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TORQUE BILATERAL COMPARISON BETWEEN NMISA AND INMETRO

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Abstract:
This paper presents the results of a bilateral comparison in torque measurements between NMISA in South Africa and INMETRO in Brazil. For this comparison, NMISA used a 20 kN·m torque comparator machine with a proposed uncertainty of 0.03 % ($k = 2$) across the entire measuring range. INMETRO used a 3 kN·m lever deadweight standard machine with uncertainty of 0.01 %. The comparison was conducted for both clockwise and counter-clockwise directions. Comparison analysis considered measurement data in the range of 200 N·m to 1 000 N·m. The maximum relative deviation observed for the bilateral is 2×10^{-4} in both directions.

Keywords: torque; bilateral comparison; comparator machine; relative deviation

1. INTRODUCTION

The National Metrology Institute of South Africa (NMISA) has, in the past, been able to provide traceability in the calibration of torque transducers in the range of 10 N·m to 1 000 N·m using a beam and weights torque rig. This rig however, had limited capacity to support the growing need for torque traceability above 1 000 N·m in South Africa. Furthermore, the rig had high measurement uncertainty and only square type transducers could be calibrated. Therefore, to address the need of traceability above 1 000 N·m with better measurement uncertainty, NMISA acquired a new torque comparator machine (TCM). The TCM can generate torque from 50 N·m up to 20 kN·m. Square drive, smooth shaft and flange type transducers can all be calibrated by comparison method using the TCM. The calibration measurement capability (CMC) of the TCM is proposed at 0.03 % across the whole measurement range. To support the claimed CMC, NMISA needed to conduct interlaboratory comparisons (ILCs) with other National Metrology Institutes (NMIs) with preferably better torque CMCs registered in the Key Comparison Data Base (KCDB). For this reason, NMISA approached the National Institute of Metrology, Quality and Technology (INMETRO) in Brazil to participate in a bilateral torque comparison in the range of 50 N·m to 1 000 N·m to prove claimed CMC at the lower range of the TCM. NMISA also approached National Metrology Institute of Japan (NMIJ) to conduct a CIPM key comparison in the range 10 kN·m and 20 kN·m to prove CMC in the higher ranges of the TCM. The CIPM key comparison (CCM.T-K2.1) between NMISA and NMIJ is currently ongoing. However, the bilateral comparison between NMISA and INMETRO was concluded, and the results are presented in this paper.

2. MACHINE EVALUATION

The claimed CMC of the TCM shown in Figure 1 at the lower torque range was evaluated through a bilateral comparison with INMETRO who used their 3 kN·m torque standard machine (TSM) shown in Figure 2.

Figure 1: The 20 kN·m TCM at NMISA

Figure 2: The 3 kN·m TSM at INMETRO

Table 1 shows details of the torque machines used for the bilateral comparison.

Table 1: Details of the torque machines used

Institute	**Torque standard machine capabilities**		
	Type	**Capacity**	**Exp. Unc. (*k* = 2)**
NMISA	Comparator	20 kN·m	0.03 %
INMETRO	Lever deadweight	3 kN·m	0.01 %

NMISA provided a 500 N·m (with 100 % overrange capability) HBM, TB2 type torque transducer with serial number 211330022 as an artefact for the comparison. Smooth shaft adaptations were provided to enable the artefact to be calibrated using the TSM at INMETRO. An HBM bridge amplifier model MGCplus with serial number 80127915 accompanied the transducer. The amplifier was used with the following settings: Absolute (ABS), 0.5 Hz Bessel filter, 5 V excitation voltage and ±2.5 mV/V measuring range.

The measurements were performed based on the methodology of the DIN 51309 [1]. The artefact was calibrated in both clockwise (CW) and counter-clockwise (CCW) directions at the loading steps of 50 N·m, 100 N·m, 200 N·m, 300 N·m, 400 N·m, 600 N·m, 800 N·m, 1 000 N·m following the application series in Figure 3. NMISA calibrated the transducer twice. Round 1 of measurements were performed before the artifact was sent to INMETRO (for their set of measurements) and Round 2 of measurements after the artifact returned to NMISA. All measurements were performed at 20 °C ± 1 °C. The time intervals during the measurements were: 30 s waiting time before recording the indicated value, 180 s waiting time after the first three pre-loads and 180 s waiting time after pre-load at each new position with zero torque applied.

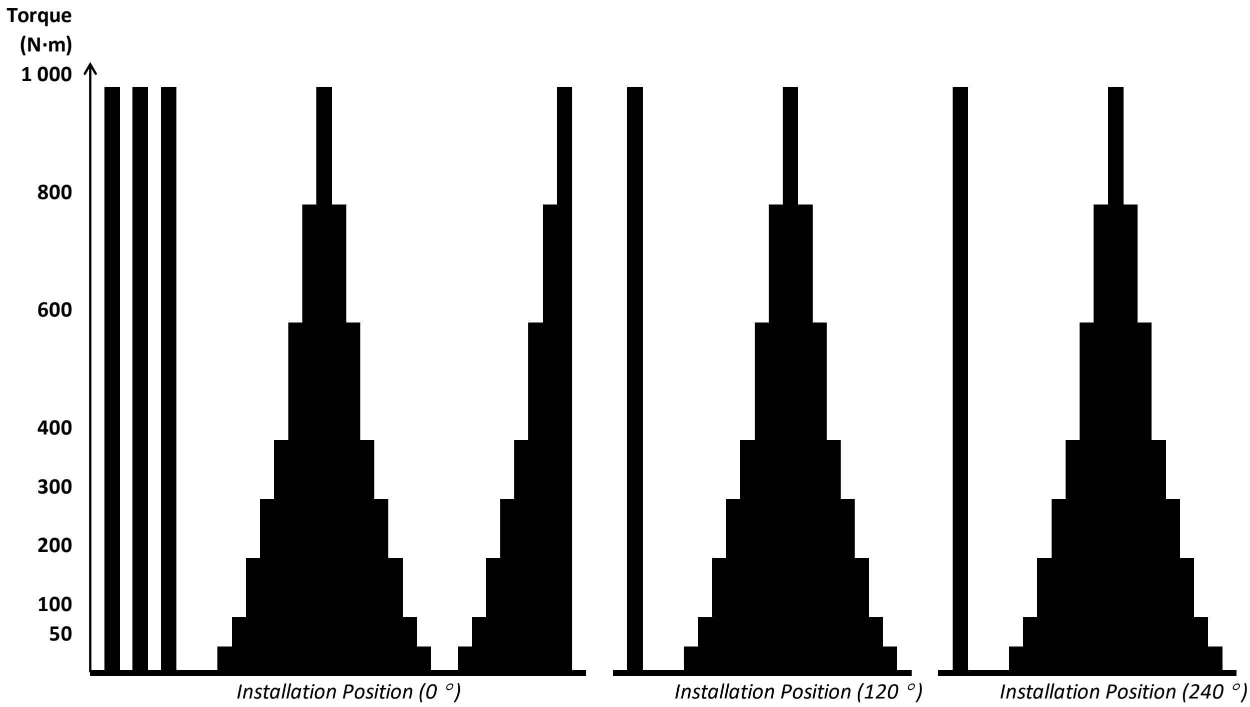

Figure 3: Torque application series for each position

Comparison analysis considered measurement data in the range of 200 N·m to 1 000 N·m, to consider the most accurate range of the artefact. The measurement result is the mean deflection calculated from readings measured in three positions for measurement of the artefact in CW and CCW directions by each participant according to DIN 51309 for Case I [1]. These results for CW and CCW measurements are depicted in Table 2. The relative deviation from INMETRO is calculated using equation (*1*).

$$Rel.\,dev. = \frac{X_{\mathrm{NMISA}} - X_{\mathrm{INMETRO}}}{X_{\mathrm{INMETRO}}} \qquad (1)$$

where X_{NMISA} (Round 1 or Round 2) and X_{INMETRO} are the resultant mean deflections.

Table 2: CW and CCW deviation in NMISA measurements from INMETRO (reference)

Torque / N·m	Mean deflection / mV/V			*Rel. dev.*	
	X_{INMETRO}	X_{NMISA} Round 1	X_{NMISA} Round 2	Round 1	Round 2
200	0.400 13	0.400 11	0.400 08	-5.6E-05	-1.2E-04
300	0.600 21	0.600 17	0.600 12	-6.6E-05	-1.5E-04
400	0.800 30	0.800 24	0.800 16	-7.6E-05	-1.7E-04
600	1.200 48	1.200 39	1.200 27	-7.1E-05	-1.7E-04
800	1.600 70	1.600 57	1.600 40	-8.1E-05	-1.9E-04
1 000	2.000 94	2.000 78	2.000 55	-8.0E-05	-1.9E-04
-200	-0.400 12	-0.400 11	-0.400 08	-3.1E-05	-1.0E-04
-300	-0.600 23	-0.600 17	-0.600 12	-9.7E-05	-1.8E-04
-400	-0.800 27	-0.800 24	-0.800 18	-3.4E-05	-1.1E-04
-600	-1.200 54	-1.200 41	-1.200 31	-1.1E-04	-1.9E-04
-800	-1.600 75	-1.600 60	-1.600 47	-9.3E-05	-1.7E-04
-1 000	-2.001 02	-2.000 83	-2.000 66	-9.5E-05	-1.8E-04

The graphical representation of these relative deviations between NMISA and INMETRO measurements are shown in Figure 4.

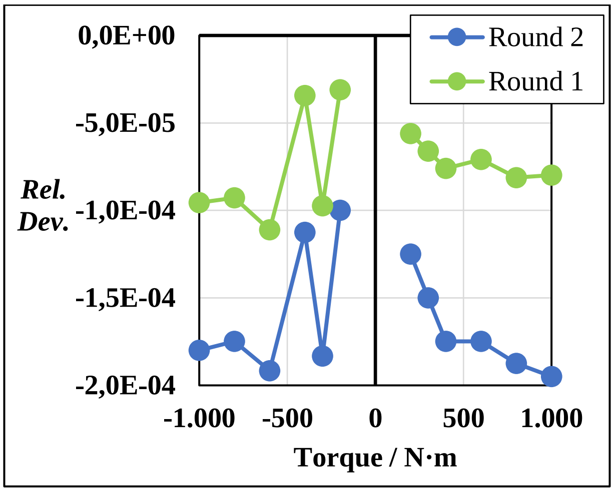

Figure 4: Relative deviation between NMISA and INMETRO

The relative deviations between NMISA and INMETRO are within 2×10^{-4} for the range investigated. Furthermore, the normalised error (E_{n}) values are calculated for the bilateral and used as a way of assessing measurement equivalence with respect to the measurement uncertainty. The uncertainties calculated for each round of measurements were based mainly on five contributors: machine uncertainty (CMC), reproducibility, repeatability, resolution and zero deviation, The resulted measurement uncertainty for CW and CCW are depicted in Table 3 together with the relative deviations.

Table 3: Deviation and relative expanded uncertainties

Torque / N·m	*Rel. dev.*		Exp. Uncertainty *U* (*k* = 2) / %		
	Round 1	Round 2	U_{INMETRO}	U_{NMISA} Round 1	U_{NMISA} Round 2
200	-5.6E-05	-1.2E-04	0.011 2	0.030 1	0.030 4
300	-6.6E-05	-1.5E-04	0.010 7	0.030 1	0.030 3
400	-7.6E-05	-1.7E-04	0.010 3	0.030 1	0.030 4
600	-7.1E-05	-1.7E-04	0.010 5	0.030 0	0.030 4
800	-8.1E-05	-1.9E-04	0.010 2	0.030 0	0.030 4
1 000	-8.0E-05	-1.9E-04	0.010 1	0.030 0	0.030 5
-200	-3.1E-05	-1.0E-04	0.011 2	0.030 1	0.030 4
-300	-9.7E-05	-1.8E-04	0.010 4	0.030 1	0.030 4
-400	-3.4E-05	-1.1E-04	0.012 9	0.030 0	0.030 3
-600	-1.1E-04	-1.9E-04	0.010 4	0.030 0	0.030 3
-800	-9.3E-05	-1.7E-04	0.010 2	0.030 0	0.030 3
-1 000	-9.5E-05	-1.8E-04	0.010 9	0.030 0	0.030 3

Equation (2) is used to calculate the E_{n} values.

$$E_{\mathrm{n}} = \frac{X_{\mathrm{NMISA}} - X_{\mathrm{INMETRO}}}{\sqrt{U_{\mathrm{NMISA}}^2 + U_{\mathrm{INMETRO}}^2}} \qquad (2)$$

where X_{NMISA} and X_{IMMETRO} are the average deflection at each applied torque for all positions and U_{NMISA} and U_{INMETRO} are the expanded uncertainties of measurements for NMISA and INMETRO respectively.

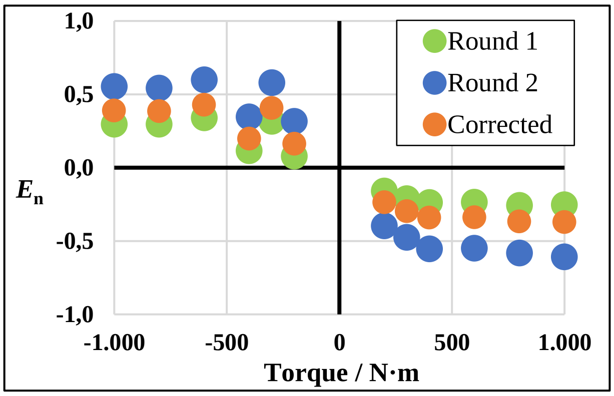

Figure 5: Bilateral results comparison (normalised error E_{n})

As depicted in Figure 5 and shown in Table 4, E_{n} values are below ± 1 across the bilateral torque range for Round 1 and Round 2. This indicates good agreement in measurements with respect to the uncertainties. To correct for the possible drift (due to artefact and reference standard) between the NMISA Round 1 (November 2019) and Round 2 (July 2020) measurements, an average value was used as the measurement result. Linear interpolation was assumed to adjust the average value to meet the same date (February 2020) of the measurements performed at INMETRO. The uncertainty contribution due to drift was included as an additional source to the NMISA uncertainty budget and the combined uncertainty was considered. E_{n} values for the drift-corrected values were calculated and are shown in Table 4 and Figure 5 together with the E_n values for Round 1 and Round 2. The relative deviations between the average measurements from NMISA and INMETRO results are plotted in Figure 6. The combined uncertainty for each loading step by INMETRO and NMISA (including the drift) are incorporated in the same plot.

Table 4: CW and CCW corrected values and uncertainty including drift analysis for NMISA

Torque / N·m	**NMISA corrected values**		**E_n Corrected**	**E_n Round 1**	**E_n Round 2**
	Average value / mV/V	**U_{NMISA} (k = 2) / %**			
200	0.400 10	0.030 5	-0.24	-0.16	-0.40
300	0.600 15	0.030 5	-0.30	-0.21	-0.47
400	0.800 21	0.030 6	-0.34	-0.24	-0.55
600	1.200 35	0.030 6	-0.34	-0.24	-0.55
800	1.600 51	0.030 7	-0.37	-0.26	-0.58
1 000	2.000 70	0.030 8	-0.37	-0.25	-0.61
-200	-0.400 10	0.030 5	0.16	0.08	0.32
-300	-0.600 15	0.030 5	0.41	0.32	0.58
-400	-0.800 22	0.030 4	0.20	0.12	0.35
-600	-1.200 37	0.030 5	0.43	0.34	0.60
-800	-1.600 55	0.030 5	0.39	0.30	0.54
-1 000	-2.000 77	0.030 5	0.39	0.30	0.56

The NMISA corrected values corresponding to the same date as measurements at INMETRO further indicate good agreement for this bilateral comparison, since the E_n values are all within ± 1 as listed in Table 4 for both CW and CCW directions.

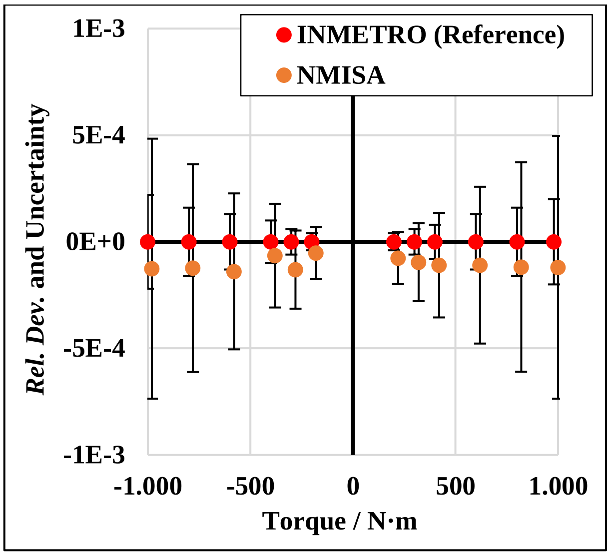

Figure 6: Relative deviations for NMISA average value from INMETRO measurements

3. SUMMARY

The normalised error values for the bilateral measurements carried out between NMISA and INMETRO using their TSM are less than one for the entire comparison range. The maximum relative deviation observed for the bilateral is 2×10^{-4} (0.02 %). The result of the comparison indicates that the claimed CMC of 0.03 % (k = 2) for the TCM can be adequate for the lower torque operational range up to 1 000 N·m.

4. REFERENCES

[1] DIN 51309, "Materials testing machines - Calibration of static torque measuring devices", Issue 12, 2005.