Report on the AFRIMETS.M.T-S1 supplementary torque comparison for 500 N·m and 1000 N·m between NIS (Egypt) and PTB (Germany)

K.M. Khaled*, Andreas Bruege**, Rolf Kumme**

* National Institute of Standards (NIS), khaled.abdelaziz@nis.sci.eg

**Physikalisch-Technische Bundesanstalt (PTB)

1. Introduction

It is recognised that for the purposes of international trade and scientific collaboration, the national measurement systems of countries around the world should agree which is the basis of the SI. The centre of each country's national measurement system tends to be its national measurement institute (NMI), and it is important that NMIs compare their standards with each other on a regular basis. Recently, NIS built a 1 kN·m primary standard torque calibration machine to provide the highest level of the traceability pyramid from 5 N·m up to 1000 N·m in both clockwise and anticlockwise directions with a relative expanded uncertainty of 9×10^{-5} with k =2. NIS agreed with PTB to participate in this comparison as a pilot to compare the NIS machine with the PTB's 1 kN·m primary standard torque calibration machine. The purpose of this comparison is to support the claimed CMC of NIS. Furthermore, this comparison will help NIS to support other AFRIMETS countries throughout another torque comparison.

Figure 1: NIS 1 kN·m primary torque standard machine

2. Organization

A protocol for this supplementary comparison was issued as a result of a discussion between the National Institute of Standards (NIS), force and material metrology laboratory and the Physikalisch-Technische Bundesanstalt (PTB), force and torque laboratory.

3. Participants

Table 1: Participants and the Torque Standard Machines used

Country	Institute	Torque Standard Machine			Remarks
		Capacity kN·m	Type	Relative expanded uncertainty of applied torque	
Egypt	NIS	1	Deadweight	$W_{N0} = 9 \times 10^{-5}$	Participant Organizer
Germany	PTB	1	Deadweight	$W_{P0} = 2 \times 10^{-5}$	Pilot

4. Time schedule for the measurements

The comparison was conducted during 2022, starting with the measurements at NIS and then at PTB. The following timetable is the scheduled measuring time**.**

Table 2: Schedule of the comparison

Institute / Country	**Time of measurements**
NIS/Egypt	March 2022
PTB/Germany	July 2022

5. Traveling Standards

5.1 Description

A transfer torque transducer of type TN with a capacity of 1000 N·m manufactured by HBM (Serial number: #014440034, Bridge 1) was used in this comparison as an artefact. NIS offered cables and a DMP40S2 measuring amplifier (Serial number: #122820045) during the comparison measurements.

5.2 Handling

The torque transducer and the measuring amplifier were transferred between the two institutes by an airplane transport and packed in such a way as to ensure robustness and protect them from being deformed or damaged.

6. Method of measurement

The primary torque standard machines of NIS and PTB will be compared in accordance with the scheme given in Table (3). One torque transducer should be used to compare the machines with an amplifier of the highest resolution and stability. Each will be used at two torque steps to enable the machines to be compared.

Table 3: Comparison scheme

NIS Machine	PTB Machine	Calibration Mode	Test	Torque Steps	Transducer
1000 N·m DWTSM	1000 N·m DWTSM	Clockwise	A1	1000 N·m 500 N·m	1000 N·m (S. No.: #014440034, Bridge 1, TN type)
		Anti-clockwise	A2	-1000 N·m -500 N·m	

To minimize the effects of torque transducer creep, each transducer calibration will be carried out by a strict time torque profile, including the preloads which will always perform at the start of each test and after each rotation of the transducer in the machine. The time between every two successive readings is six minutes.

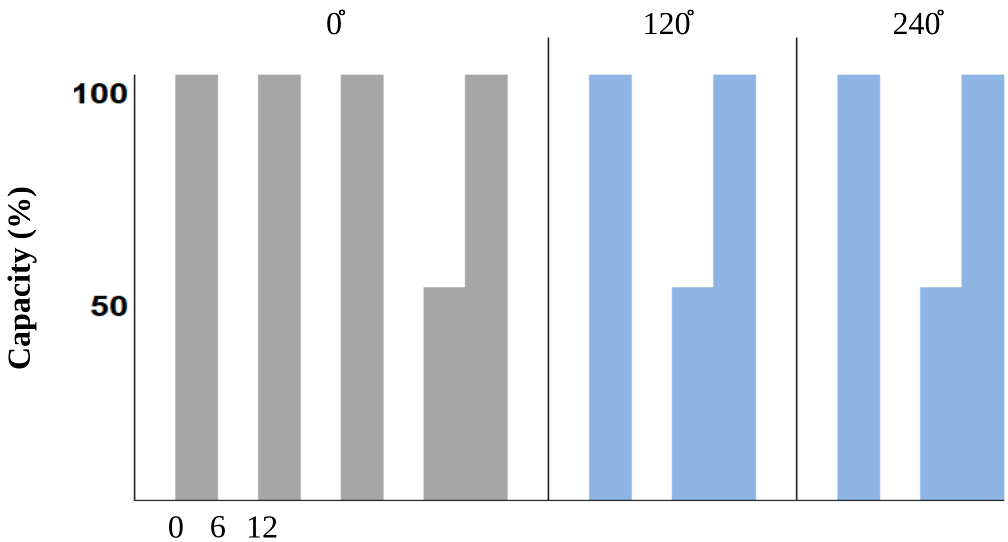

Figure 2: Comparison scheme

The rotation of the transducer should be carried out in a time interval of 10 minutes after removing the load and before taking the next zero reading (which will not be taken into account for the calculation). Three outputs will be obtained at each of three orientations, symmetrically distributed about the central axis of the machine – the deflections will be calculated by subtracting the transducer output at zero torque (before the application of the torque) from the transducer output under torque.

7. Influence of temperature and humidity on the artefact

The effect of temperature on the sensitivity of the artefact at both comparison torque steps was investigated to correct the temperature differences between participants with linear assumption as shown in Figures (3) and (4) for CW and ACW directions, respectively. Figures (5) and (6) show the effect of humidity on the sensitivity of the artefact to correct the humidity differences between participants with a linear assumption for CW and ACW directions, respectively.

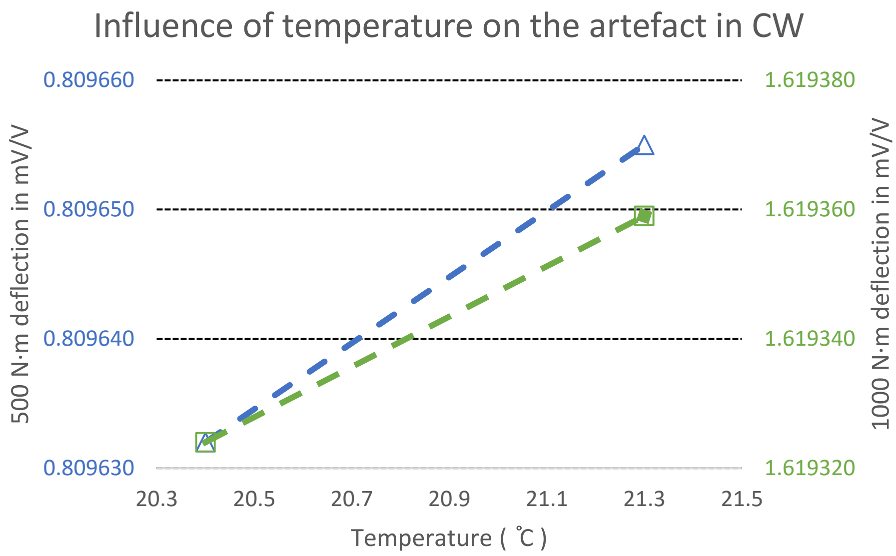

Figure 3: Effect of temperature on the artefact in CW direction

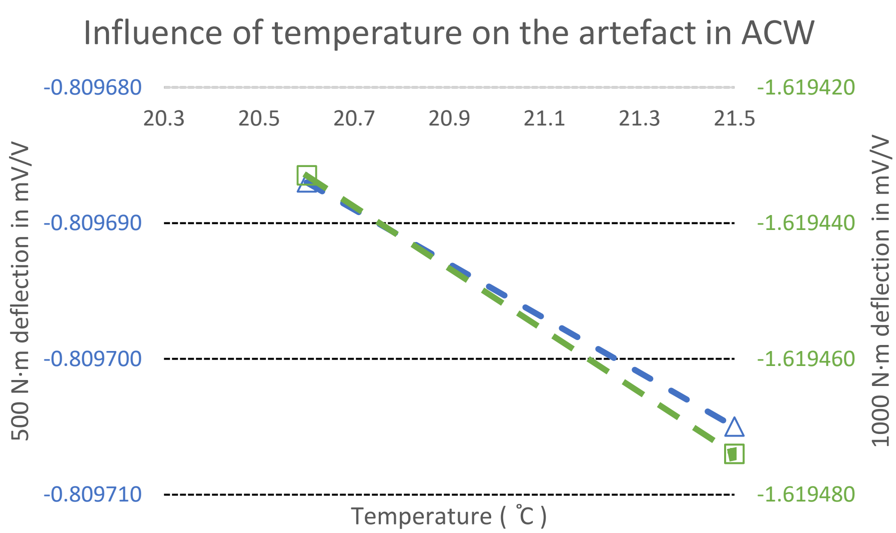

Figure 4: Effect of temperature on the artefact in ACW direction

Table (4) shows the temperature and humidity coefficients and the associated uncertainties of the artefact used. The results reveal proportional relation between sensitivity and either temperature or humidity for the artefact used.

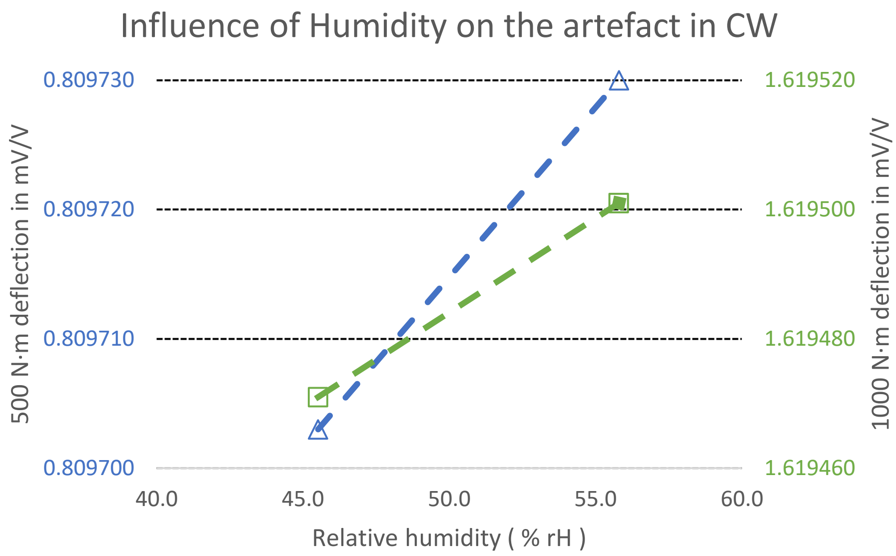

Figure 5: Effect of humidity on the artefact in CW direction

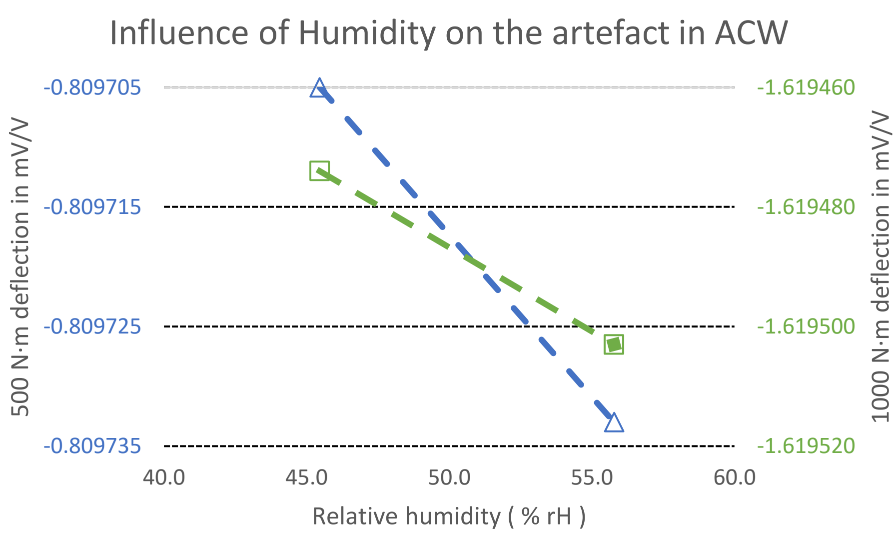

Figure 6: Effect of humidity on the artefact in ACW direction

Table 4: Temperature and humidity coefficients and expanded uncertainties of the artefact

Comparison step (N·m)	Temperature coefficient (mV/V / K)		Humidity coefficient (mV/V / %rH)	
	CW	ACW	CW	ACW
500	0.000026 ± 0.000013	-0.000020 ± 0.000013	0.000003 ± 0.000001	-0.000003 ± 0.000001
1000	0.000039 ± 0.000020	-0.000046 ± 0.000018	0.000003 ± 0.000001	-0.000003 ± 0.000001

8. Results

Table (5) shows the stability of the artefact used which was observed over 2 successive calibrations carried out at PTB in 2017 and 2022. The calculated drift over the comparison cycle (4 months) was used as the stability error of the artefact used. Table (6) show the measurement uncertainties of NIS and PTB. The relative expanded uncertainties of NIS measurements (W_{N}) and PTB measurements (W_{P}) are calculated as the following equations:

$$W_{\mathrm{N}} = 2 \times \sqrt{\left(\frac{W_{\mathrm{N0}}}{2}\right)^2 + w_{\mathrm{N1}}^2 + w_{\mathrm{N2}}^2 + w_{\mathrm{N3}}^2 + w_{\mathrm{N4}}^2 + w_{\mathrm{N5}}^2} \quad (1)$$

$$W_{\mathrm{P}} = 2 \times \sqrt{\left(\frac{W_{\mathrm{P0}}}{2}\right)^2 + w_{\mathrm{P1}}^2 + w_{\mathrm{P2}}^2} \quad (2)$$

Table 5: Stability error of the artefact

	2017		2022*					
Applied torque	Average response	Relative expanded uncertainty	Average response	Relative expanded uncertainty	Drift over 5 years	Drift over a month	Drift over 4 months**	Relative uncertainty due to stability w_{N5}
N·m	mV/V	%	mV/V	%	mV/V	mV/V	mV/V	
1000	1.619443	0.003	1.619415	0.003	0.000028	0.0000005	0.000002	9.84×10^{-07}
500	0.809668	0.004	0.809681	0.002	0.000013	0.0000002	0.000001	9.44×10^{-07}
-500	-0.809709	0.003	-0.809697	0.003	0.000012	0.0000002	0.000001	8.84×10^{-07}
-1000	-1.619549	0.004	-1.619510	0.002	0.000039	0.0000007	0.000003	1.40×10^{-06}

*The results have been corrected due to temperature and humidity differences.
** The value is multiplied by 1.5 to compensate the nonlinearity and shorter-term variations.

Table 6: Measurement uncertainties

Torque (N·m)	NIS						PTB		
	Relative Repeat-ability	Relative Repro-ducibility	Relative temperature correction	Relative humidity correction	Relative stability	Relative Expanded uncertainty	Relative Repeat-ability	Relative Repro-ducibility	Relative Expanded uncertainty
	w_{N1}	w_{N2}	w_{N3}	w_{N4}	w_{N5}	W_N	w_{P1}	w_{P2}	W_P
1000	8.23×10^{-07}	5.36×10^{-06}	6.05×10^{-07}	5.12×10^{-06}	9.84×10^{-07}	9.1×10^{-05}	2.06×10^{-07}	3.97×10^{-06}	2.2×10^{-05}
500	2.97×10^{-06}	3.66×10^{-06}	3.99×10^{-07}	5.45×10^{-06}	9.44×10^{-07}	9.1×10^{-05}	3.57×10^{-07}	3.22×10^{-06}	2.1×10^{-05}
-500	8.45×10^{-06}	4.12×10^{-06}	5.75×10^{-06}	7.32×10^{-06}	8.84×10^{-07}	9.4×10^{-05}	1.07×10^{-06}	4.45×10^{-06}	2.2×10^{-05}
-1000	3.44×10^{-06}	2.83×10^{-06}	7.72×10^{-06}	9.56×10^{-06}	1.40×10^{-06}	9.4×10^{-05}	5.35×10^{-07}	2.18×10^{-06}	2.0×10^{-05}

Table (7) shows the uncorrected NIS measurements due to temperature and relative humidity. The NIS measurements were conducted at 21.13℃ and 41 rH % for CW direction and at 21.53℃ and 44 rH % for ACW direction. While, the PTB measurements were conducted at 21.1 ℃ and 35.8 rH % for both CW and ACW directions.

Table 7: NIS uncorrected measurements

	NIS
Torque	Average
N·m	mV/V
1000	1.619361
500	0.809654
-500	-0.809701
-1000	-1.619479

Table (8) and Figure (7) show the corrected NIS results due to temperature and relative humidity differences, PTB results and the corresponding normalized error (E_n). All E_n values are less than unity. Thus, it has been demonstrated that torque realized by the 1000 N·m DWTSMs of NIS and of PTB are equivalent to each other.

Table 8: Average deflections, uncertainties and the E_n-values of NIS-PTB torque comparison

	NIS		PTB		
Torque	Average	Rel. Expanded uncertainty	Average	Rel. Expanded uncertainty	E_n-value
N·m	mV/V	mV/V	mV/V	mV/V	
1000	1.619345	0.000148	1.619380	0.000035	-0.22
500	0.809640	0.000074	0.809656	0.000017	-0.23
-500	-0.809670	0.000076	-0.809675	0.000018	-0.06
-1000	-1.619436	0.000152	-1.619470	0.000033	-0.21

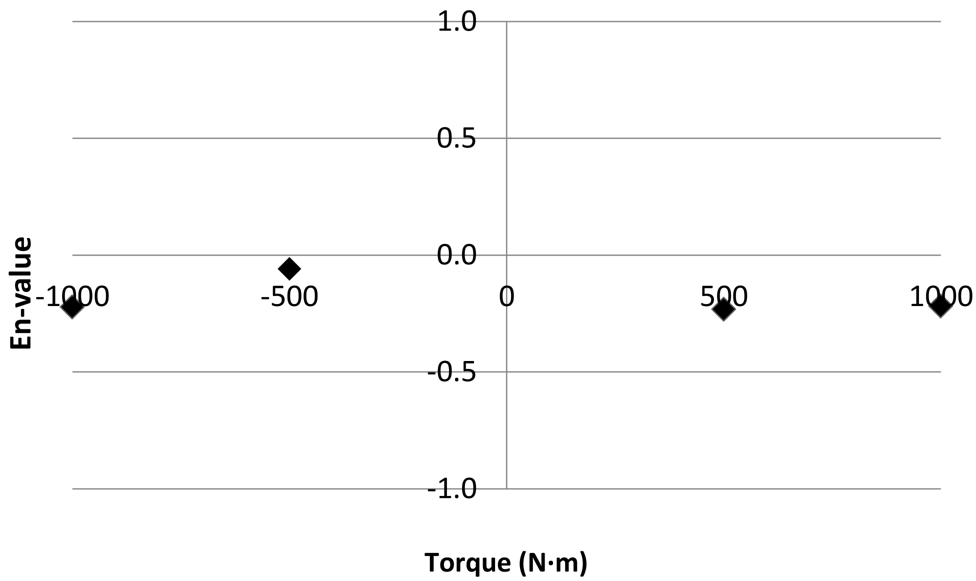

Figure 7: E_n-values of the NIS-PTB torque comparison

9. Summary

The AFRIMETS.M.T-S1 supplementary comparison has been conducted between NIS (Egypt) and PTB (Germany) at the torque of 500 N·m and 1000 N·m in both clockwise and anticlockwise directions. The comparison results revealed the equivalence of torque realized by the 1000 N·m DWTSMs of NIS and of PTB within their measurement uncertainties.

10. References

[1] Dirk Röske, “Final Report on the Torque Key Comparison CCM.T-K1 Measurand Torque: 0 N·m, 500 N·m, 1000 N·m”, 2009 Metrologia 46 07002.

[2] K.M. Khaled , D. Röske, A.E. Abuelezz, M.G. Elsherbiny, "Humidity and temperature effects on torque transducers, bridge calibration unit and amplifiers", Measurement 74 (2015) 31–42.

[3] K.M. Khaled , D. Röske, A.E. Abuelezz, M.G. Elsherbiny, "The influence of temperature and humidity on the sensitivity of torque transducers", Measurement 94 (2016) 186–200.