National Institute of Metrology (Thailand)

Report on APMP Supplementary Comparison

Measurement of flatness of optical flat by interferometry

APMP.L-S8

Final report

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1 Document control

Version Draft A.1 Issued on January 2017.

Version Draft A.2 Issued on April 2017.

Version Draft B.1 Issued on June 2017.

Version Draft B.2 Issued on December 2017.

Version Draft B.3 Issued on February 2018.

2 Introduction

The broad objective of the Asia Pacific Metrology Program (APMP) is to improve the measurement capabilities in the Asia Pacific region by sharing facilities and experience in metrology. Comparison of calibrations by different laboratories on given artifacts adds confidence in the measurement of standards and leads to international acceptance of the measurements carried out by these laboratories. This intercomparison concerns the calibration of flatness of optical flat. NIMT is responsible as pilot laboratory with a kind assistance from NMIJ.

Standards prepared by NMIJ were circulated in a single loop to all laboratories consist of:

- Two (2) optical flats

On receipt of the artefacts, each laboratory made note of the condition of the artefacts before commencing measurement. Details of how the individual laboratories carried out the measurements are described in Section 5.

3 Measurement conditions

Measurement conditions for each standard are described in section 5 of this document. If the participants cannot follow, an approximation may be made with a detailed description of how the measurement conditions have varied.

3.1 Participants

Participants are listed in Table 1.

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
NIMT	Dr. Jariya Buajarern National Institute of Metrology (Thailand), NIMT 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand	+66 25775100 ext 1216 jariya@nimt.or.th
NMIJ/AIST	Dr. Youichi Bitou National Metrology Institute of Japan, NMIJ National Institute of Advanced Industrial Science and Technology (AIST) Tsukuba Central 3, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563, Japan	+81 298614041 y-bitou@aist.go.jp
NIM	Dr. Xue Zi	+86 1064524915

	National Institute of Metrology, NIM Beisanhuandonglu 18, Beijing 100013, China	xuez@nim.ac.cn
NMC	Dr. Liping Zhao National Metrology Centre/Agency for Science, Technology and Research , NMC, A*STAR 1 Science Park Drive, Singapore 118221	+65 62791949 zhao_liping@nmc.a-star.edu.sg
MSL	Mr. Neil Swift Measurement Standards Laboratory of New Zealand, 69 Gracefield Rd, Lower Hutt 5040, New Zealand	+6449313214 neil.swift@callaghaninnovation.govt.nz
NPLI	Dr. Ashish Agarwal National Physical Laboratory India, Dr. K S Krishnan Raod, New Delhi 110012, India	Phone: +91 11 4560 8673 / 8673 Fax: +91 11 45609310 Email: ashish@nplindia.org
NMISA	Ms. Faith Hungwe National Metrology Institute of South Africa CSIR Building 5, Meiring Naude Road Brummeria, Pretoria	+27 12 841 4936 fhungwe@nmisa.org

3.2 Schedule

The program was started in 2015 with measurements at NMIJ. The order for measurement is listed in Table 2. Each laboratory was expected to carry out all required measurement in a two week period and allow a further two week period for transferring the artifacts to the next listed laboratory. Those scheduled for December or January were allowed four weeks for measurement due to expected public holidays and a further two week period for transfer. Due to customs clearance difficulties experienced by NIMT and NIM and CARNET reissuing process, the program was delayed by 7 months. To check the stability of the artifacts, NMIJ repeated measurements at the end of the schedule. The second measurement was only used for monitoring the stability of the artifacts.

Table 2. Schedule of the comparison.

Laboratory	Planned starting date	Starting date of measurement	Actual date	Results received
NMIJ	July 2015	July 2015	July 2015	15 October 2015
NIMT	August 2015	September 2015	September 2015	30 September 2015
NIM	September 2015	November 2015	November 2015	23 May 2016
NMC	October 2015	December 2015	February 2016	28 March 2016
NPLI	November 2015	January 2016	March 2016	25 April 2016
MSL	December 2015	February 2016	April 2016	22 September 2016
NMISA	January 2016	March 2016	August 2016	29 September 2016
NMIJ	February 2016	April 2016	September 2016	7 November 2016

4 Artefacts

4.1 Description of artefacts

Two optical flats: Flat A and Flat B were circulated. Both optical flats are made of quartz. Dimensions of both flats are given in the following table 3. The face of optical flat to be measured is indicated by arrow (↑) as shown in Figure 1 and Figure 2.

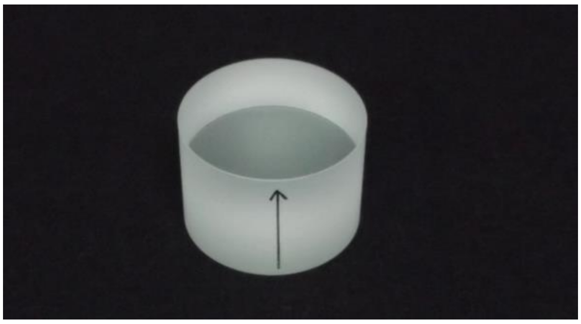


Figure 1 – Optical flat A

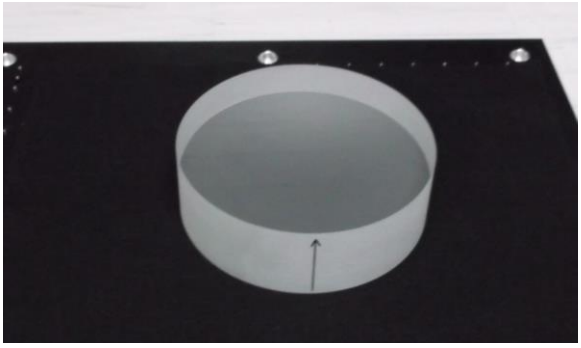


Figure 2 – Optical flat B

Table 3. List of artefacts.

Identification	**Diameter /mm**	**Thickness / mm**	**Effective diameter / mm**
A	70	50	60
B	160	50	150

4.2 Stability of artefacts

The optical flats were measured twice by NMIJ, at the dates indicated in Table 4. The table shows the measured flatness with the stated expanded uncertainties (*k*=2). No obvious deviation was observed and the deviations were well below their measurement uncertainties.

Table 4. Stability of the artefacts.

Identification	Flatness, nm		$U_{95\%}$, nm	Difference, nm
	July 2015	November 2016		
A	92.5	90.7	10	1.8
B	101.3	101.1	10	0.2

Figure 3 and Figure 4 illustrate the contour map of the optical flats obtained from July 2015 and November 2016, respectively.

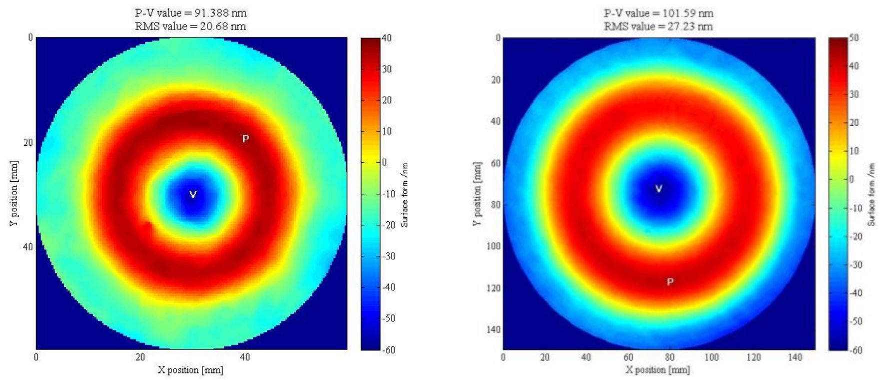


Figure 3 – Optical flats measured in July 2015

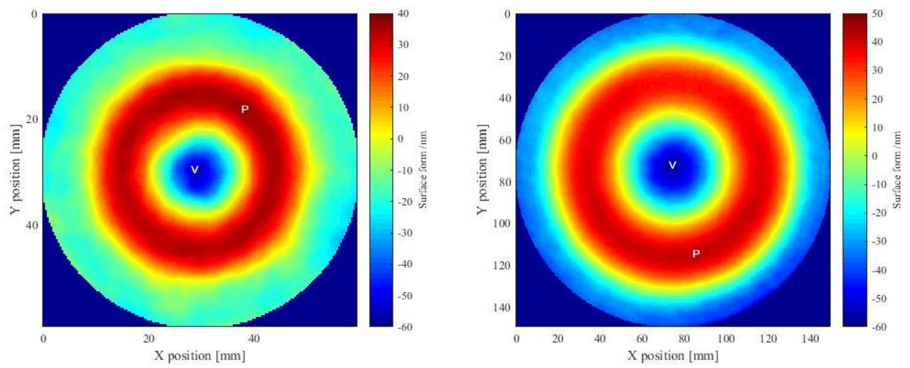


Figure 4 – Optical flats measured in November 2016

5 Measuring instructions

5.1 Measurands

The measurand whose value is to be reported is the P-V value (difference between the maximum point and the minimum point) within an effective diameter, position of peak (P) and position of valley (V).

5.2 Measurement method

The optical flats were measured by using flatness interferometer. There are two configurations of flatness interferometer used in this comparison, vertical type and horizontal type, as shown in Figure 5 and Figure 6, respectively.

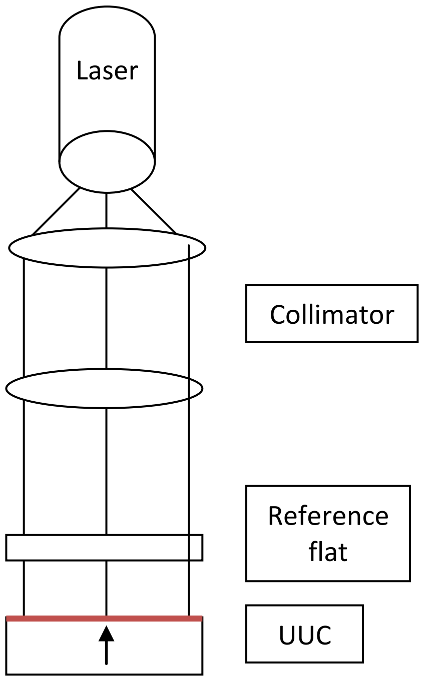


Figure 5 – Flatness interferometer: vertical orientation

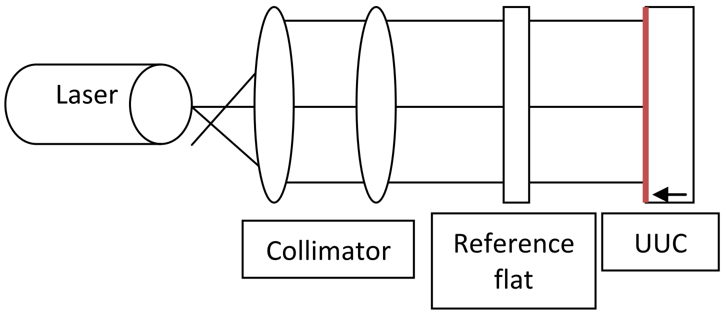


Figure 6 – Flatness interferometer: horizontal orientation

5.3 Traceability

Detail of the equipment used and measurement traceability of all laboratories are listed in Table 5. All NMIs apart from NPLI performed absolute calibration of their transmission flat themselves.

Table 5. Equipment used and measurement traceability.

Laboratory Code	Equipment used	Configuration	Mounting used	Maximum diameter, mm	Traceability
NMIJ	Fujinon	Vertical		300	NMIJ
NIMT	Fujinon F-601	Vertical	-	60	NIMT
NIM	Zygo GPI interferometer	Horizontal	Customized two nylon fixture with the inner sides are a little larger than the optical flats.	300	NIM
NMC	Zygo GPI-XP	Vertical	Adjustable mount with self centering element holder and V-block	150	NPL
MSL	Intellium H2000 interferometer	Vertical	-	200	MSL
NMISA	Zygo GPI-XP	Horizontal	Adjustable mount with self centering element holder and V-block	100	NMISA
NPLI	Zygo	Horizontal	Adjustable mount with self centering element holder	152	NPL

6 Results

6.1 Results and standard uncertainties as reported by participants

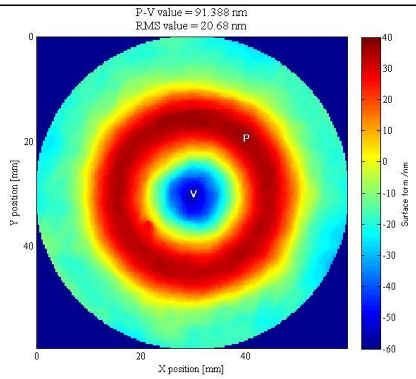
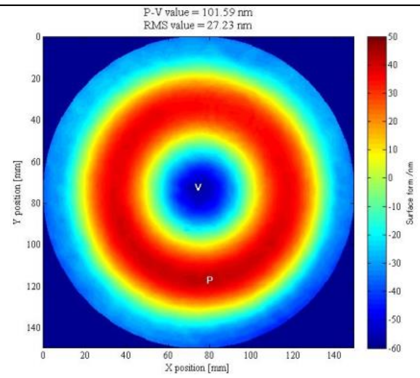
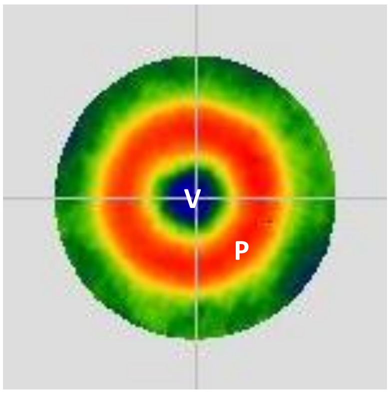
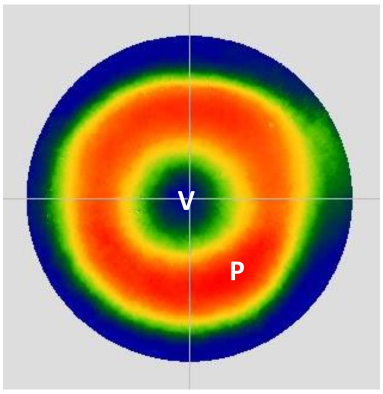
The uncertainty of measurement was estimated according to the ISO Guide to the Expression of Uncertainty in Measurement. Table 6 summarizes the measurement result reported by all participants.

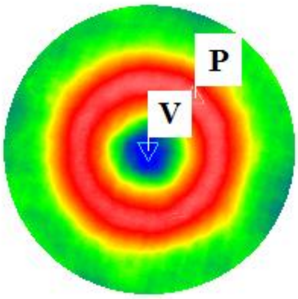
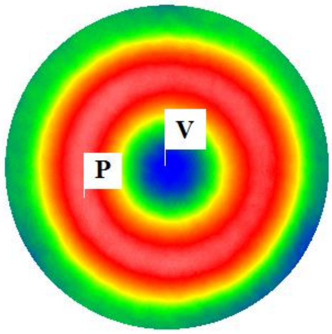
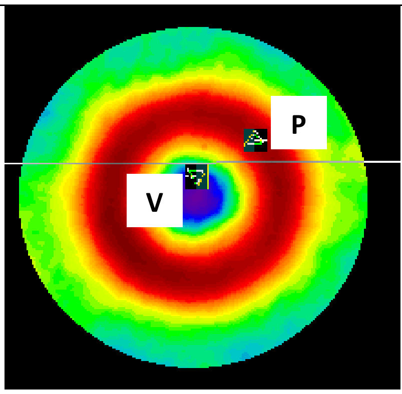
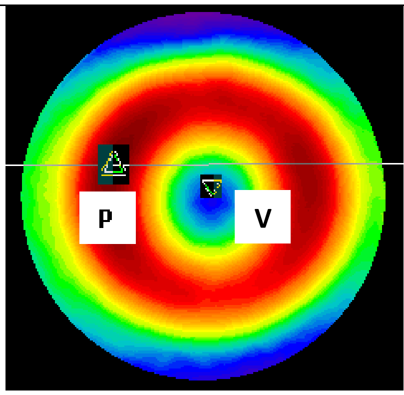
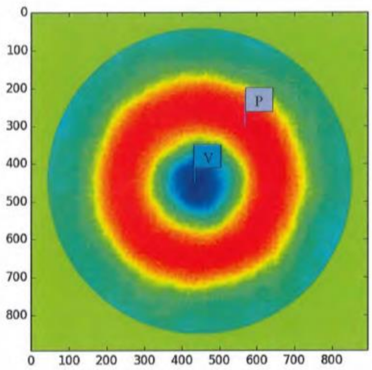
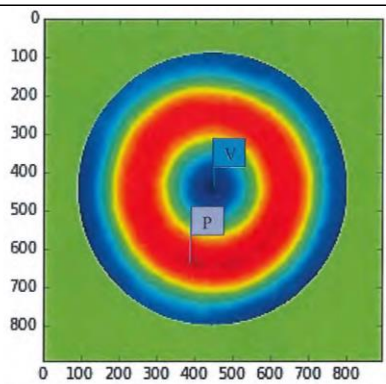
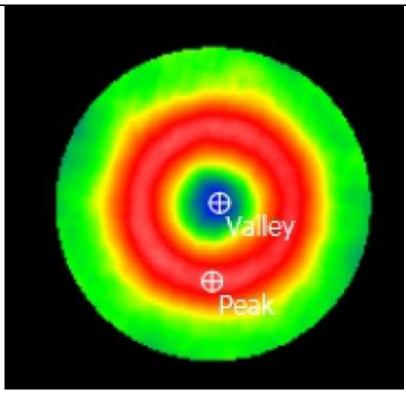
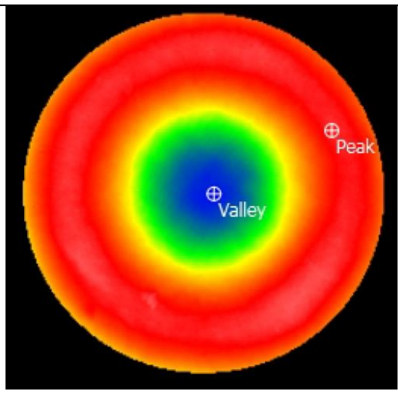
Table 6. Reported measurement result.

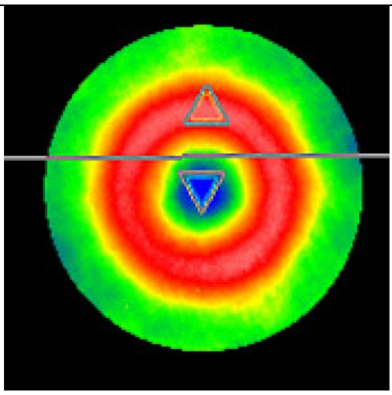
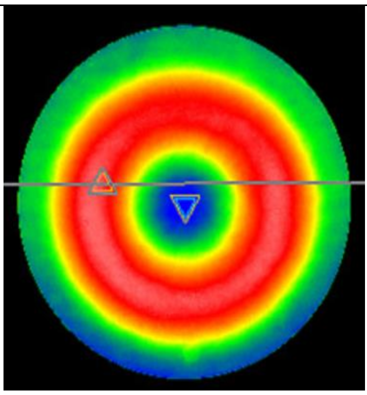
NMI	Flat A				Flat B			
	Diameter, mm	Flatness, nm	$U_{95\%}$, nm	En	Diameter, mm	Flatness, nm	$U_{95\%}$, nm	En
NMIJ	60	92.5	10	0.30	150	101.3	10	0.19
NIMT	60	102.44	40	0.19	150	113.12	40	0.26
NIM	60	96	7	0.19	150	103	9	0.02
NMC	60	92	40	0.08	150	128	40	0.63
MSL	60	103	27.5	0.29	150	107	21.5	0.20
NMISA	60.2	92.61	15	0.17	98	92.49	15	0.75
NPLI	60	97	21	0.09	150	117	22	0.66
Reference value		95.07	5.02			102.87	5.57	
Rb			0.402				0.971	
Rb Limit			1.468				1.468	

Graphical profile of Flat A and Flat B reported by all participants are summarized in Table 7. Position of the peak and valley are indicated as letter "P" and "V", respectively. While the position of the valley for all participants are the same, the position of the peak varies a little especially for Flat B. However, this variation can be neglected since the overall contours of both flats are similar for all laboratories.

Table 7. Reported graphical contours of Flat A and Flat B.

NMI	Flat A	Flat B
NMIJ		
NIMT		

NIM		
NMC		
MSL		
NMISA		

NPLI		

6.2 Supplementary comparison reference value analysis

The supplementary comparison reference values (SCRVs) were calculated for each artifact using the weighted mean. To each result (x_i) a normalized weight, w_i, was attributed, given by:

$$w_i = C \cdot \frac{1}{[u(x_i)]^2} \quad (1)$$

where the normalizing factor, C, is given by:

$$C = \frac{1}{\sum_{i=1}^{N} \left(\frac{1}{u(x_i)} \right)^2} \quad (2)$$

The weighted mean $\bar{x}_w$ is given by:

$$\bar{x}_w = \sum_{i=1}^{N} w_i \cdot x_i \quad (3)$$

and the uncertainty of the weighted mean is calculated by:

$$u(\bar{x}_w) = \sqrt{\frac{1}{\sum_{i=1}^{N} \left(\frac{1}{u(x_i)} \right)^2}} = \sqrt{C} \quad (4)$$

For the determination of the SCRV, statistical consistency of the results contributing to the SCRV is required. A check for statistical consistency of the results with their associated uncertainties can be made by the Birge ratio, R_B, which compares the observed spread of the results with the expected spread from the individual reported uncertainties.

The Birge ratio is defined as

$$R_B = \frac{u_{ext}(\bar{x}_w)}{u(\bar{x}_w)} \quad (5)$$

where $u_{ext}(\bar{x}_w)$ is the external standard deviation

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(N-1)} \cdot \frac{\sum_{i=1}^{N} w_i (x_i - \bar{x}_w)^2}{\sum_{i=1}^{N} w_i}} \qquad (6)$$

The data in a comparison are consistent provided that

$$R_B < \sqrt{1 + \sqrt{\frac{8}{N-1}}} \qquad (7)$$

where N is the number of laboratories.

For each laboratory's result, the E_n value is calculated. E_n is defined as the ratio of the deviation from the weighted mean, divided by the expanded uncertainty of this deviation.

$$En = \frac{|x_i - \bar{x}_w|}{\sqrt{U^2(x_i) - U^2(\bar{x}_w)}} \qquad (8)$$

The E_n values and R_B values are summarized in Table 6. Measurement results from all laboratories are well consistent with E_n values below one and the calculated R_B values are well below their limit.

Figure 7 and Figure 8 illustrate the deviation of the reported value from SCRV for flat A and flat B, respectively.

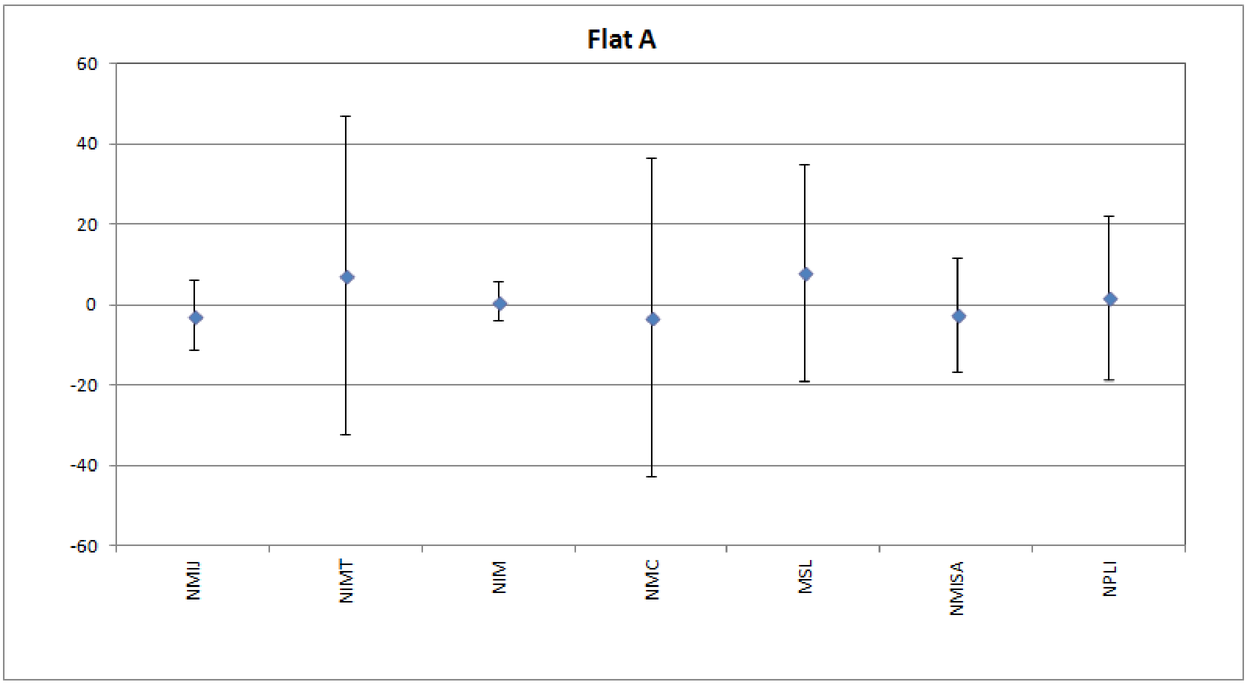


Figure 7 – Deviation from SCRV for Flat A

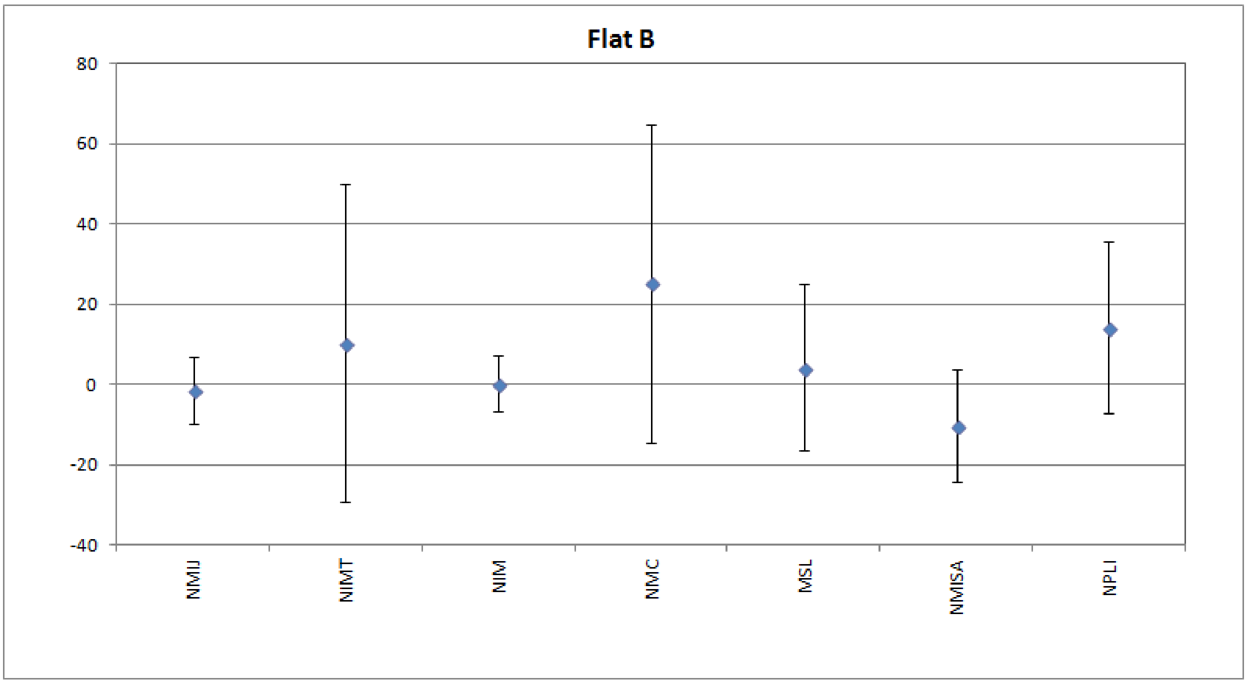


Figure 8 – Deviation from SCRV for Flat B

7 References

[1] Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM), JCGM 100.2008 GUM 1995 with minor corrections, International Organization for Standardization, Geneva, Switzerland, 2008.

[2] ISO/IEC 17043 Conformity assessment – General requirements for proficiency testing, International Organization for Standardization, Geneva, Switzerland, 2010.

[3] M.G. Cox, “The Evaluation of Key Comparison Data”, Metrologia, 2002, 39, 589-595.