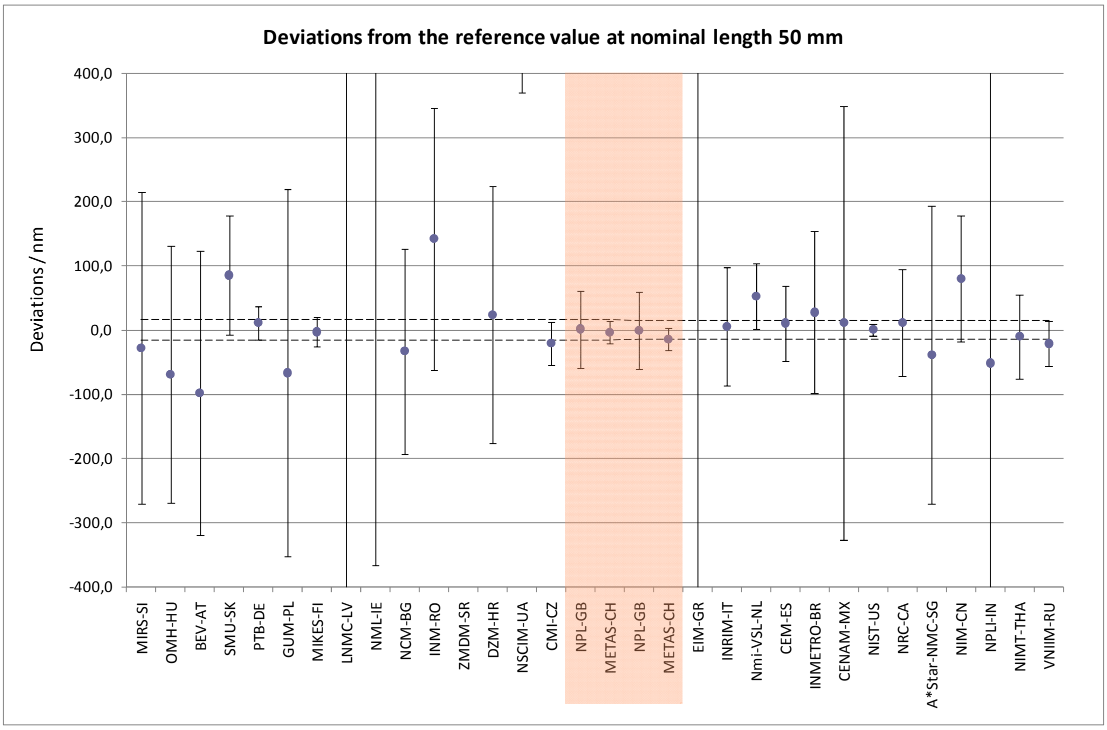
Deviations from the reference value at nominal length 50 mm
Deviations / nm
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OMH-HU
BEV-AT
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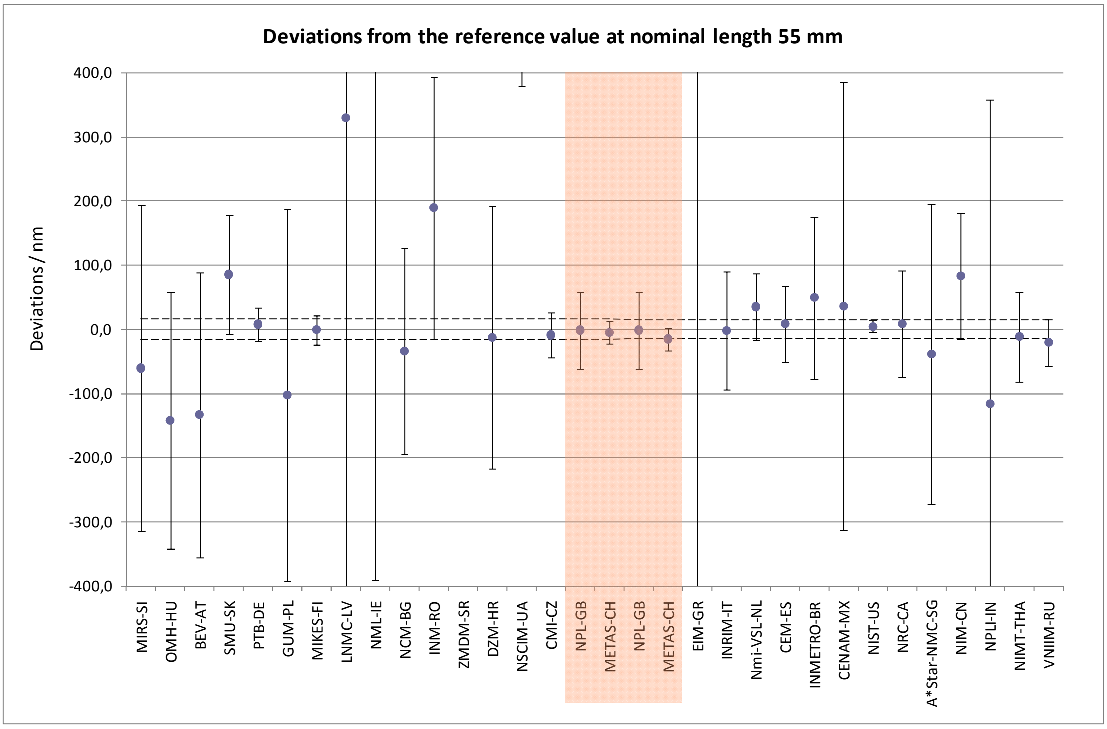
Deviations from the reference value at nominal length 55 mm
Deviations / nm
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100,0
0,0
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-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
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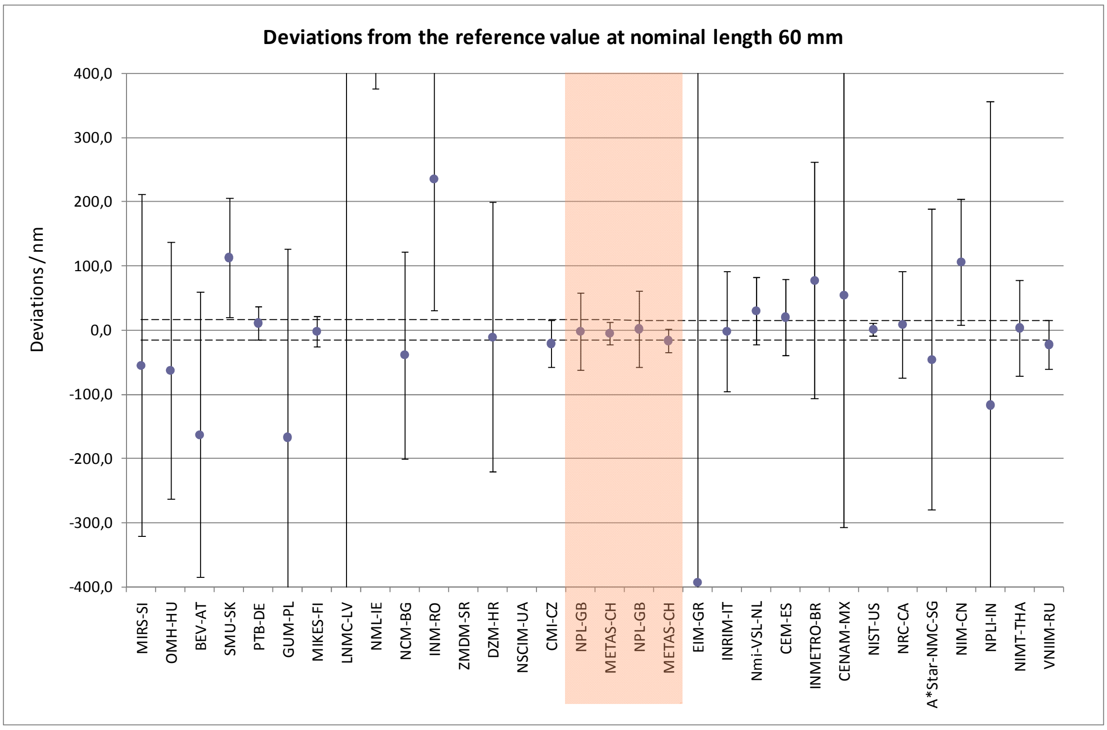
Deviations from the reference value at nominal length 60 mm
Deviations / nm
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100,0
0,0
-100,0
-200,0
-300,0
-400,0
MIRS-SI
OMH-HU
BEV-AT
SMU-SK
PTB-DE
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MIKES-FI
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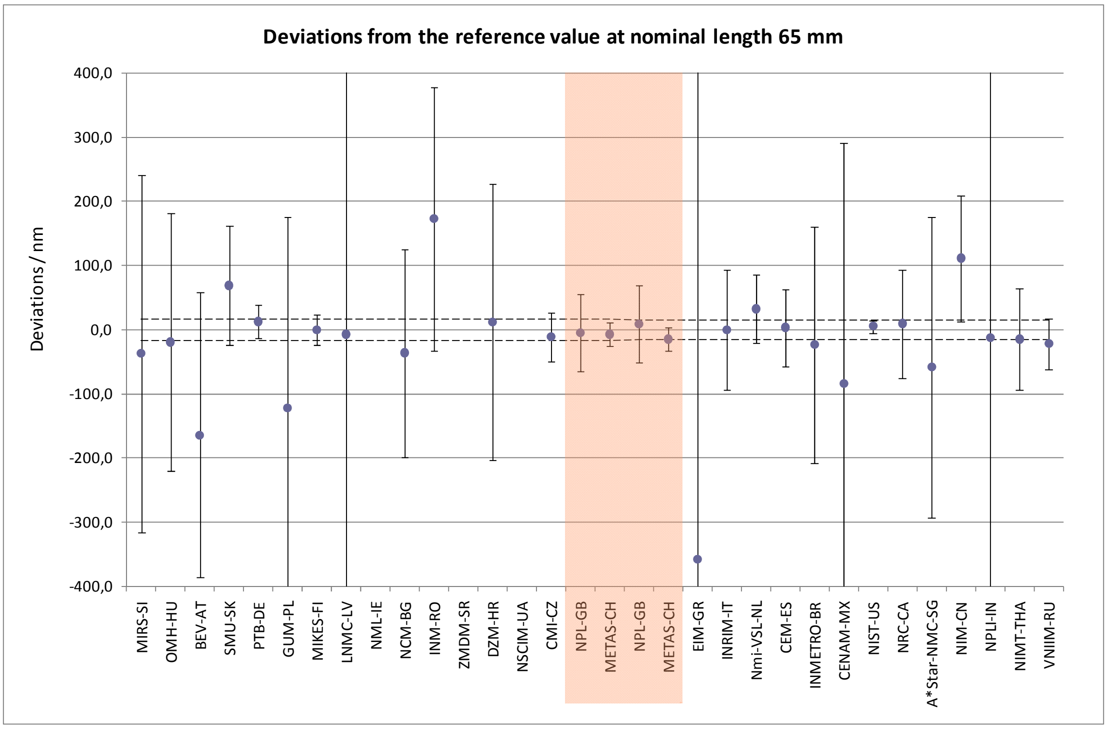
Deviations from the reference value at nominal length 65 mm
Deviations / nm
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200,0
100,0
0,0
-100,0
-200,0
-300,0
-400,0
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OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
LNMC-LV
NML-IE
NCM-BG
INM-RO
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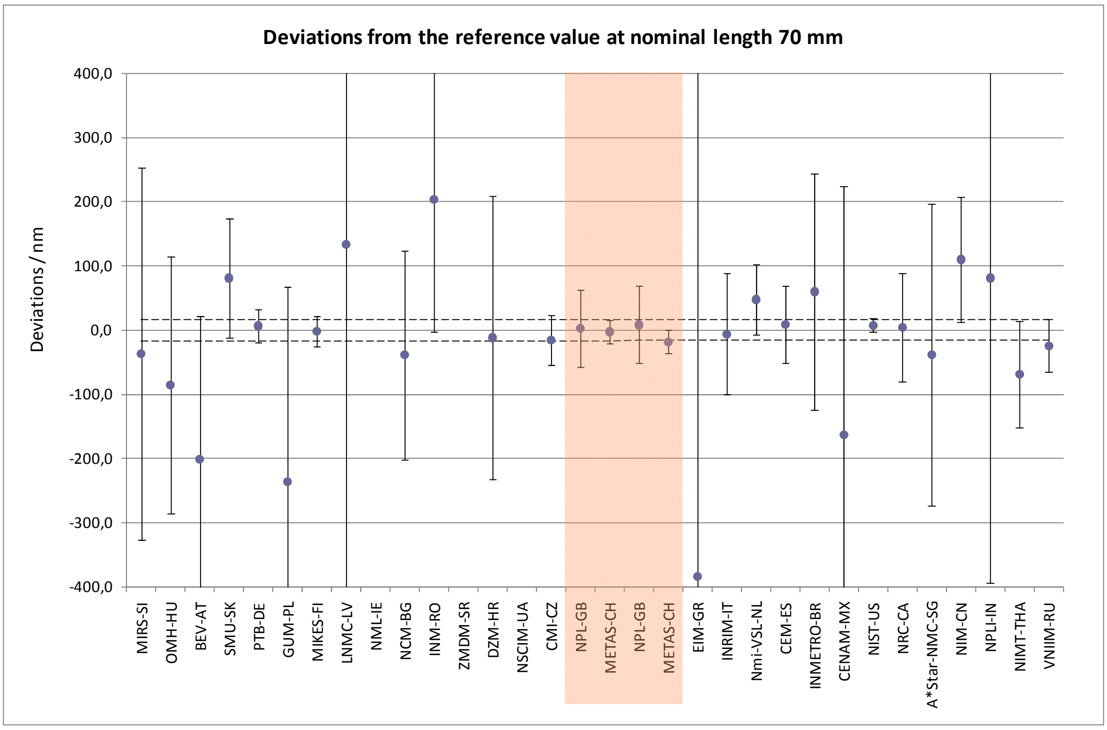
Deviations from the reference value at nominal length 70 mm
Deviations / nm
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200,0
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0,0
-100,0
-200,0
-300,0
-400,0
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BEV-AT
SMU-SK
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MIKES-FI
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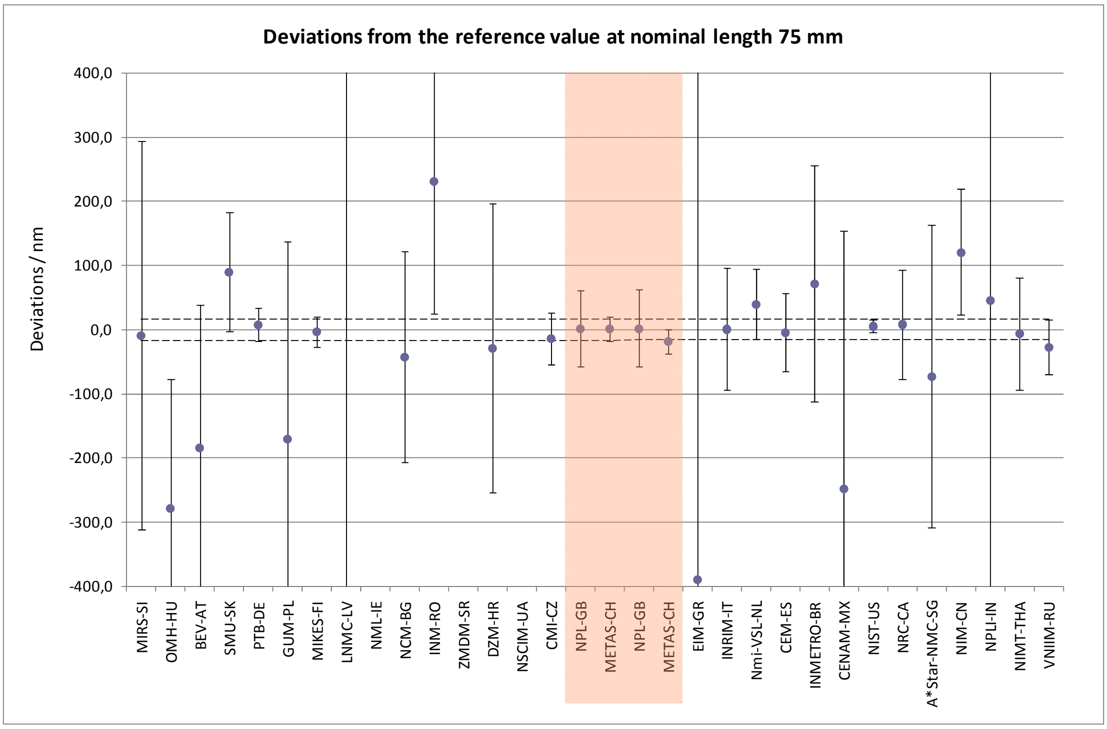
Deviations from the reference value at nominal length 75 mm
Deviations / nm
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-200,0
-300,0
-400,0
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OMH-HU
BEV-AT
SMU-SK
PTB-DE
GUM-PL
MIKES-FI
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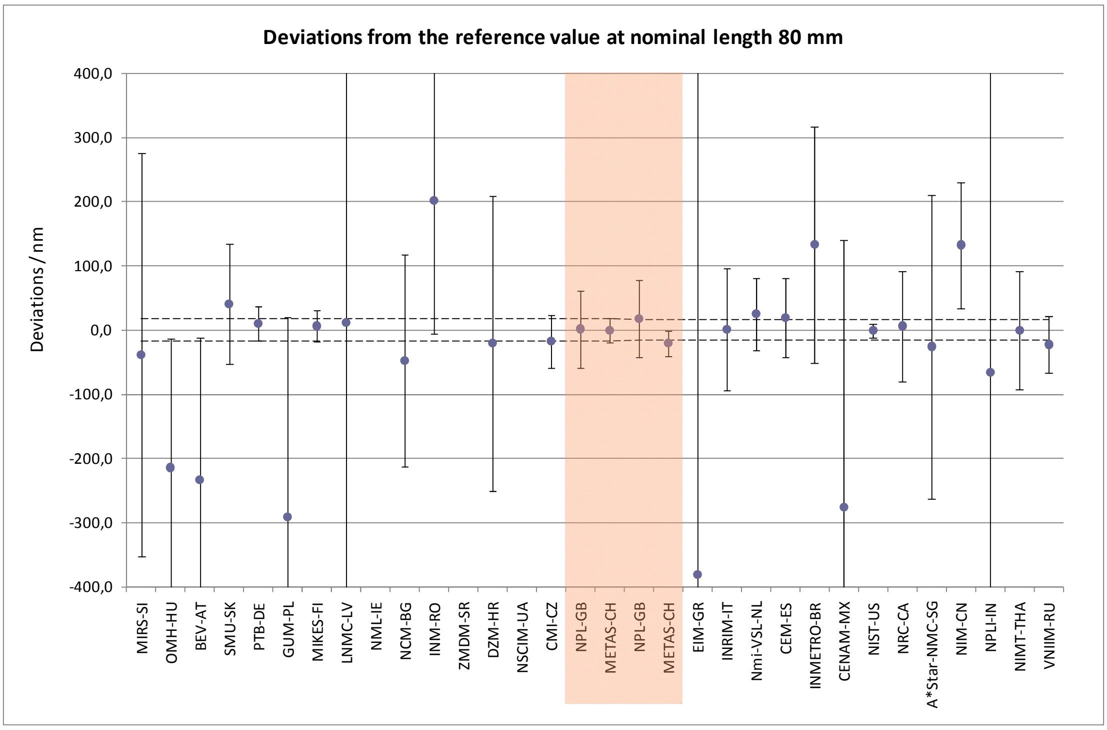
Deviations from the reference value at nominal length 80 mm
Deviations / nm
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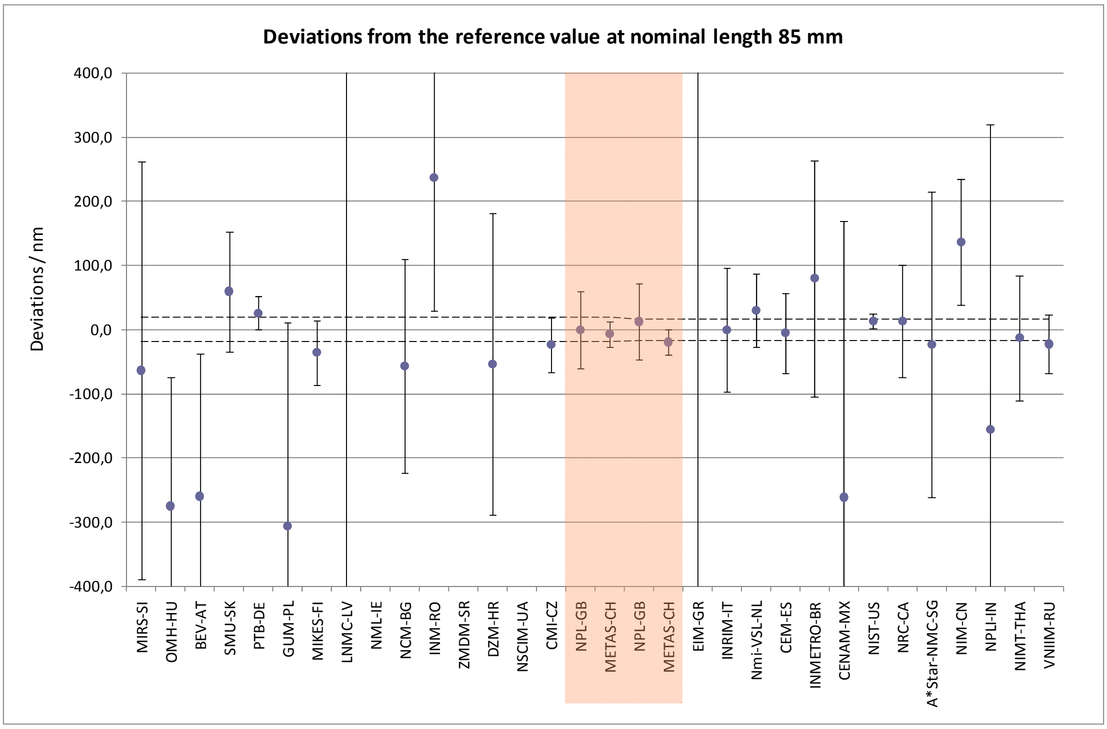
Deviations from the reference value at nominal length 85 mm
Deviations / nm
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BEV-AT
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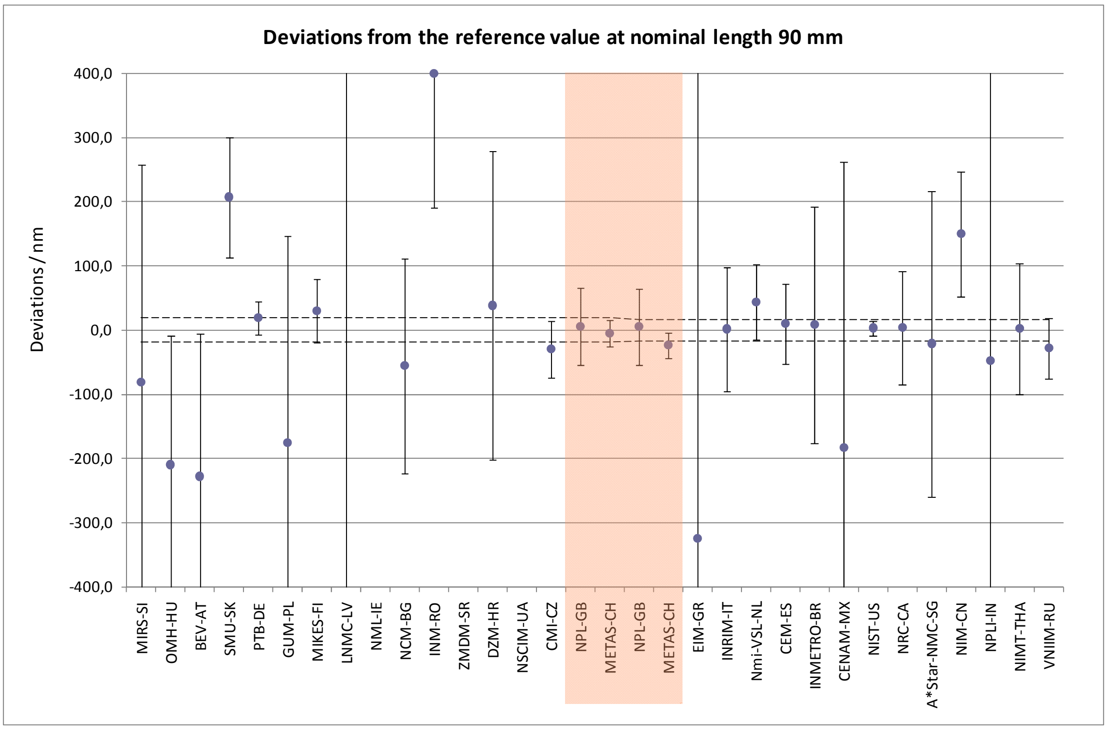
Deviations from the reference value at nominal length 90 mm
Deviations / nm
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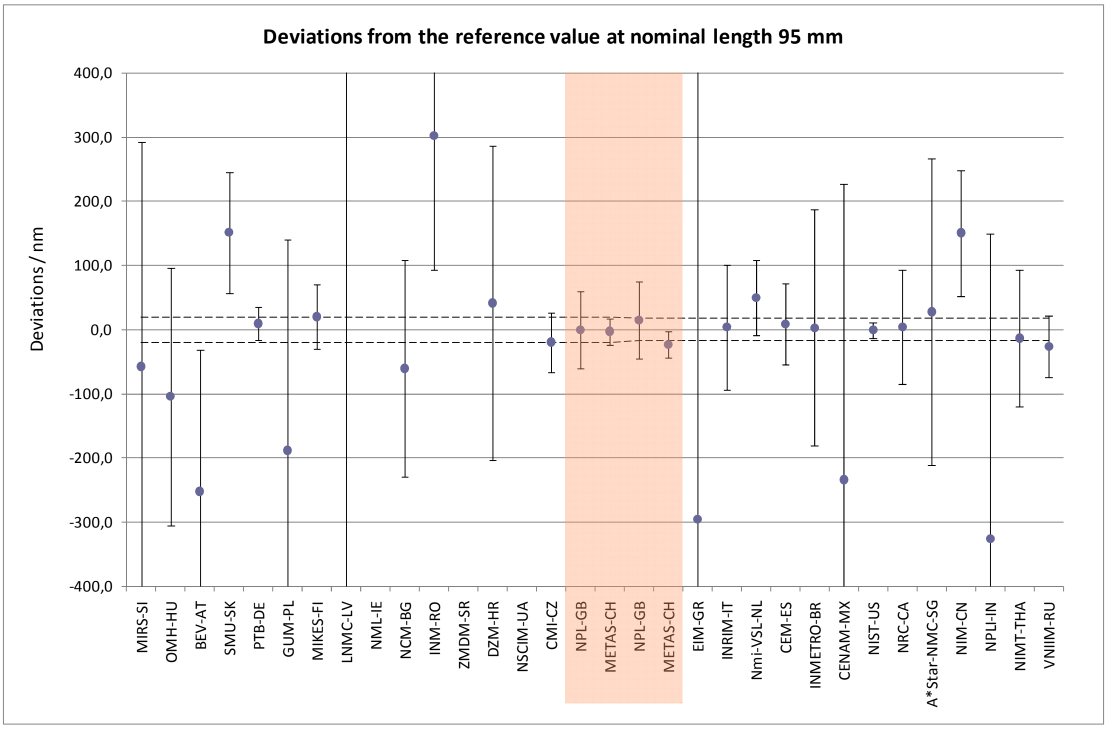
Deviations from the reference value at nominal length 95 mm
Deviations / nm
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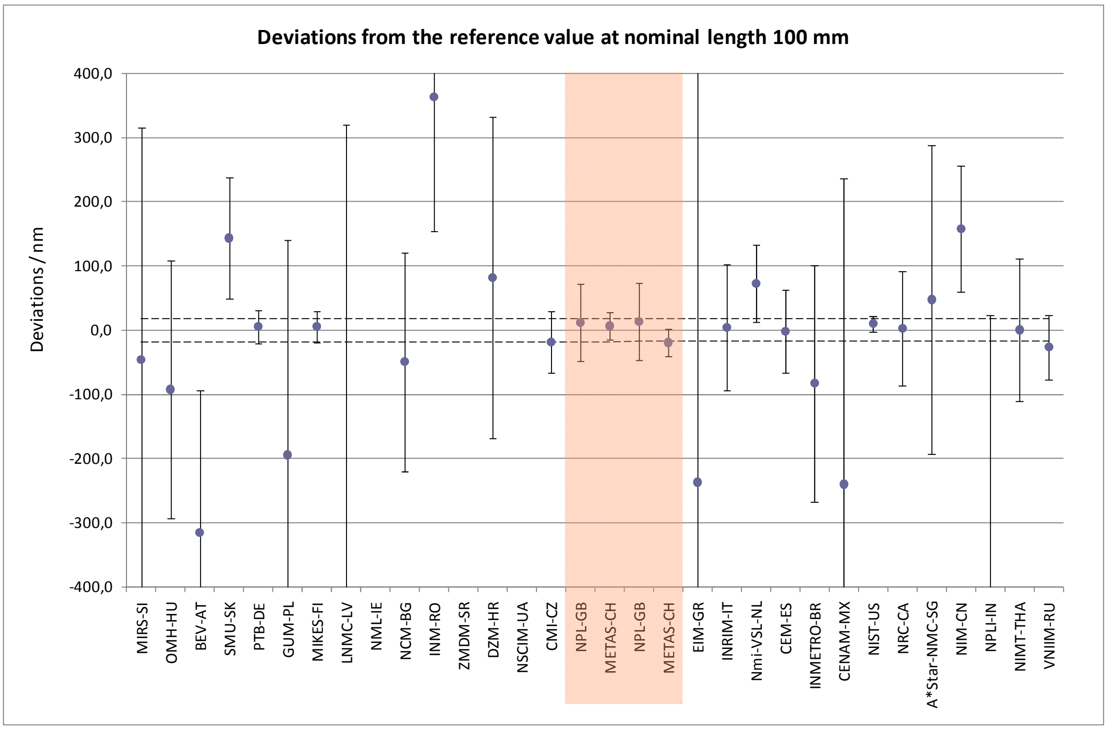
Deviations from the reference value at nominal length 100 mm
Deviations / nm
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9 Conclusions

The intention of this comparison was to determine and to document capabilities of the participating NMIs to carry out line scale calibrations on high quality line scales produced for industrial purposes. The line scales used for the comparison were designed and produced by NPL in UK. Two scales of same design and very similar quality were kindly donated by NPL.

The idea for the comparison arised at the Euramet TCL meeting in October 2005. The comparison started in July 2006 and the last measurement was performed in December 2008. Originally, 31 NMIs expressed interest for participating in the comparison. During the comparison, two laboratories decided not to perform measurements due to technical reasons and one new laboratory was approved to take part. At the end 30 laboratories reported their results.

Participating laboratories were divided into 2 groups in accordance with their geographical position (in order to minimize travel times and expenses for the transportation of the standards). Linking laboratories between the groups were chosen among participants in Nano3 project (NPL and METAS).

Although the standards traveled through a large number of laboratories, no significant damages were noticed. Some laboratories reported some dirt and scratches, but no significant influence on the results were indicated. The comparison ran quite well within the schedule in spite of some customs problems. Changes in the schedule are indicated in chapter 2.4.

Results were evaluated for each group separately and also after linking groups by using Bayesian statistics [2]. The performance of the participants was evaluated by using E_n value as the acceptance criterion. The reference value was calculated as the weighted mean of reported results for each measuring point. The Birge criterion and Chi-test were used for approving calculated reference values.

In the conclusion it can be summarised that the comparison was successful and has shown realistic picture about calibration and measurement capabilities of participating laboratories.

10 Acknowledgment

The pilot laboratory would like to thank all involved experts and other staff from the participating NMIs for their co-operation and performed technical and formal work. Special thanks should be addressed to the linking laboratories NPL-UK and METAS-CH for offering technical support through extensive discussions about the analysis of the results.

However, the comparison would not be possible without the generous support of the producer and owner of the line scales – NPL from UK. At this occasion the pilot laboratory is expressing very special thanks to NPL and to Dr. Michael McCarthy personally.

11 References

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