AFRIMETS

Supplementary Comparison

on

Calibration of Feeler gauges

(AFRIMETS.L-S2.2.n01)

Renamed from (AFRIMETS.L-S5)

(2019-2022)

Final report

2024

Prepared by: *Dr.Eng. Ahmed ElMelegy*

Giza, Egypt

Contents

Page No.

1. Abstract

National Metrology Institutes from 8 African countries, namely Egypt, Nigeria, Kenya, Tanzania, Zambia, Zimbabwe, Botswana, and South Africa have participated in an international supplementary comparison on the calibration of feeler gauges. This comparison was a part of larger supplementary comparison between 13 African countries for the calibration of hand measuring instruments. This larger comparison which was carried out during the period between December 2019 – December 2022 has been piloted by NIS, Egypt and has been registered in BIPM-KCDB database on December 2019 with the identifier AFRIMETS.L-S5. The artifacts have been prepared by NIS, Egypt and measured before sent to circulate between all participant countries in round-robin scheme and returned back again for NIS, Egypt where a final measurement was made for stability check. The main purpose of these comparisons is to support submission of CMCs for calibration of hand length measuring instruments in BIPM-KCDB.

1. ***Introduction***

In December 2019, the Egyptian National Institute of Standards (NIS), Egypt has initiated a comparison for the calibration of length hand measuring instruments which is considered the standard activity in most African metrology institutes. It was not possible to conduct comparison for the calibration all length hand measuring instruments, so a number of 6 hand measuring instruments have been selected, which are external micrometer, caliper, dial gauge, setting rods, pin gauges and feeler gauges. The comparison was carried out during the period from December 2019 to December 2022 and was piloted by NIS, Egypt. The comparison has been registered in BIPM-KCDB database on December 2019 by the identifier AFRIMETS.L-S5 and was given the internal AFRIMET identifier AFRIMETS L11. The comparisons were carried out according to the protocol approved by all participants before initiating the comparison. The artifacts have been prepared and measured by NIS, Egypt before they were circulated between all participant countries in round-robin scheme and returned back again for NIS, Egypt where a final measurement was made for stability check. The main purpose of these comparisons is to support submission of CMCs for calibration of hand length measuring instruments in BIPM-KCDB.

In this report, 8 African countries, namely Egypt, Morocco, Nigeria, Tanzania, Zambia, Zimbabwe, Botswana, and South Africa have participated in an international supplementary comparison on the calibration of feeler gauges. It A feeler gauge of 13 blatts with thickness range from (0.05 – 1) mm was prepared by NIS, Egypt for the comparison.

2. *Participants*

8 African countries, namely Egypt, Morocco, Nigeria, Zambia, Zimbabwe, Botswana, and South Africa have participated in an international supplementary comparison on the calibration of feeler gauges. NIS, Egypt was acting as the pilot laboratory. The rest of the 13 countries which are Ghana, Ethiopia, Kenya, Malawi, and Mauritius did not participate in the feeler gauge comparison. The list of participants of this comparison are listed in the following table with their details:

Table 1 shows the participants NMIs in the feeler gauge comparison

No.	Participant	Correspondence	E-mail Address Phone number	Address
1	NIS (Pilot) (Egypt)	Osama Terra (Organizer)	Osama.terra@gmail.com +201141172900	Tersa Street, Haram, Giza, Egypt. P. code: 12211, P.O. Box: 136 Giza
		Ahmed Elmelegy (Pilot lab.)	ahmedme3@yahoo.com +201112145450	
2	LPEE/LNM (Morocco)	Lhossain Mechkour	mechkour@lpee.ma Tel : +212 5 22 48 87 94	km 7, Route d'El Jadida, Casablanca – Maroc
3	NMI/SON (Nigeria)	Bede Obayi	beobayi@yahoo.com	52, Lome Crescent, Zone 7, Wuse, Abuja
4	TBS (Tanzania)	Joseph James Angela Charles	mahillajj@yahoo.co.uk joseph.mahilla@tbs.go.tz angela.charles@tbs.go.tz Tel.: + 255 22 2450206	Morogoro/Sam Nujoma Roads, Ubungo, P.O. Box 9524 Dar-es- Salaam
5	ZMA (Zambia)	Daniel Mutale	dmmutalezs@gmail.com +260 955135366	Zambia Metrology Agency Plot # 4526 Lechwe House Freedom Way, Lusaka, Zambia. P.O.Box: 30989 Lusaka
6	SIRDC- NMI (Zimbabwe)	Burnhard Gandah	bgandah@sirdc.ac.zw burnhardg@gmail.com Tel: +263 778330014	1574 Alpes Road, Technology Drive Hatcliffe P.O. Box 6640 Harare
7	BOBS (Botswana)	Modiriemang Kame Pamidzani Ntima	kame@bobstandards.bw Ntima@bobstandards.bw Pamidzani.ntima@gmail.co m Tel. (+267) 3903200 Tel. (+267) 72607660	Private Bag B0 48 Gaborone
8	NMISA (South Africa)	Zanele Nzimande Patrick Masina	znzimande@nmisa.org pmasina@nmisa.org Tel. +27 12 841 2944	Private Bag X34 Lynnwood Ridge Pretoria 0040

3. *Form of Comparison*

The comparison is made according to round robin scheme. All artifacts including the feeler gauges are calibrated first at NIS, Egypt then shipped to the next country in the timetable, and so on. Malawi withdrew from the comparison since they were not ready by that time. Since not all countries participated in the 6 calibration activities, participants will differ from one report to the others. For feeler gauges, only 8 countries participated (shown in blue in figure 1).

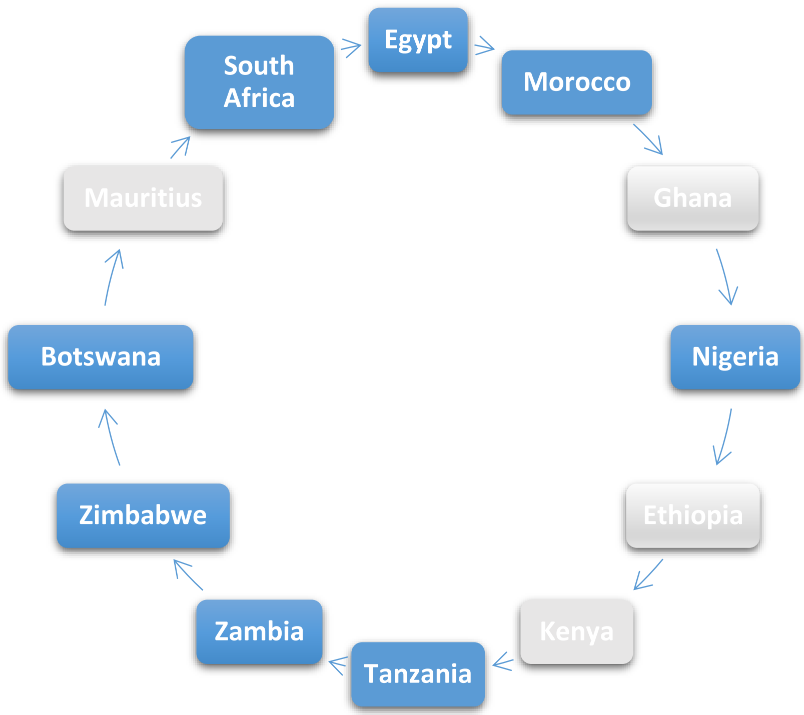


Figure 1: The transportation sequence and measurements of the artifacts.

4. *Timetable*

The sequence of transferring the standards was made according to the protocol. However, delays occur due to the Covid-19 pandemic which took place at the start of the comparison in 2020. Table 2 shows the comparison planned timetable of the protocol. A delay of around one and half year almost from the planned time table.

Table 2 shows the comparison time table at the protocol

Activity	Start Date	End date	Remarks
First calibration at NIS, Egypt	25 November 2019	10 December 2019	
Delivery to LPEE/LNM, Morocco	11 December 2019	31 December 2019	
Calibration at LPEE/LNM, Morocco	1 January 2020	15 January 2020	
Delivery to GSA, Ghana	16 January 2020	5 February 2020	
Calibration at GSA, Ghana	6 February 2020	20 February 2020	

Delivery to NMI/SON, Nigeria	21 February 2020	10 March 2020	
Calibration at NMI/SON, Nigeria	11 March 2020	25 March 2020	
Delivery to NMIE, Ethiopia	26 March 2020	15 April 2020	
Calibration at NMIE, Ethiopia	16 April 2020	30 April 2020	
Delivery to KEBS, Kenya	1 May 2020	20 May 2020	
Calibration at KEBS, Kenya	21 May 2020	5 June 2020	
Delivery to TBS, Tanzania	6 June 2020	26 June 2020	
Calibration at TBS, Tanzania	27 June 2020	12 July 2020	
Delivery to MBS, Malawi	13 July 2020	3 August 2020	Withdrawn
Calibration at MBS, Malawi	4 August 2020	20 August 2020	
Delivery to ZABS, Zambia	21 August 2020	10 September 2020	
Calibration at ZABS, Zambia	11 September 2020	30 September 2020	
Delivery to SIRDC/NMI, Zimbabwe	1 October 2020	20 October 2020	
Calibration at SIRDC/NMI, Zimbabwe	21 October 2020	5 November 2020	
Delivery to BOBS, Botswana	6 November 2020	26 November 2020	
Calibration at BOBS, Botswana	27 November 2020	12 December 2020	
Delivery to MSB, Mauritius	13 December 2020	2 January 2021	
Calibration at MSB, Mauritius	3 January 2021	18 January 2021	
Delivery to NMISA, South Africa	19 January 2021	9 February 2021	
Calibration at NMISA, South Africa	10 February 2021	28 February 2021	
Delivery to NIS, Egypt	1 March 2021	20 March 2021	
Calibration at NIS, Egypt	21 March 2021	5 April 2021	
Final Chance for Submitting the Results	6 April 2021	20 April 2021	
Pre-Draft A	21 April 2021	20 June 2021	

5. ***Description of the artifact:***

NIS artifact is feeler gauge as shown in figure 2 that has thickness range from (0.05 – 1) mm. 6 blatts of thickness values 0.2, 0.4, 0.6, 0.8 and 1.0 mm are considered for comparison measurements

Figure 2: photograph of Feeler gauges (similar one)

6. *Calibration method used by each participant*

Different methods are used by each participant for the calibration of feeler gauges. The used methods by each participant are summarized in table 3

Table 3 methods used for calibration of Feeler gauges by each participant

	Participant	Method used for calibration of Feeler gauges
1	NIS (Egypt)	25 mm Digital micrometer
2	LPEE/LNM(Morocco)	Reference measuring bench TRIMOS
3	NMI/SON (Nigeria)	0-1 inch digital micrometer
4	TBS (Tanzania)	Standard Universal Length Machine
5	ZMA (Zambia)	External micrometer
6	SIRDC- NMI (Zimbabwe)	Gauge blocks and submicron micrometer as comparator
7	BOBS (Botswana)	Horizontal Measuring Machine - Trimos
8	NMISA (South Africa)	Wedge comparator

7. *Calibration results*

The following table (table 4) shows the results for all participant in feeler gauges calibration comparison. The results of each participant and the calibration uncertainty for the calibration of the three feeler gauges are shown as a single row in table 4.

Table 4. Calibration results by each participant.

Nr	Institute, Country	Nominal 0.20	U, mm	Nominal 0.40	U, mm	Nominal 0.60	U, mm	Nominal 0.80	U, mm	Nominal 1.00	U, mm
1	NIS (Egypt) (Pilot)	0.200	0.0015	0.403	0.0015	0.613	0.0015	0.806	0.0015	0.997	0.0018
2	LPEE/LNM (Morocco)	0.202	0.0026	0.405	0.0026	0.616	0.0026	0.807	0.0026	1.005	0.0026
3	NMI/SON (Nigeria)	0.201	0.0014	0.402	0.0035	0.612	0.0023	0.805	0.0027	0.995	0.0030

4	TBS (Tanzania)	0.200	0.001	0.4003	0.001	0.6006	0.001	0.8043	0.001	0.9946	0.001
5	ZMA (Zambia)	0.200	0.003	0.406	0.003	0.610	0.003	0.806	0.003	0.998	0.003
6	SIRDC- NMI (Zimbabwe)	0.1984	0.0013	0.4027	0.0013	0.6134	0.0013	0.8063	0.0013	0.9951	0.0013
7	BOBS (Botswana)	0.200	0.0022	0.400	0.0022	0.607	0.0022	0.801	0.0022	1.000	0.0022
8	NMISA (South Africa)	0.1987	0.0004	0.4018	0.0004	0.6134	0.0004	0.8049	0.0004	0.9954	0.0004
1	NIS (Egypt) (After)	0.199	0.0015	0.402	0.0015	0.612	0.0015	0.806	0.0015	0.997	0.0015

8. *Traceability*

Reference for the calibration of the feeler gauges should be traceable to SI unit of length though unbroken traceability chain. The following table demonstrates the traceability of the measurement of each participant that are deduced from the calibration report.

Table 5. Traceability of calibration results by each participant.

Nr.	Participant	Traceability
1	NIS (Egypt)	To SI units of length through NIS primary length standard (He Ne 633 laser)
2	LPEE/LNM (Morocco)	Not mentioned
3	NMI/SON (Nigeria)	Not mentioned
4	TBS (Tanzania)	To SI units of length through NMISA standards
5	ZMA (Zambia)	To SI units of length through NMISA standards
6	SIRDC- NMI (Zimbabwe)	To SI units of length through NMISA standards
7	BOBS (Botswana)	To SI units of length through NMISA standards
8	NMISA (South Africa)	the national measuring standard for length

The status of some NMIs having traceability through NMISA standards did not affect the analysis of comparison results.

9. *Analysis of the results*

9.1. *Transportation Stability*

Drifts of the artifact's values can occur during the transportation of the artifacts and handling over the long period of comparison. Therefore, a stability check must be performed to assure that this change will not affect the comparison results. The instability of the artifacts is assessed according to the following equation:

$$\Delta_{ins} = \left| x_{NIS_2} - x_{NIS_1} \right|$$

where, x_{NIS_2} is the measurement of the pilot (NIS, Egypt) after the comparison and x_{NIS_1} is the measurement of the pilot before the comparison. The instability of each artifact during the transportation will add additional contribution to the uncertainty of the reference value:

$$u_{ad}(x_i) = \frac{\Delta_{ins}}{2\sqrt{3}}$$

Additional criteria are applied to ensure the stability of the results which is:

$$\Delta_{ins} \le 0.9\sqrt{u_{CRV}^2 + u_{min}^2}$$

where, the u_{CRV} is the uncertainty in the comparison reference value and u_{min} is the uncertainty of the participant with the lowest uncertainty.

Therefore, the total combined uncertainty for each participant after adding the uncertainty due to the stability will be

$$u_a^2(x_i) = u^2(x_i) + u_{ad}^2(x_i)$$

Table 6. Stability measurement for each artifact

Nominal thickness, (mm)	Δ_{ins} (mm)	$u_{ad}(x_i)$ mm	$0.9\sqrt{u_{CRV}^2 + u_{min}^2}$ mm	Status
0.20	0.0010	0.0003	0.00139	Fulfilled
0.40	0.0010	0.0003	0.00140	Fulfilled
0.60	0.0010	0.0003	0.00140	Fulfilled
0.80	0.0000	0.0000	0.00138	Fulfilled
1.00	0.0000	0.0000	0.00165	Fulfilled

Table 7. correction of combined uncertainties for each participant

Nr	Institute, Country	Nominal 0.2	$u_a(x_i)$, mm	Nominal 0.4	$u_a(x_i)$, mm	Nominal 0.6	$u_a(x_i)$, mm	Nominal 0.8	$u_a(x_i)$, mm	Nominal 1.0	$u_a(x_i)$, mm
1	NIS (Egypt) (Pilot)	0.2000	0.0008	0.4030	0.0008	0.6130	0.0008	0.8060	0.0008	0.9970	0.0009
2	LPEE/LNM (Morocco)	0.2020	0.0013	0.4050	0.0013	0.6160	0.0013	0.8070	0.0013	1.0050	0.0013
3	NMI/SON (Nigeria)	0.2010	0.0008	0.4020	0.0018	0.6120	0.0012	0.8050	0.0014	0.9950	0.0015
4	TBS (Tanzania)	0.2000	0.0006	0.4003	0.0006	0.6006	0.0006	0.8043	0.0005	0.9946	0.0005
5	ZMA (Zambia)	0.2000	0.0015	0.4060	0.0015	0.6100	0.0015	0.8060	0.0015	0.9980	0.0015
6	SIRDC- NMI (Zimbabwe)	0.1984	0.0007	0.4027	0.0007	0.6134	0.0007	0.8063	0.0007	0.9951	0.0007
7	BOBS (Botswana)	0.2000	0.0011	0.4000	0.0011	0.6070	0.0011	0.8010	0.0011	1.0000	0.0011
8	NMISA (South Africa)	0.1987	0.0004	0.4018	0.0004	0.6134	0.0004	0.8049	0.0002	0.9954	0.0002

9.2. *Reference value of the comparison*

The CRV (comparison reference value) was calculated using the weighted mean method according to the equation:

$$x_{CRV} = \sum_{i=1}^{N} w_i \, x_i$$

Where w_i is the weights and is calculated by the equation:

$$w_i = \frac{u_a^{-2}(x_i)}{\sum_{i=1}^{N} u_a^{-2}\,(x_i)}$$

and where u_a^2 is the uncertainty contribution of each participant including the uncertainty due to the stability analysis:

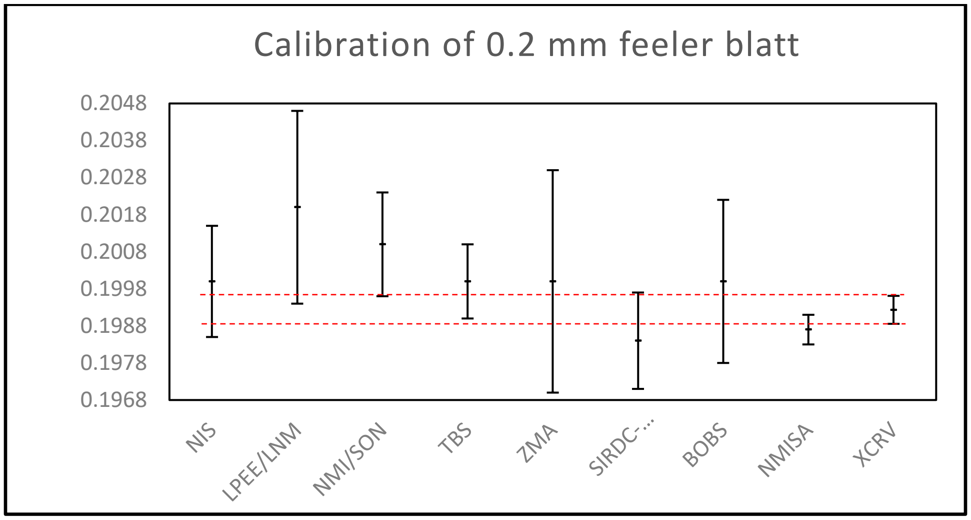
The standard uncertainty in the CRV value is calculated according to the following equation:

$$u(x_{CRV}) = \frac{\sqrt{\sum_{i=1}^{N} \frac{u^2\ (x_i)}{u_a^4\,(x_i)}}}{\sum_{i=1}^{N} u_a^{-2}\,(x_i)}$$

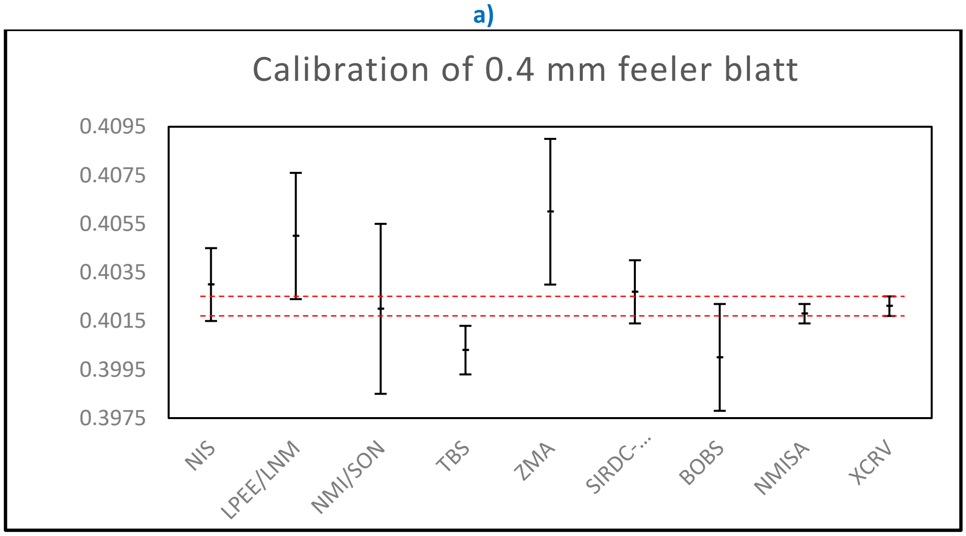
Calculation of the CRV and its uncertainty are given in table 6 and figure 2. The calculation is made after removing the inconsistent data according to section 9.3

Table 8. Comparison CRV and its uncertainty

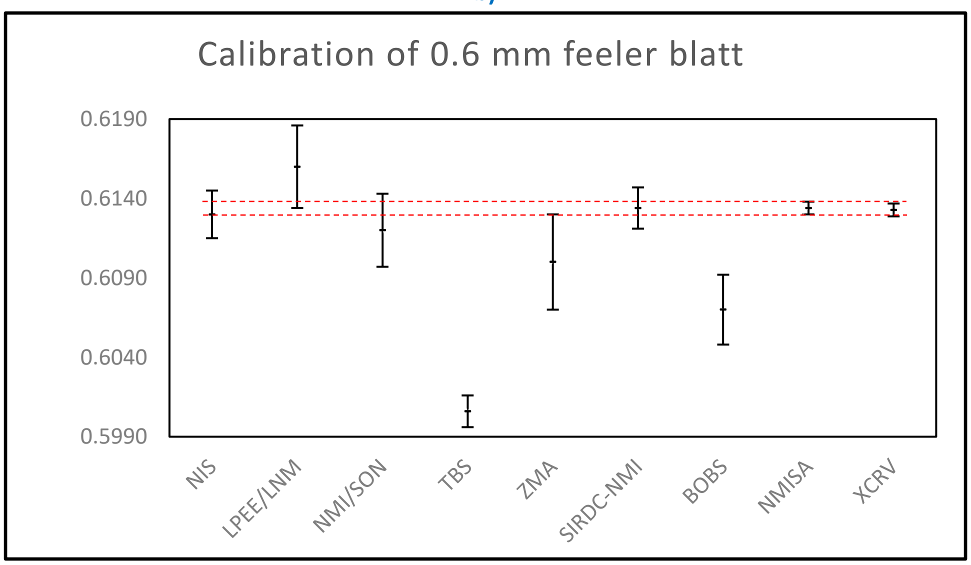
Nominal thickness, (mm)	CRV value (thickness) (mm)	Expanded Uncertainty (@ *K*=2), (mm)
0.2	0.19923	0.00038
0.4	0.40211	0.00040
0.6	0.61328	0.00040
0.8	0.80503	0.00034
1.0	0.99537	0.00035


Calibration of 0.2 mm feeler blatt
0.2048
0.2038
0.2028
0.2018
0.2008
0.1998
0.1988
0.1978
0.1968
NIS
LPEE/LNM
NMI/SON
TBS
ZMA
SIRDC-...
BOBS
NMISA
XCRV

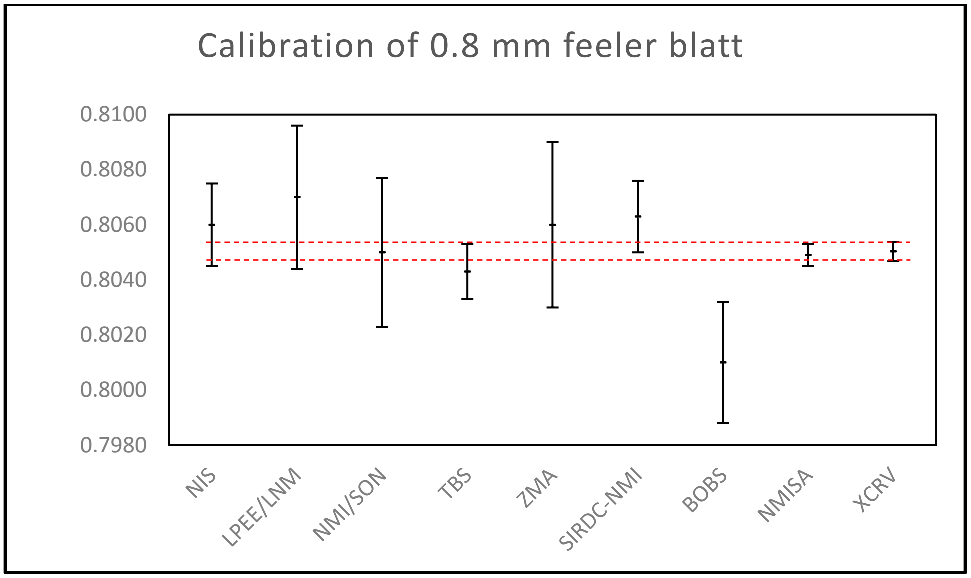
a)


Calibration of 0.4 mm feeler blatt
0.4095
0.4075
0.4055
0.4035
0.4015
0.3995
0.3975
NIS
LPEE/LNM
NMI/SON
TBS
ZMA
SIRDC-...
BOBS
NMISA
XCRV

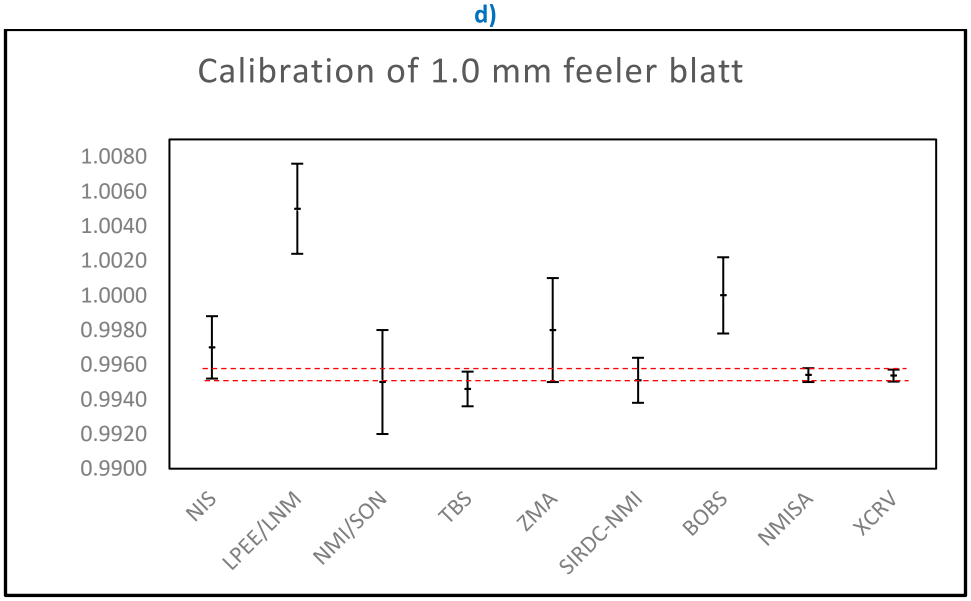
b)


Calibration of 0.6 mm feeler blatt
0.6190
0.6140
0.6090
0.6040
0.5990
NIS
LPEE/LNM
NMI/SON
TBS
ZMA
SIRDC-NMI
BOBS
NMISA
XCRV

c)



d)



e)

Figure 3. The results of the participants in comparison with the CRV and it's uncertainty (expanded), a, b, c, d & e.

9.3. Consistency check of the results

Before calculating the CRV and its uncertainty a consistency of the comparison results must be examined. To determine the consistency of comparisons results Chi-square value χ^2_{obs} is calculated according to the following equation:

$$\chi^2_{obs} = \sum_{i=1}^{n} \frac{(x_i - x_{CRV})^2}{u_a^2(x_i)} \qquad 3$$

For the data to be consistent, the following condition must satisfy

$$\Pr\{\chi^2(v) > \chi^2_{obs}\} < 0.05 \qquad 4$$

Where v is the degrees of freedom which is the number of participant minus one and P_r denotes "probability of" and $\chi^2(v)$ is the inverse of the chi-square cumulative distribution function with degree of freedom specified by v for the probability of 0.05 (corresponding to the 95 % level of confidence). In this case, the participant with the highest value of χ^2_{obs} is excluded from the next round of evaluation and a new reference value, reference standard uncertainty, and chi-squared values are calculated again without the excluded laboratory. If the consistency check did not fail then y was accepted as the x_{CRV} and the $u(x_{CRV})$ are accepted. The number of participants N=8, therefore, the degrees of freedom υ = N–1 =7. From the Chi-Square table at 95 % confidence level, we obtain $\chi^2_{0.05}$= 14.07.

Table 9: Consistency check (Not satisfied)

Nominal thickness, (mm)	χ^2_{obs}	$\chi^2_{0.05}$ (υ=7)	Consistency $\chi^2_{obs} \le \chi^2_{0.05}$?
0.2	**16.297**	**14.07**	**Failed**
0.4	**26.314**	**14.07**	**Failed**
0.6	**415.488**	**14.07**	**Failed**
0.8	**23.895**	**14.07**	**Failed**
1.0	**78.947**	**14.07**	**Failed**

9.3.1. Variation of solving inconsistency

For this comparison the consistency ($\chi^2_{obs} \le \chi^2_{0.05}$) is failed for five measurements. The consistency for these measurements can be reached in different ways:

- By inserting an additional uncertainty s^2 following the Paul-Mandel method. This method allows reaching the consistency by enlarging relative uncertainties of all participants.
- By excluding the data of the participant with large deviations from tentative CRV.

At predraft A stage all participants approved the possibility of adding s^2 uncertainty and excluding data of any participant from the CRV calculations.

9.3.2. *Inserting an additional uncertainty following the Paul-Mandel method*

- The calculations with additional uncertainty s^2, which was added to relative uncertainties of each participant according to Paul-Mandel method, were made for feeler gauges of thickness values of 0.2, 0.4 and 0.6 mm. The s^2 value was found by trial and error method to satisfy the consistency conditions:

$$\chi^2_{obs} \le \chi^2_{0.05}(\nu) \qquad 5$$

The chosen minimum additional uncertainty values s^2 and χ^2 values for this case are presented in the table 10.

We can see that s^2 uncertainty including gives mostly small increase of total uncertainty and allows achieving results consistency.

Table 10. correction of combined uncertainties for each participant including s^2

Nr	Institute, Country	Nominal 0.2	$u_a(x_i)$, mm (with s^2)	Nominal 0.4	$u_a(x_i)$, mm (with s^2)	Nominal 0.6	$u_a(x_i)$, mm (with s^2)
1	NIS (Egypt) (Pilot)	0.2000	0.0009	0.4030	0.0013	0.6130	0.0008
2	LPEE/LNM (Morocco)	0.2020	0.0014	0.4050	0.0017	0.6160	0.0014
3	NMI/SON (Nigeria)	0.2010	0.0008	0.4020	0.0020	0.6120	0.0012
4	TBS (Tanzania)	0.2000	0.0007	0.4003	0.0012	0.6006	0.0006
5	ZMA (Zambia)	0.2000	0.0016	0.4060	0.0018	0.6100	0.0015
6	SIRDC- NMI (Zimbabwe)	0.1984	0.0008	0.4027	0.0012	0.6134	0.0008
7	BOBS (Botswana)	0.2000	0.0012	0.4000	0.0015	0.6070	0.0012
8	NMISA (South Africa)	0.1987	0.0005	0.4018	0.0011	0.6134	0.0004

- For feeler gauges, the results from the following participants are removed before calculating the CRV and its uncertainty for the data to be consistent:
  - Participants TBS & BOBS @ 0.6 mm
  - Participant BOBS @ 0.8 mm
  - Participants LPEE/LNM & BOBS @ 1.0 mm
- The new consistency check is presented in table 11.

Table 11: Consistency check (satisfied)

Nominal thickness, (mm)	χ^2_{obs}	$\chi^2_{0.05}$	Consistency $\chi^2_{obs} \le \chi^2_{0.05}$?
0.2	**12.482**	**14.07**	**Satisfied**
0.4	**12.702**	**14.07**	**Satisfied**
0.6	**9.812**	**11.07**	**Satisfied**
0.8	**10.759**	**12.59**	**Satisfied**
1.0	**8.982**	**11.07**	**Satisfied**

9.4. Performance Evaluation

The purpose of the evaluation of performance methods is to provide a normalized performance evaluation so that all results are comparable and the performance of each participant can be measured. In such calibration schemes, the performance of the participants is evaluated by measuring whether the results of the participants are within the uncertainty of the CRV. The performance is evaluated using the normalized error number E_n, where;

$$E_n = \frac{(x_i - x_{CRV})}{\sqrt{U_{a_i}^2 + U_{\mathrm{CRV}}^2}} \qquad 6$$

Where; x_i and U_{a_i} are the result and its corresponding adjusted expanded uncertainty of each participant, respectively. x_{CRV} and U_{CRV} are the CRV and its expanded uncertainty, respectively. E_n is interpreted as follows:

$$|\boldsymbol{E_n}| \leq \mathbf{1} \rightarrow \textbf{Satisfactory performance}$$

$$|\boldsymbol{E_n}| > 1 \rightarrow \text{Unsatisfactory performance}$$

Table 12. Evaluation of performance for the participants using E_n

Nominal thickness, (mm)	$\lvert E_n \rvert$							
	NIS	LPEE/LNM	NMI/SON	TBS	ZMA	SIRDC-NMI	BOBS	NMISA
0.2	0.3	0.9	1.0	0.4	0.1	0.8	0.2	1.5
0.4	0.5	1.0	0.1	1.7	1.2	0.3	1.0	0.6
0.6	0.2	1.0	0.5	11.6	1.1	0.1	2.8	0.3
0.8	0.6	0.7	0.0	0.3	0.3	0.9	1.8	0.3
1.0	0.9	3.7	0.1	0.7	0.9	0.2	2.1	0.1

10. Conclusion:

- The results from 8 National Metrology Institutes from Egypt, Morocco, Nigeria, Tanzania, Zambia, Zimbabwe, Botswana and South Africa have participated in an AFRIMET supplementary comparison on the calibration of Feeler gauges. The comparison reference value has obtained from the results using the weighted mean method after performing consistency check of the results using the Chai-square method. The Normalized error number En is used to evaluate the performance of all participants. All results are found satisfactory except:

- LPEE/LNM @ 1.0 mm feeler gauge.
- TBS and ZMA @ 0.4 mm and 0.6 mm feeler gauges.
- BOBS @ 0.6 mm, 0.8 mm and 1.0 mm feeler gauges.
- NMISA @ 0.2 mm feeler gauge.

are found unsatisfactory (En>1).

11. List of References

[1] Guide to preparation of Key Comparison Reports in Dimensional Metrology (GD3), A Lewis, T Coveney 30 Nov 2020.
[2] Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting, CIPM MRA-G-11
[3] M. G. Cox, “The evaluation of key comparison data”, metrologia, 39, 589-595, 2002.
[4] Consensus Values and Weighting Factors, R.C. Paule, J. Mandel, J. Res. NBS, Vol.87, N 5, 1982, 377-385.