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Final Report on the Torque Comparison EURAMET.M.T-S1 Measurand Torque: 1 N·m, 5 N·m, 10 N·m, 50 N·m, 200 N·m, 500 N·m, and 1000 N·m

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1. General information about the EURAMET.M.T-S1

In 2007, the Egyptian NIS asked the German PTB for a comparison of reference-type torque calibration machines. Two PTB machines of this type, namely the 20 N·m and the 2000 N·m machines are traced back to the German Primary 1 kN·m Torque Standard Machine (TSM) by utilizing precision torque transducers calibrated on this TSM as references. NIS has also tow reference machines with capacities of 20 N·m and 1000 N·m. It was agreed to compare these machines using four travelling standards and torques of 1 N·m, 5 N·m, 10 N·m, 50 N·m, 200 N·m, 500 N·m, and 1000 N·m all in clockwise and anti-clockwise directions. As pilot laboratory the torque working group of PTB was appointed.
The 1 kN·m Torque Standard Machine (TSM) was used for PTB’s measurements within the CIPM Torque Key Comparison CCM.T-K1. The results of this inter-comparison are published on the BIPM website [1].

Table1: Participants in the EURAMET.M.T-S1 torque comparison: countries, institutes and code numbers used in the report

Country (alphabetical order)	Institute	Code letter
Egypt	NIS	E
Germany	PTB	P

2. Principles of the comparison

The purpose of these measurements is to compare the units of the given quantities as realized throughout the world. In the field of torque, this is done by using torque transducers of high quality, high-precision frequency-carrier amplifiers and very stable bridge standards. The torque transducers were subject to similar loading schemes in the torque calibration machines of the participants following a strict measurement protocol and using similar amplifiers. The following loading scheme was agreed:

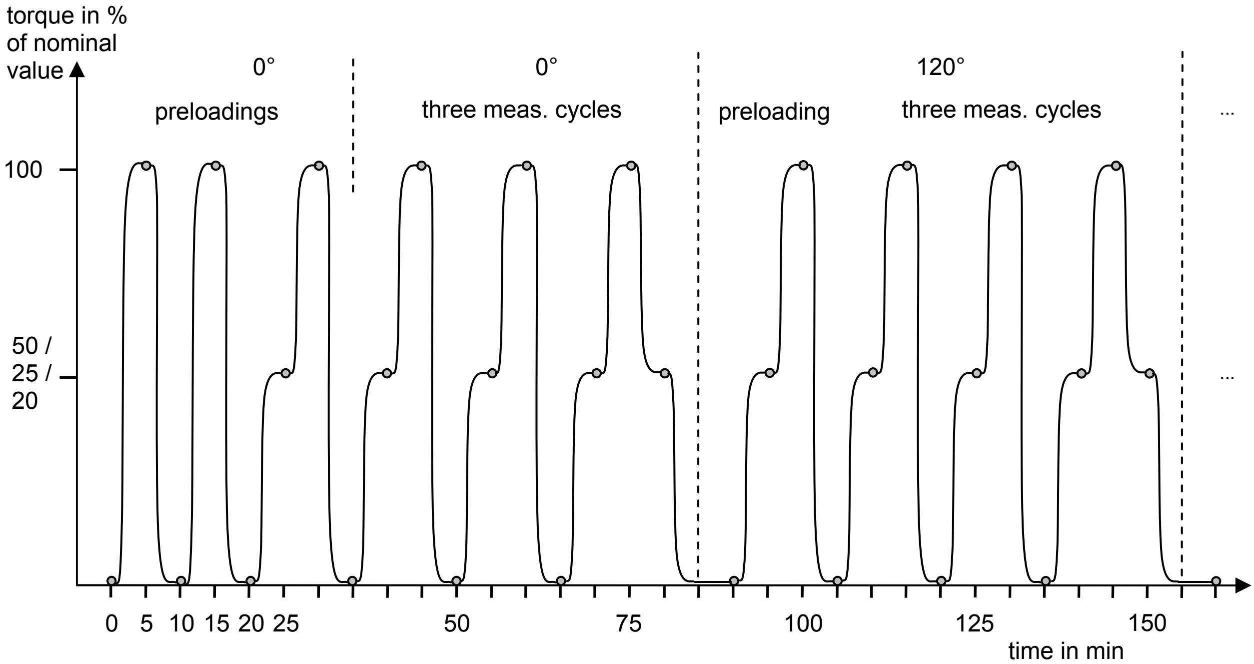

Figure 1. Diagram of the measurement sequence of the EURAMET.M.T-S1

The torque transducer was rotated from 0° to 240° with 120° steps. Except the first mounting position with six load cycles – three for stabilization and three for the repeatability measurement - in all other positions one preload and three measurement cycles (as shown for the 120° position in figure 1) were carried out, i.e. at transducer positions of 120° and 240°.

Table2: Participants in the EURAMET.M.T-S1 torque comparison: countries, institutes and code numbers used in the report

Part	NIS Machine	PTB Machine	Calibration Mode	Test	Torque steps	Transducer
A	1000 N·m Ref. M/C	2000 N·m Dm-KE	Clockwise	A1	500 N·m (50%) 1000 N·m	TT1, **1000 N·m** S/N #33945-99
			Anti-Clockwise	A2	-500 N·m (50%) -1000 N·m	
B	1000 N·m Ref. M/C	2000 N·m Dm-KE	Clockwise	B1	50 N·m (25%) 200 N·m	TB2, **200 N·m** S/N 080830117
			Anti-Clockwise	B2	-50 N·m (25%) -200 N·m	
C	20 N·m Ref. M/C	20 N·m Dm-KE	Clockwise	C1	5 N·m (50%) 10 N·m	TT1, **10 N·m** S/N #36835-02
			Anti-Clockwise	C2	-5 N·m (50%) -10 N·m	
D	20 N·m Ref. M/C	20 N·m Dm-KE	Clockwise	D1	1 N·m (20%) 5 N·m	TT1, **5 N·m** S/N #37103-03
			Anti-Clockwise	D2	-1 N·m (20%) -5 N·m	

The comparison measurements had to be done with each torque transducer at the torque steps defined in Table 2. Between 0% and 100% of the nominal torque there is another torque step – depending on the transducer - at 50%, 25% or 20%. In contrast to the CCM.T-K1 where dead-weight machines were compared, measurements with decremental torque are also carried out now in the last series of each mounting position in order to investigate the influence of hysteresis. One of the four transducers is a TB2 torque measuring flange with adaptors at both ends. The other three transducers are TT1 transducers of shaft type. The construction principles of the two transducer types are different, but the mechanical interface is the same – round shafts with 50 mm (1000 N·m and 200 N·m), resp. 15 mm (10 N·m and 5 N·m) diameter and a suitable length fitting for ETP-50 or ETP-15 hydraulic couplings. The transducers had been selected for their very stable characteristics and their known history.

3. Realization of the comparison

Due to the limited number of participants no special comparison type formation was necessary. The transducers were measured at the pilot laboratory and returned after the measurement at the participating laboratory to the pilot. In the case of too large deviations, i.e. the corrected results for incremental torque deviated by more than $1 \cdot 10^{-4}$ for a given transducer the pilot repeated the measurements with this certain device. This was the case for the transducers A and D.

4. Limitations of the comparison

From the results of the CCM.T-K1 it is known, that the travelling standards (transducers TB2 and TT1) with higher capacity are very stable, especially the hermetically closed TB2 [2]. The low-capacity transducers are much more sensitive to temperature and humidity changes. It was agreed to bring the transducers to the participant by airplane in the hand luggage of a person from the pilot laboratory. The environmental conditions on site and during the transportation were logged and corrections to the calibration results were applied. In order to get comparable results some other known effects had to be considered. These are possible deviations of the amplifiers (DMP40) of the participating laboratories. The creep influence due to different loading times the machines was not taken into account, because the loading regimes are very similar. The creep correction could therefore be neglected.

Due to the fact that there is no real reference value (the transfer transducers do not provide constant values), the following facts should be accepted: there is no absolute numerical reference value and only relative deviations can be compared.

5. Uniformity of the measured values

In practice, it is not possible to calibrate the DMP40 amplifiers of the participating laboratories against an absolute reference standard. The uniformity of the different DMP40s was confirmed with reference to a K148 bridge standard. Each participating laboratory measured the indication of its own DMP40 against the signal of the pilot's K148, which was delivered together with the transducers. The measurements with the K148 were carried out with suitably selected voltage ratios near the signals of the transducers for the given torque steps. These measurements show that there are maximum relative deviations of the zero-reduced indications of up to 35 ppm between the different DMPs. Although these deviations are very small, the participant's E calibration results were corrected using (1):

$$Y'_{\mathrm{E}} = Y_{\mathrm{E}} \cdot (1 + d_{\mathrm{E}}(V/V_{\mathrm{S}})) \qquad (1)$$

with Y_{E} being the uncorrected and Y'_{E} the corrected deflections, $d_{\mathrm{E}}(V/V_{\mathrm{S}})$ are the relative deviations between the indications of the pilot's DMP40 and the DMP40 of participant E.

6. Characteristics of the transducers

The chronological order of the calibrations in the pilot and the participating laboratory is given in table 3.

Table 3: Chronological order of the calibrations during the comparison (all dates in 2008)

Measurement	A		B		C		D	
	cw	acw	cw	acw	cw	acw	cw	acw
P(1)	21.05.	21.05.	25.05.	25.05.	27.05.	27.05.	25.05.	26.05.
E	02.06.	03.06.	03.06.	04.06.	04.06.	04.06.	05.06.	05.06.
P(2)	17.07.	17.07.	-	-	-	-	25.08.	25.08.

Humidity influence on the sensitivity

The humidity effect on the sensitivity can be an important factor if the environmental humidity at the participating laboratory is not the same as that at the pilot. The humidity sensitivities of the different transducer types were taken from the CCM.T-K1 key comparison [1]. All measuring results were corrected for the influence of the relative humidity deviation using the corresponding values of table 4.

Temperature influence on the sensitivity
The temperature effect on the sensitivity can be an important factor if the environmental temperature in the participating laboratory is not the same as that at the pilot. The temperature sensitivities of the different transducer types were taken from the CCM.T-K1 comparison [1]. All measuring results were corrected for the influence of the temperature deviation using the corresponding values of table 5.

Table 4: Calculated humidity coefficients e_{rH} of the transfer transducers (from measurements only in clockwise direction)

	Air humidity coefficient e_{rH} in (nV/V)/%		Uncertainty of the humidity coefficient (k = 2) in (nV/V)/%	
	20%, 25% or 50% of nom. torque	100% nom. torque	20%, 25% or 50% of nom. torque	100% nom. torque
TB2	0.40	1.06	2	2
TT1	-4.0	-8.0	2	2

Table 5: Calculated temperature coefficients e_T of the transfer transducers (from measurements only in clockwise direction)

	Temperature coefficient e_T in (nV/V)/K		Uncertainty of the temperature coefficient (k = 2) in (nV/V)/K	
	20%, 25% or 50% of nom. torque	100% nom. torque	20%, 25% or 50% of nom. torque	100% nom. torque
TB2	0.02	-0.2	2	2
TT1	5.9	11.7	2	2

Using the values e_{rH} and e_T given in tables 4 and 5, for each of the participants i the deflections can be corrected taking into account the corresponding deviations Δ from the ideal environmental conditions (T = 21°C, rH = 40%) according to (2):

$$Y'''_i = Y''_i + e_{rH} \cdot \Delta rH + e_T \cdot \Delta T \tag{2}$$

with Y''_i being the uncorrected and Y'''_i the corrected deflections.

Stability of the transfer transducers
The stability of travelling standards was investigated in detail during the CCM.T-K1 key comparison. With a reproducibility of a few parts in 10^6 the TB2 transducer was extremely stable, but also the 1 kN·m TT1 was stable enough for comparing machines at a level of 10 ppm standard uncertainty. In this comparison, machines with a relative standard uncertainty of 100 ppm (PTB, 2 kN·m), 200 ppm (PTB, 20 N·m) and 300 ppm (NIS), resp. 700 ppm (NIS, 1 N·m) had to be compared. Therefore, it was not expected to have problems with the 200 N·m and the 1000 N·m transducers (A and B). A problem could be the very small transducers with 5 N·m and 10 N·m capacity (C and D). The measurements showed that with both low-capacity transducers sufficiently good results could be obtained, except the results for the 5 N·m transducer (D).

7. Results of the measurements: reported deflections and uncertainties, calculated corrections

All results are given in the tables in section 7.1: the deflections as reported by the participants and the values with

- corrections for the amplifier used according to 5, additionally
- corrections for the environmental conditions according to 6 (sections "Humidity influence on the sensitivity" and "Temperature influence on the sensitivity").

The pilot reports the arithmetical mean of all measurements made in this laboratory and the corresponding corrected values.
A proposal for the calculation of the weighted mean and a χ^2 test is given in the annex A.1 according to procedure A in [3]. In the parts A.2, A.3 and A.4 the calculation of the comparison reference values (RV), of the relative deviations of the deflections from the corresponding RV and of the degrees of equivalence are proposed.

The following designations are used in the tables 6 to 8:

$X_{P\text{-}Rep}$ = Deflection reported by participant x (for the pilot: mean of all measurements), in mV/V
$X_{P\text{-}DMP}$ = Deflection for participant x - corrected for the influence of the DMP40, in mV/V
$X_{P\text{-}Envir}$ = Deflection for participant x - additionally corrected for the influence of the environment - in mV/V
$W_{P\text{-}Rep}$ = Relative expanded (k = 2) uncertainty of $X_{P\text{-}Rep}$
$W_{P\text{-}DMP}$ = Relative expanded (k = 2) uncertainty of $X_{P\text{-}DMP}$
$W_{P\text{-}Envir}$ = Relative expanded (k = 2) uncertainty of $X_{P\text{-}Envir}$
cw = clockwise torque
acw = anti-clockwise torque

Table 6: Uncorrected deflections in mV/V and uncertainties as reported by the participants

A – cw	500 N·m		1000 N·m		500 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	0.670881	$6.0\cdot10^{-4}$	1.341858	$6.0\cdot10^{-4}$	0.670945	$6.0\cdot10^{-4}$
P	0.670833	$2.0\cdot10^{-4}$	1.341755	$2.0\cdot10^{-4}$	0.670906	$2.1\cdot10^{-4}$
A – acw	-500 N·m		-1000 N·m		-500 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	-0.670866	$6.0\cdot10^{-4}$	-1.341802	$6.0\cdot10^{-4}$	-0.670928	$6.0\cdot10^{-4}$
P	-0.670818	$2.0\cdot10^{-4}$	-1.341709	$2.0\cdot10^{-4}$	-0.670891	$2.1\cdot10^{-4}$
B – cw	50 N·m		200 N·m		50 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	0.317322	$6.0\cdot10^{-4}$	1.269620	$6.0\cdot10^{-4}$	0.317452	$6.0\cdot10^{-4}$
P	0.317331	$2.0\cdot10^{-4}$	1.269597	$2.0\cdot10^{-4}$	0.317463	$2.1\cdot10^{-4}$
B – acw	-50 N·m		-200 N·m		-50 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	-0.317318	$6.0\cdot10^{-4}$	-1.269585	$6.0\cdot10^{-4}$	-0.317441	$6.0\cdot10^{-4}$
P	-0.317331	$2.0\cdot10^{-4}$	-1.269564	$2.0\cdot10^{-4}$	-0.317447	$2.1\cdot10^{-4}$
C – cw	5 N·m		10 N·m		5 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	0.668426	$6.0\cdot10^{-4}$	1.336989	$6.0\cdot10^{-4}$	0.668408	$6.0\cdot10^{-4}$
P	0.668391	$4.0\cdot10^{-4}$	1.336882	$4.0\cdot10^{-4}$	0.668469	$4.0\cdot10^{-4}$
C – acw	-5 N·m		-10 N·m		-5 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	-0.668374	$6.0\cdot10^{-4}$	-1.336950	$6.0\cdot10^{-4}$	-0.668395	$6.0\cdot10^{-4}$
P	-0.668381	$4.0\cdot10^{-4}$	-1.336865	$4.0\cdot10^{-4}$	-0.668477	$4.0\cdot10^{-4}$
D – cw	1 N·m		5 N·m		1 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	0.393542	$1.4\cdot10^{-3}$	1.965561	$6.0\cdot10^{-4}$	0.393494	$1.4\cdot10^{-3}$
P	0.393698	$4.1\cdot10^{-4}$	1.968006	$4.1\cdot10^{-4}$	0.393855	$4.1\cdot10^{-4}$
D – acw	-1 N·m		-5 N·m		-1 N·m – decremental	
	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$X_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
E	-0.393817	$1.4\cdot10^{-3}$	-1.970442	$6.0\cdot10^{-4}$	-0.393903	$1.4\cdot10^{-3}$
P	-0.393816	$4.0\cdot10^{-4}$	-1.969987	$4.0\cdot10^{-4}$	-0.394004	$4.1\cdot10^{-4}$

Table 7: Deflections from table 6 in mV/V, corrected for the influence of the DMP40, and corresponding uncertainties

A – cw	500 N·m		1000 N·m		500 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	0.670884	$6.0 \cdot 10^{-4}$	1.341863	$6.0 \cdot 10^{-4}$	0.670948	$6.0 \cdot 10^{-4}$
P	0.670833	$2.0 \cdot 10^{-4}$	1.341755	$2.0 \cdot 10^{-4}$	0.670906	$2.1 \cdot 10^{-4}$
A – acw	-500 N·m		-1000 N·m		-500 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	-0.670867	$6.0 \cdot 10^{-4}$	-1.341805	$6.0 \cdot 10^{-4}$	-0.670930	$6.0 \cdot 10^{-4}$
P	-0.670818	$2.0 \cdot 10^{-4}$	-1.341709	$2.0 \cdot 10^{-4}$	-0.670891	$2.1 \cdot 10^{-4}$
B – cw	50 N·m		200 N·m		50 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	0.317311	$6.0 \cdot 10^{-4}$	1.269624	$6.0 \cdot 10^{-4}$	0.317441	$6.0 \cdot 10^{-4}$
P	0.317331	$2.0 \cdot 10^{-4}$	1.269597	$2.0 \cdot 10^{-4}$	0.317463	$2.0 \cdot 10^{-4}$
B – acw	-50 N·m		-200 N·m		-50 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	-0.317324	$6.0 \cdot 10^{-4}$	-1.269588	$6.0 \cdot 10^{-4}$	-0.317447	$6.0 \cdot 10^{-4}$
P	-0.317331	$2.0 \cdot 10^{-4}$	-1.269564	$2.0 \cdot 10^{-4}$	-0.317447	$2.0 \cdot 10^{-4}$
C – cw	5 N·m		10 N·m		5 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	0.668429	$6.0 \cdot 10^{-4}$	1.336994	$6.0 \cdot 10^{-4}$	0.668411	$6.0 \cdot 10^{-4}$
P	0.668391	$4.0 \cdot 10^{-4}$	1.336882	$4.0 \cdot 10^{-4}$	0.668469	$4.0 \cdot 10^{-4}$
C – acw	-5 N·m		-10 N·m		-5 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	-0.668376	$6.0 \cdot 10^{-4}$	-1.336953	$6.0 \cdot 10^{-4}$	-0.668397	$6.0 \cdot 10^{-4}$
P	-0.668381	$4.0 \cdot 10^{-4}$	-1.336865	$4.0 \cdot 10^{-4}$	-0.668477	$4.0 \cdot 10^{-4}$
D – cw	1 N·m		5 N·m		1 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	0.393543	$1.4 \cdot 10^{-3}$	1.965600	$6.0 \cdot 10^{-4}$	0.393496	$1.4 \cdot 10^{-3}$
P	0.393698	$4.1 \cdot 10^{-4}$	1.968006	$4.1 \cdot 10^{-4}$	0.393855	$4.1 \cdot 10^{-4}$
D – acw	-1 N·m		-5 N·m		-1 N·m – decremental	
	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$X_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
E	-0.393824	$1.4 \cdot 10^{-3}$	-1.970476	$6.0 \cdot 10^{-4}$	-0.393911	$1.4 \cdot 10^{-3}$
P	-0.393816	$4.1 \cdot 10^{-4}$	-1.969987	$4.0 \cdot 10^{-4}$	-0.394004	$4.1 \cdot 10^{-4}$

Table 8: Deflections from table 7 in mV/V, additionally corrected for the influence of the environment, and corresponding uncertainties

A – cw	500 N·m		1000 N·m		500 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	0.670901	$6.0 \cdot 10^{-4}$	1.341933	$6.0 \cdot 10^{-4}$	0.670965	$6.0 \cdot 10^{-4}$
P	0.670841	$2.0 \cdot 10^{-4}$	1.341790	$2.0 \cdot 10^{-4}$	0.670914	$2.1 \cdot 10^{-4}$
A – acw	-500 N·m		-1000 N·m		-500 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	-0.670844	$6.1 \cdot 10^{-4}$	-1.341711	$6.1 \cdot 10^{-4}$	-0.670907	$6.1 \cdot 10^{-4}$
P	-0.670809	$2.1 \cdot 10^{-4}$	-1.341675	$2.1 \cdot 10^{-4}$	-0.670882	$2.1 \cdot 10^{-4}$
B – cw	50 N·m		200 N·m		50 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	0.317311	$6.0 \cdot 10^{-4}$	1.269625	$6.0 \cdot 10^{-4}$	0.317441	$6.0 \cdot 10^{-4}$
P	0.317331	$2.0 \cdot 10^{-4}$	1.269596	$2.0 \cdot 10^{-4}$	0.317463	$2.0 \cdot 10^{-4}$
B – acw	-50 N·m		-200 N·m		-50 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	-0.317324	$6.0 \cdot 10^{-4}$	-1.269588	$6.0 \cdot 10^{-4}$	-0.317447	$6.0 \cdot 10^{-4}$
P	-0.317331	$2.0 \cdot 10^{-4}$	-1.269565	$2.0 \cdot 10^{-4}$	-0.317448	$2.0 \cdot 10^{-4}$
C – cw	5 N·m		10 N·m		5 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	0.668441	$6.0 \cdot 10^{-4}$	1.337043	$6.0 \cdot 10^{-4}$	0.668423	$6.0 \cdot 10^{-4}$
P	0.668401	$4.0 \cdot 10^{-4}$	1.336922	$4.0 \cdot 10^{-4}$	0.668480	$4.0 \cdot 10^{-4}$
C – acw	-5 N·m		-10 N·m		-5 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	-0.668353	$6.1 \cdot 10^{-4}$	-1.336860	$6.1 \cdot 10^{-4}$	-0.668374	$6.1 \cdot 10^{-4}$
P	-0.668371	$4.0 \cdot 10^{-4}$	-1.336824	$4.0 \cdot 10^{-4}$	-0.668466	$4.0 \cdot 10^{-4}$
D – cw	1 N·m		5 N·m		1 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	0.393547	$1.4 \cdot 10^{-3}$	1.965687	$6.0 \cdot 10^{-4}$	0.393500	$1.4 \cdot 10^{-3}$
P	0.393701	$4.1 \cdot 10^{-4}$	1.968077	$4.1 \cdot 10^{-4}$	0.393858	$4.1 \cdot 10^{-4}$
D – acw	-1 N·m		-5 N·m		-1 N·m – decremental	
	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$X_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
E	-0.393819	$1.4 \cdot 10^{-3}$	-1.970338	$6.0 \cdot 10^{-4}$	-0.393905	$1.4 \cdot 10^{-3}$
P	-0.393813	$4.1 \cdot 10^{-4}$	-1.969916	$4.1 \cdot 10^{-4}$	-0.394001	$4.1 \cdot 10^{-4}$

The expanded relative uncertainties $W_{\text{P-Rep}}$, $W_{\text{P-DMP}}$ and $W_{\text{P-Envir}}$ are calculated using

$$W_{\text{P-Rep}} = 2 \cdot w_{\text{P-Rep}} = 2 \cdot \sqrt{w_{\text{Repeat}}^2 + w_{\text{Reprod}}^2 + 2 \cdot w_{\text{Ind}}^2 + w_{\text{TSM}}^2} \tag{3}$$

$$W_{\text{P-DMP}} = 2 \cdot w_{\text{P-DMP}} = 2 \cdot \sqrt{w_{\text{P-Rep}}^2 + w_{\text{DMP}}^2} \tag{4}$$

$$W_{\text{P-Envir}} = 2 \cdot w_{\text{P-Envir}} = 2 \cdot \sqrt{w_{\text{P-DMP}}^2 + w_{\text{Envir}}^2} \tag{5}$$

with
- the repeatability w_{Repeat}, calculated as relative standard deviation of the mean value of the deflections from three runs 1, 2 and 3,
- the reproducibility w_{Reprod}, calculated as relative standard deviation of the mean value of the deflections from nine runs 1 to 9,
- the uncertainty contribution of the indication w_{Ind}, calculated as relative standard uncertainty of the indication using a rectangular distribution (the indication is given by the span of the signal change under

stable conditions without the torque applied to the transducer and cannot be better than the numerical resolution)
- the uncertainty of the applied torque defined by the participant's torque standard machine (TSM) w_{TSM},
- the uncertainty contribution of the correction for DMP40 deviations w_{DMP}, calculated applying the GUM procedure to equation (1)
- the uncertainty contribution of the correction for environmental deviations w_{Envir}, calculated applying the GUM procedure to equation (2).

8. Summary

The results of the measurements (deflections and uncertainties) reported by the participant of the comparison to the pilot laboratory were evaluated. Some known effects were included into the evaluation by correction terms. In detail, corrections for the deviations of the amplifiers of the participating laboratories and the environmental conditions on site were calculated.
The Annex contains a proposal for the calculation of the comparison reference values, the corresponding uncertainties, the relative deviations of the values from the reference value and the degrees of equivalence.

References

[1] *D. Röske*, Final Report on the Torque Key Comparison CCM.T-K1 Measurand Torque: 0 N·m, 500 N·m, 1000 N·m, Internet: http://www.bipm.org/utils/common/pdf/final_reports/M/T-K1/CCM.T-K1.pdf

[2] *D. Röske, D. Mauersberger*, On the stability of measuring devices for torque key comparisons, IMEKO XVIII World Congress and IV Brazilian Congress of Metrology, September 17-22, 2006, Rio de Janeiro/Brazil, on Proceedings-CD file \trabalhos\00181.pdf,
Internet-Link: http://www.imeko.org/publications/wc-2006/PWC-2006-TC3-040u.pdf

[3] *M. G. Cox*, The Evaluation of key comparison data, Metrologia, 2002, **39**, 589-595

ANNEX to: Final Report on the Torque Comparison EURAMET.M.T-S1 Measurand Torque: 1 N·m, 5 N·m, 10 N·m, 50 N·m, 200 N·m, 500 N·m, and 1000 N·m

A.1 Weighted means, χ^2 tests and comparison reference values

The weighted means and their corresponding uncertainties were calculated according to procedure A in [3]. A χ^2 test was performed on the data in order to check the consistency of the corrected values.
For the clockwise torque, the results shown in table A9 were obtained.

Table A9: Results of a χ^2 test on the corrected clockwise values from all participants (ν - degree of freedom = number of participants – 1, * - decremental torque)

	A			B		
	500 N·m	1000 N·m	500 N·m *	50 N·m	200 N·m	50 N·m *
χ^2_{obs}	0.08	0.11	0.06	0.04	0.01	0.05
ν	1	1	1	1	1	1
$\chi^2(\nu)$, P = 0.05	3.84	3.84	3.84	3.84	3.84	3.84
Result	Test passed	Test passed	Test passed	Test passed	Test passed	Test passed
	C			**D**		
	5 N·m	10 N·m	5 N·m *	1 N·m	5 N·m	1 N·m *
χ^2_{obs}	0.03	0.06	0.05	0.29	11.22	1.55
ν	1	1	1	1	1	1
$\chi^2(\nu)$, P = 0.05	3.84	3.84	3.84	3.84	3.84	3.84
Result	Test passed	Test passed	Test passed	Test passed	Test failed	Test passed

Unfortunately, the 5 N·m maximum torque step of transducer D did not pass this test. The reason could not be found, but the results show, that the stability of the transducer is not good enough in this point. The result of participant E deviated by more than 0.12% from the mean of the two measurements at the pilot laboratory, while this deviation for the same point (5 N·m, CW) did not exceed 0.006% and 0.009% for incremental and decremental stages for transducer C. Taking into account that the measurements at 5 N·m (D and C) were all carried out with the same reference transducer of participant E, it is most likely that the larger deviation is caused by an unstable transducer D.
Although this one result (5 N·m-D) is not very satisfying, all corrected values were considered to be consistent and the weighted means were taken as the comparison reference values for clockwise torque.
For the anti-clockwise torque, the results shown in table A10 were obtained.

Table A10: Results of a χ^2 test on the corrected anti-clockwise values from all participants (ν - degree of freedom = number of participants - 1, * - decremental torque)

	A			B		
	-500 N·m	-1000 N·m	-500 N·m *	-50 N·m	-200 N·m	-50 N·m *
χ^2_{obs}	0.03	0.01	0.01	0.01	0.01	0.05
ν	1	1	1	1	1	1
$\chi^2(\nu)$, P = 0.05	3.84	3.84	3.84	3.84	3.84	3.84
Result	Test passed	Test passed	Test passed	Test passed	Test passed	Test passed
	C			**D**		
	-5 N·m	-10 N·m	-5 N·m *	-1 N·m	-5 N·m	-1 N·m *
χ^2_{obs}	0.01	0.01	0.14	0.01	0.35	0.11
ν	1	1	1	1	1	1
$\chi^2(\nu)$, P = 0.05	3.84	3.84	3.84	3.84	3.84	3.84
Result	Test passed	Test passed	Test passed	Test passed	Test passed	Test passed

For all anti-clockwise parts of the inter-comparison the values passed the χ^2 test, therefore the corrected values were considered to be consistent and the weighted means were taken as the comparison reference values for anti-clockwise torque. All calculated "mV/V" comparison reference values ($RV_{mV/V}$) x'_{ref} and their corresponding uncertainties $u(x'_{ref})$ are given in table A11.

Table A11: Reference values x_{ref} in mV/V and corresponding standard uncertainties $u(x_{ref})$ in nV/V, * - decremental torque

cw	A			B		
	500 N·m	1000 N·m	500 N·m *	50 N·m	200 N·m	50 N·m *
x_{ref} in mV/V	0.670847	1.341805	0.670920	0.317329	1.269599	0.317461
$u(x_{ref})$ in nV/V	64.7	129.2	66.3	30.2	120.7	30.4
cw	C			D		
	5 N·m	10 N·m	5 N·m *	1 N·m	5 N·m	1 N·m *
x_{ref} in mV/V	0.668413	1.336960	0.668462	0.393689	1.967324	0.393829
$u(x_{ref})$ in nV/V	111.6	223.2	111.8	77.4	331.5	77.4
acw	A			B		
	-500 N·m	-1000 N·m	-500 N·m *	-50 N·m	-200 N·m	-50 N·m *
x_{ref} in mV/V	-0.670813	-1.341678	-0.670885	-0.317330	-1.269567	-0.317448
$u(x_{ref})$ in nV/V	65.8	131.4	67.4	30.2	120.7	30.4
acw	C			D		
	-5 N·m	-10 N·m	-5 N·m *	-1 N·m	-5 N·m	-1 N·m *
x_{ref} in mV/V	-0.668365	-1.336835	-0.668438	-0.393814	-1.970048	-0.393994
$u(x_{ref})$ in nV/V	112.6	225.2	112.9	77.6	333.1	77.7

A.2 Relative deviations of the results from the comparison reference values

For reporting the results and calculating the degrees of equivalence, instead of using the transducer-dependent sensitivities in mV/V from table A11 the round torque values in N·m were taken as the RVs x_{ref}. The assigned uncertainties $u(x_{\text{ref}})$ were calculated from the relation

$$u(x_{\text{ref}}) = \frac{x_{\text{ref}}}{x'_{\text{ref}}} \cdot u(x'_{\text{ref}}) \tag{6}$$

and are given in mN·m in table A12.

Table A12: Reference values x_{ref} and corresponding standard uncertainties $u(x_{ref})$, both in N·m, * - decremental torque

cw	A			B		
	500 N·m	1000 N·m	500 N·m *	50 N·m	200 N·m	50 N·m *
x_{ref} in N·m	500.00	1000.00	500.00	50.000	200.000	50.000
$u(x_{ref})$ in N·m	0.05	0.10	0.05	0.005	0.019	0.005
cw	C			D		
	5 N·m	10 N·m	5 N·m *	1 N·m	5 N·m	1 N·m *
x_{ref} in N·m	5.0000	10.0000	5.0000	1.0000	5.0000	1.0000
$u(x_{ref})$ in N·m	0.0008	0.0017	0.0008	0.0002	0.0008	0.0002
acw	A			B		
	-500 N·m	-1000 N·m	-500 N·m *	-50 N·m	-200 N·m	-50 N·m *
x_{ref} in N·m	-500.00	-1000.00	-500.00	-50.000	-200.000	-50.000
$u(x_{ref})$ in N·m	0.05	0.10	0.05	0.005	0.019	0.005
acw	C			D		
	-5 N·m	-10 N·m	-5 N·m *	-1 N·m	-5 N·m	-1 N·m *
x_{ref} in N·m	-5.0000	-10.0000	-5.0000	-1.0000	-5.0000	-1.0000
$u(x_{ref})$ in N·m	0.0008	0.0017	0.0008	0.0002	0.0008	0.0002

The corrected results of the participants given in table 10 in mV/V are now converted to torque units in N·m using

$$Y_{\text{P-N·m}} = \frac{x_{\text{ref}}}{x'_{\text{ref}}} \cdot Y_{\text{P-Envir}} \tag{7}$$

and are given in table A13. The relative uncertainties W don't need to be converted.

Table A13: Deflections from table 8 converted to torque units in N·m and corresponding expanded relative uncertainties (k = 2)

	500 N·m		1000 N·m		500 N·m – decremental	
A – cw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	500.040	0.150	1000.096	0.301	500.034	0.150
P	499.995	0.051	999.989	0.102	499.996	0.052
	-500 N·m		-1000 N·m		-500 N·m – decremental	
A – acw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	-500.023	0.153	-1000.024	0.306	-500.016	0.153
P	-499.997	0.052	-999.997	0.103	-499.998	0.053
	50 N·m		200 N·m		50 N·m – decremental	
B – cw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	49.9972	0.0150	200.0041	0.0600	49.9969	0.0150
P	50.0003	0.0050	199.9995	0.0200	50.0004	0.0051
	-50 N·m		-200 N·m		-50 N·m – decremental	
B – acw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	-49.9990	0.0150	-200.0033	0.0600	-50.0000	0.0150
P	-50.0001	0.0050	-199.9996	0.0200	-50.0000	0.0051
	5 N·m		10 N·m		5 N·m – decremental	
C – cw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	5.00021	0.00151	10.00063	0.00301	4.99971	0.00150
P	4.99991	0.00100	9.99972	0.00201	5.00013	0.00101
	-5 N·m		-10 N·m		-5 N·m – decremental	
C – acw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	-4.99990	0.00153	-10.00019	0.00306	-4.99952	0.00153
P	-5.00004	0.00101	-9.99992	0.00202	-5.00021	0.00101
	1 N·m		5 N·m		1 N·m – decremental	
D – cw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	0.99964	0.00070	4.99584	0.00150	0.99916	0.00070
P	1.00003	0.00020	5.00192	0.00102	1.00007	0.00020
	-1 N·m		-5 N·m		-1 N·m – decremental	
D – acw	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$	$X_{P\text{-}Envir}$	$W_{P\text{-}Envir}$
E	-1.00001	0.00070	-5.00074	0.00151	-0.99978	0.00070
P	-1.00000	0.00021	-4.99966	0.00102	-1.00002	0.00021

The figures A3 to A10 show the resulting deviations from the RVs and the corresponding uncertainties.

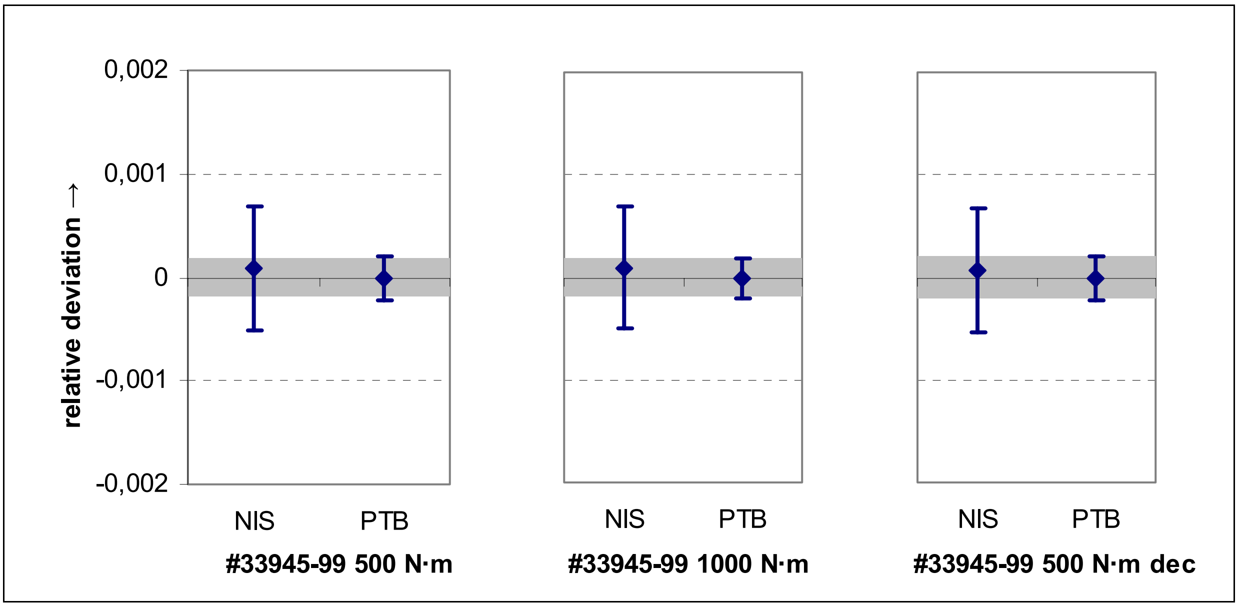

Figure A3. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, $k = 2$) for transducer A at clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

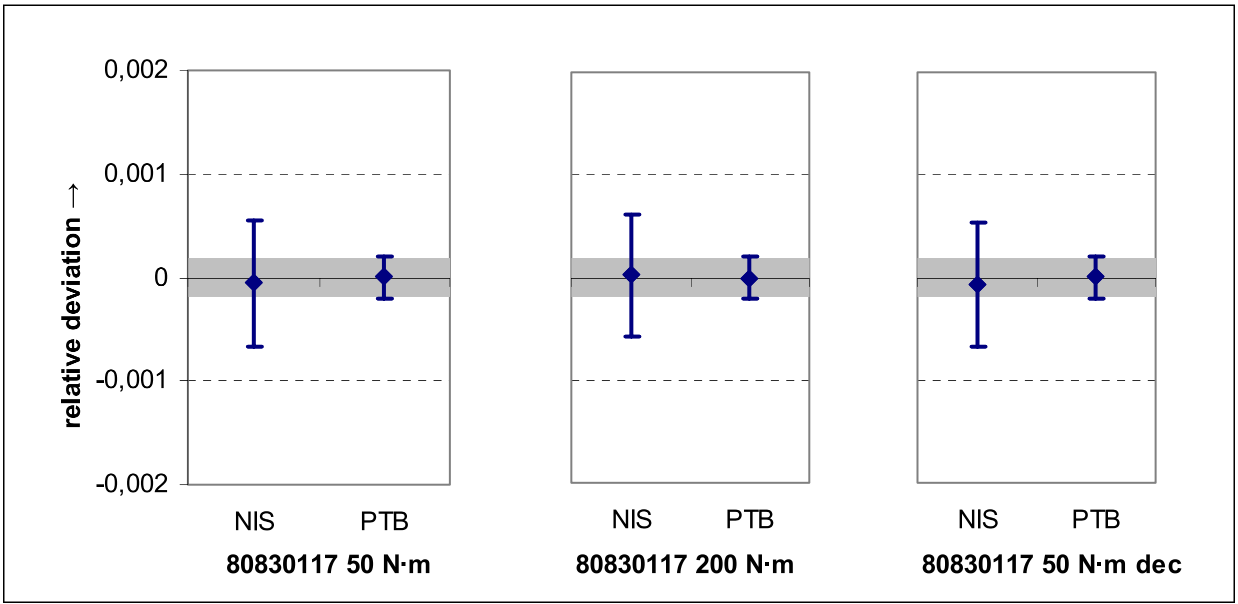

Figure A4. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, $k = 2$) for transducer B at clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

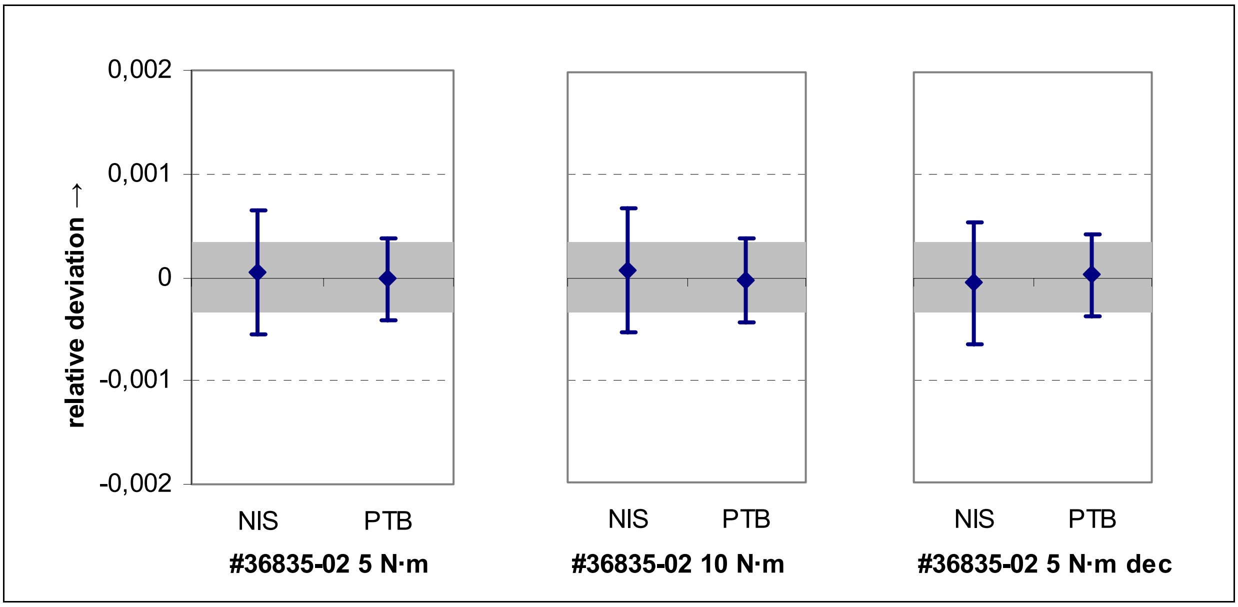

Figure A5. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, $k = 2$) for transducer C at clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

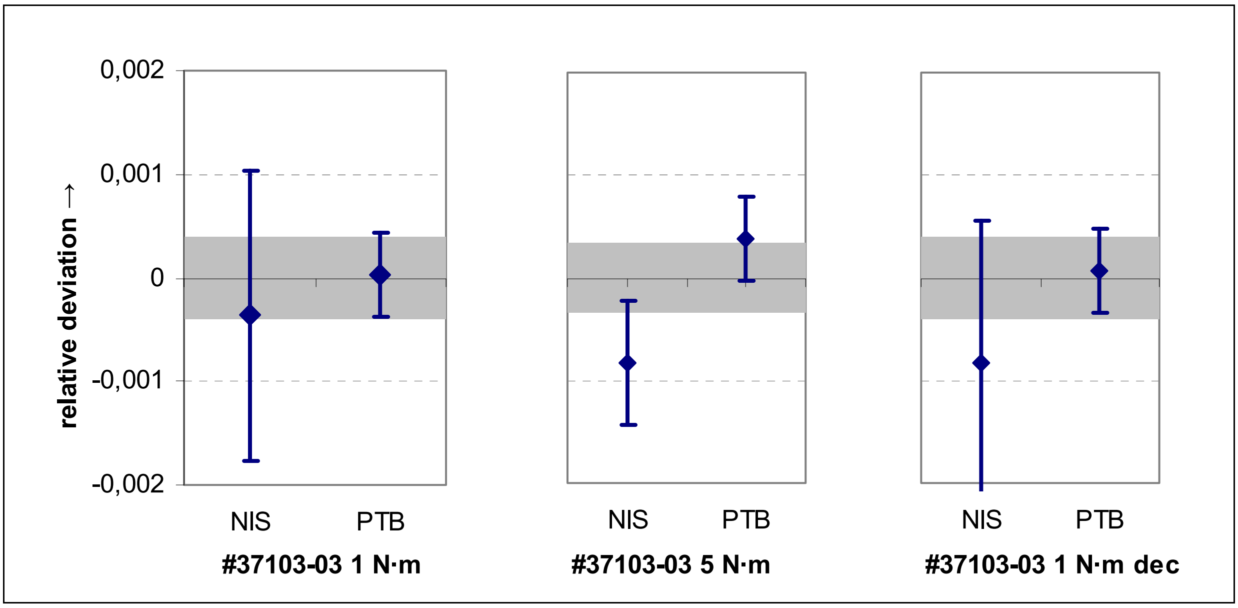

Figure A6. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, $k = 2$) for transducer D at clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

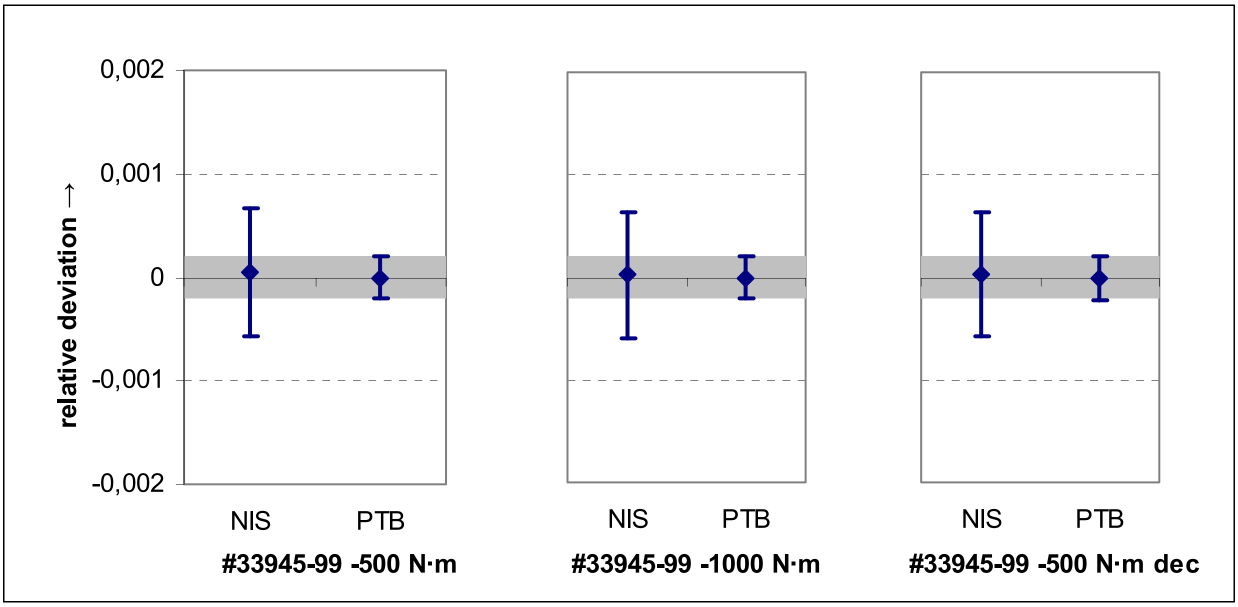

Figure A7. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, k = 2) for transducer A at anti-clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

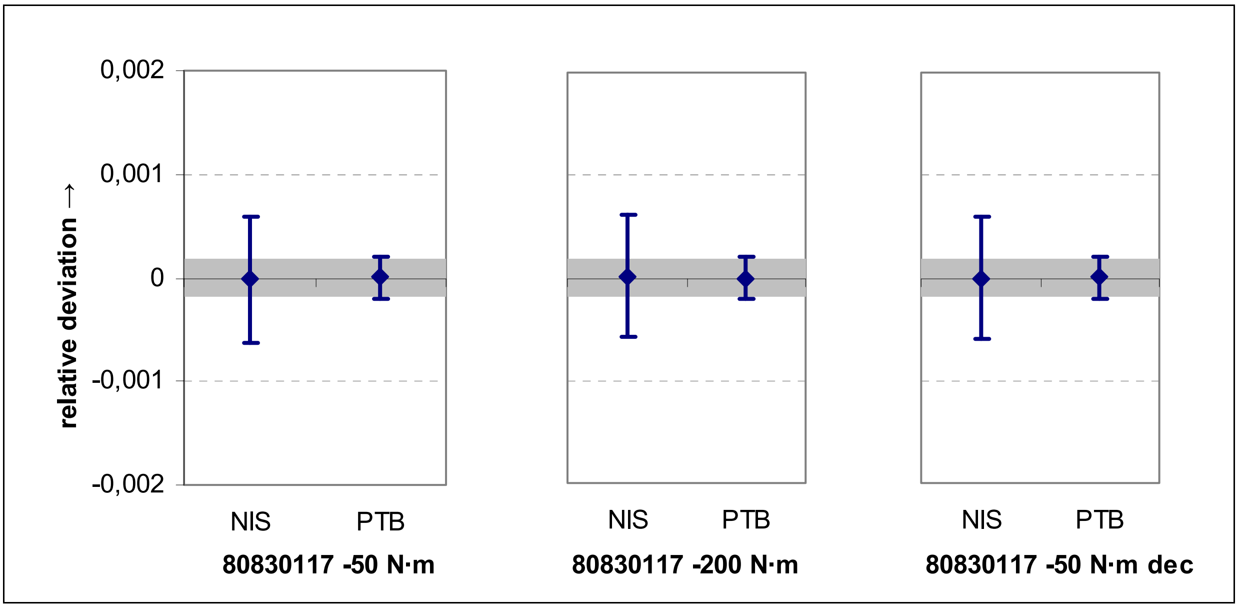

Figure A8. Relative deviations of the corrected deflections for the participating laboratories from the RV (grey band = relative expanded uncertainty, k = 2) for transducer B at anti-clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

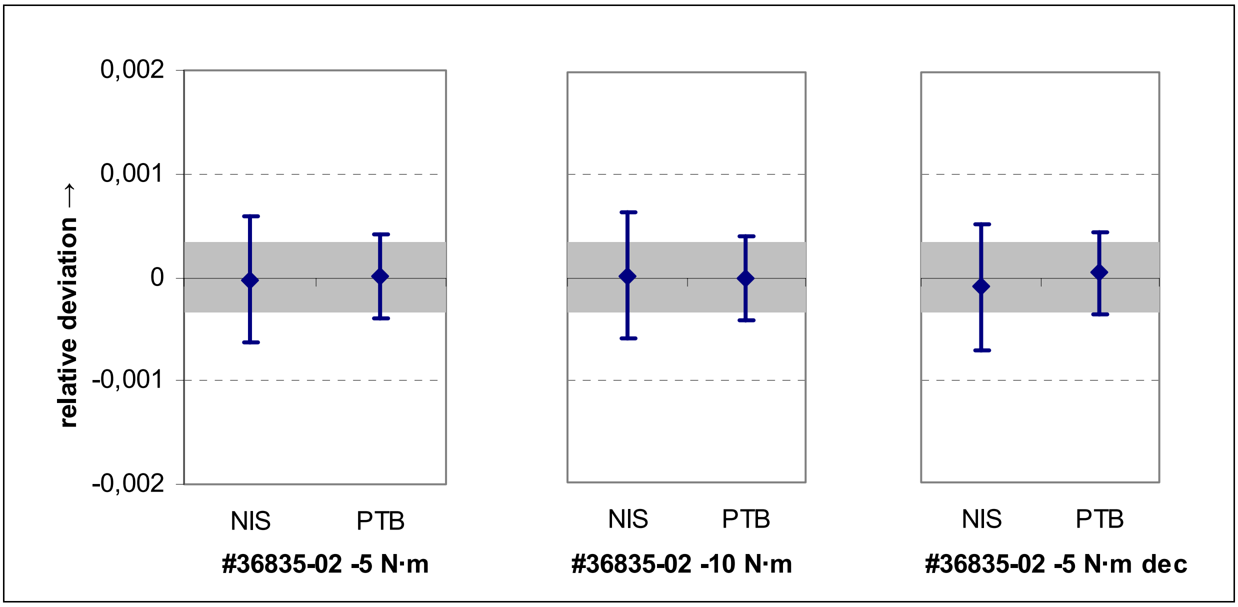

Figure A9. Relative deviations of the corrected deflections for the participating laboratories (except participant F) from the KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TT1 at 500 N·m anti-clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

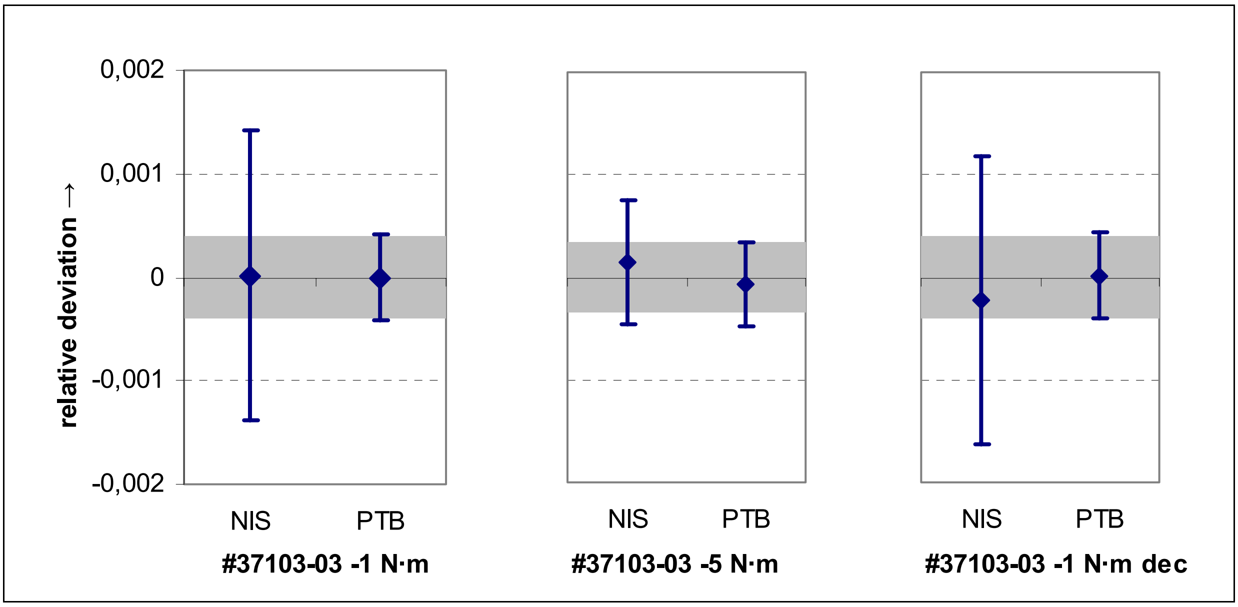

Figure A10. Relative deviations of the corrected deflections for the participating laboratories (except participant F) from the KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TT1 at 1000 N·m anti-clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

A.3 Degrees of equivalence

The degrees of equivalence (d_i, $U(d_i)$) between the corrected values from the participants and the comparison reference values were calculated according to procedure A in [3]. The figures A11 to A18 show the results, the values are given in table A13.

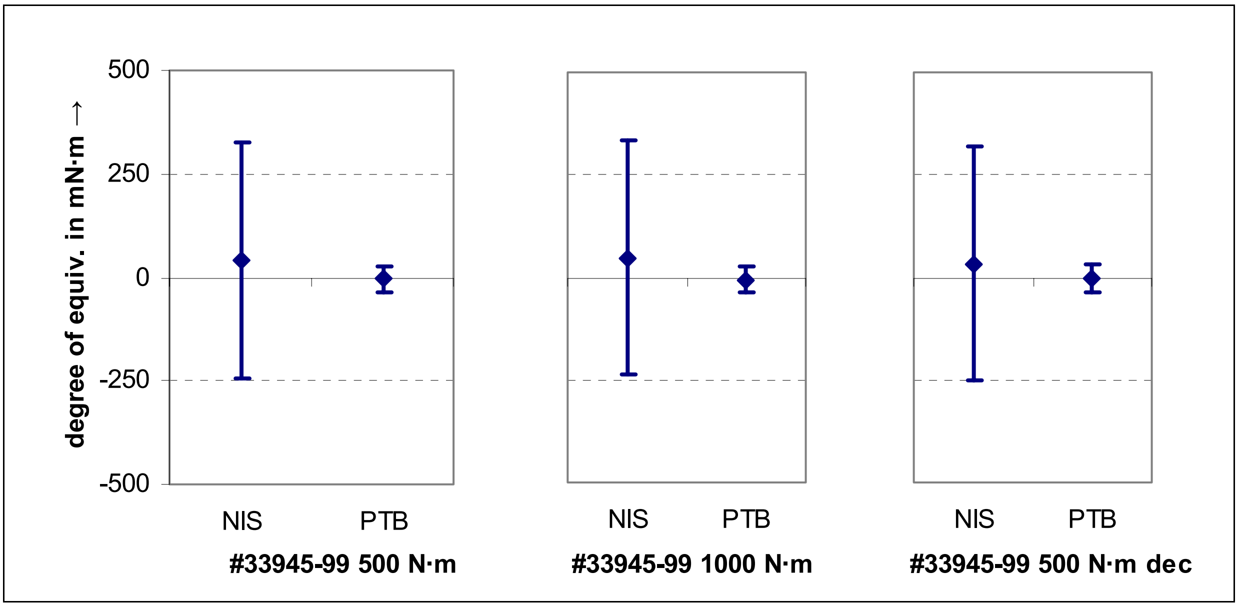

Figure A11. Degrees of equivalence for all measurements made by the participating laboratories with transducer A at clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

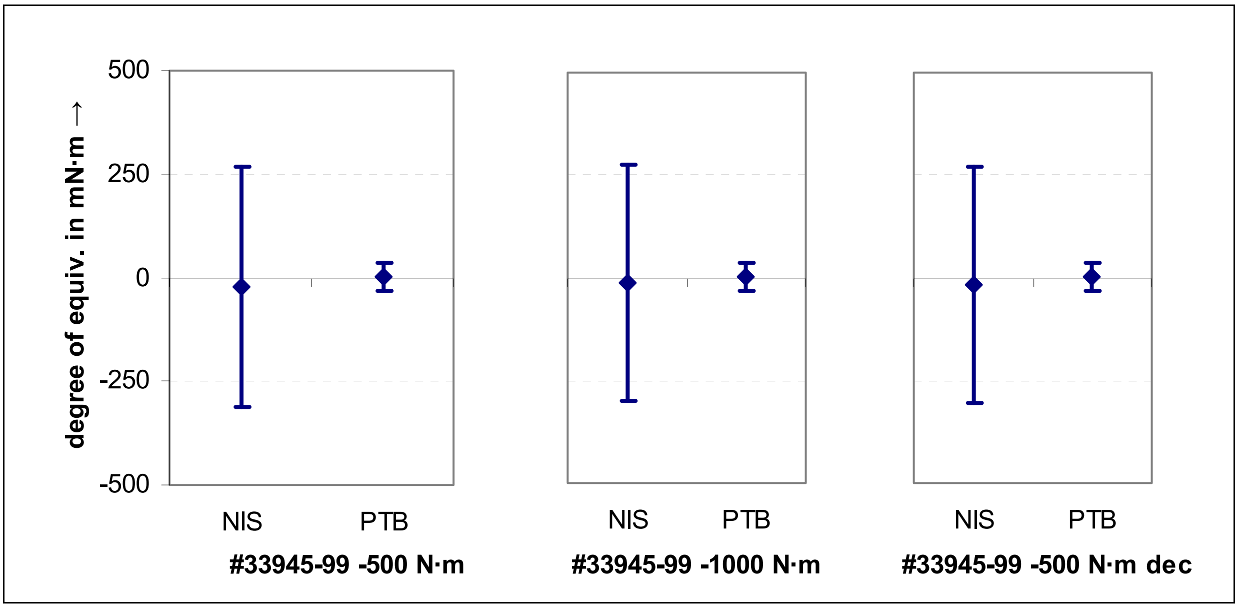

Figure A12. Degrees of equivalence for all measurements made by the participating laboratories with transducer A at anti-clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

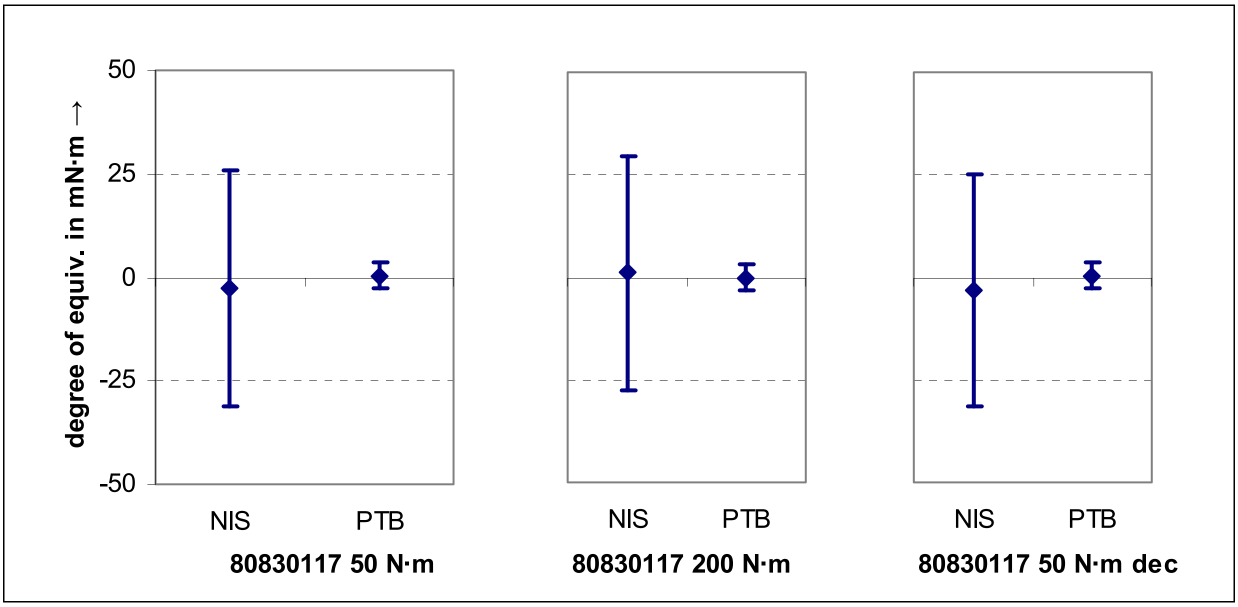

Figure A13. Degrees of equivalence for all measurements made by the participating laboratories with transducer B at clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

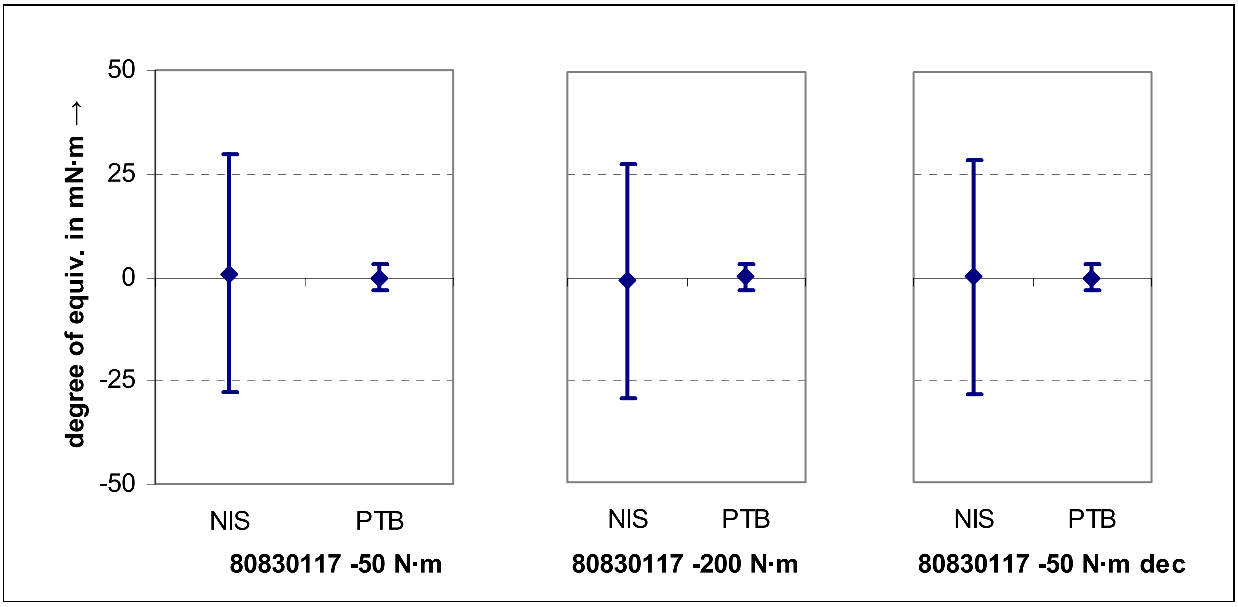

Figure A14. Degrees of equivalence for all measurements made by the participating laboratories with transducer B at anti-clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

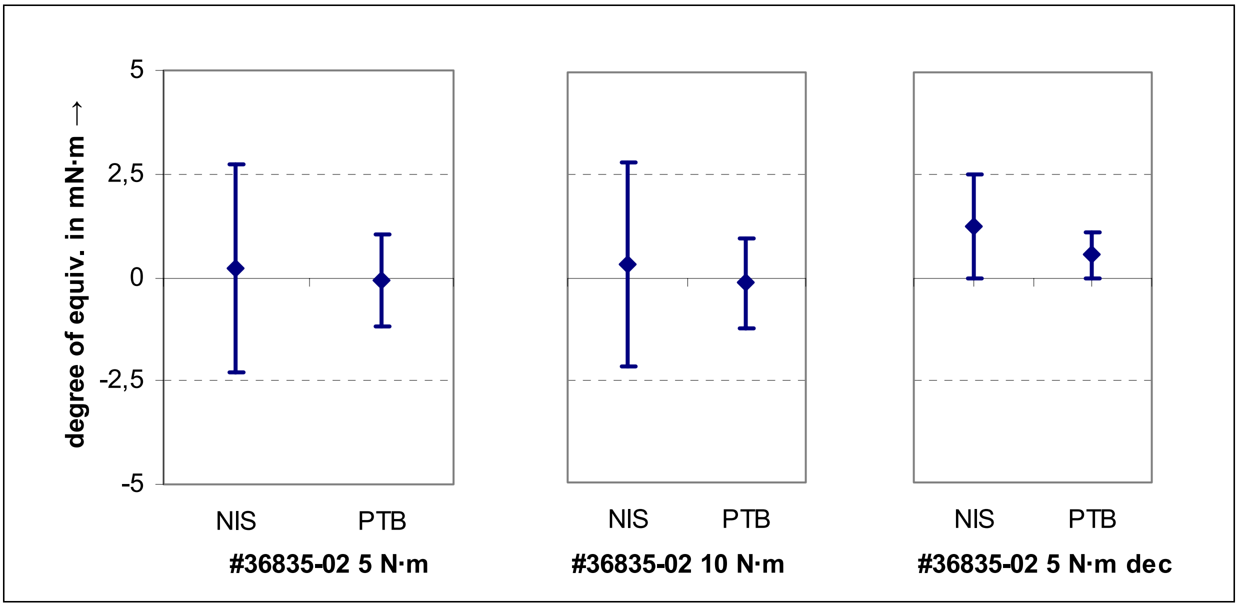

Figure A15. Degrees of equivalence for all measurements made by the participating laboratories with transducer C at clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

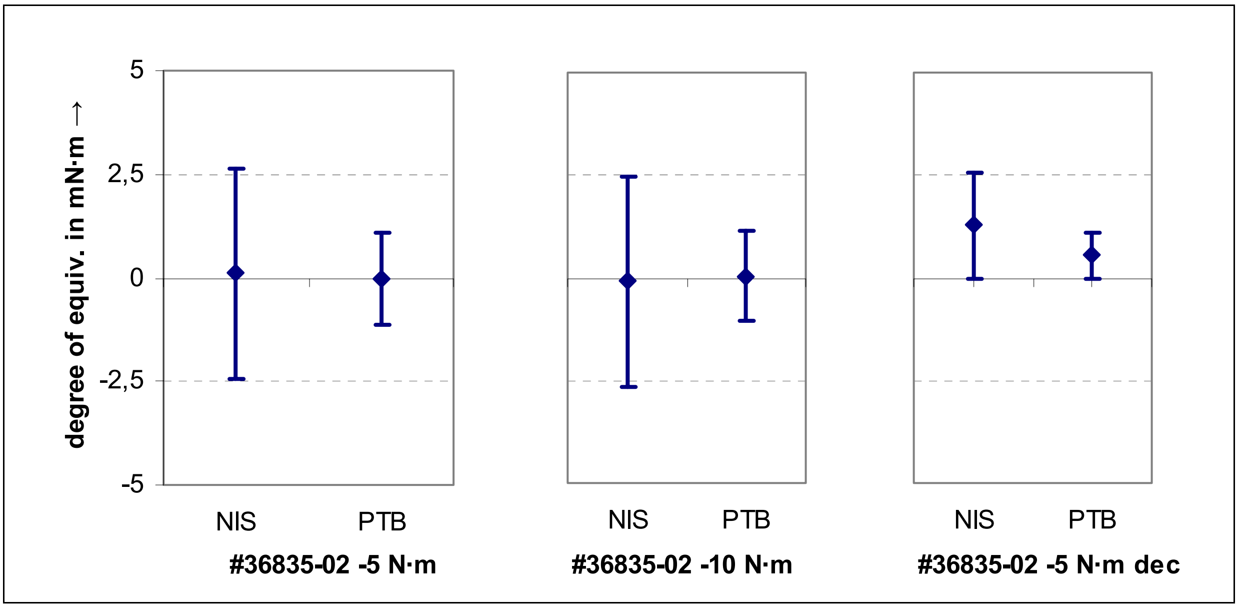

Figure A16. Degrees of equivalence for all measurements made by the participating laboratories with transducer C at anti-clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

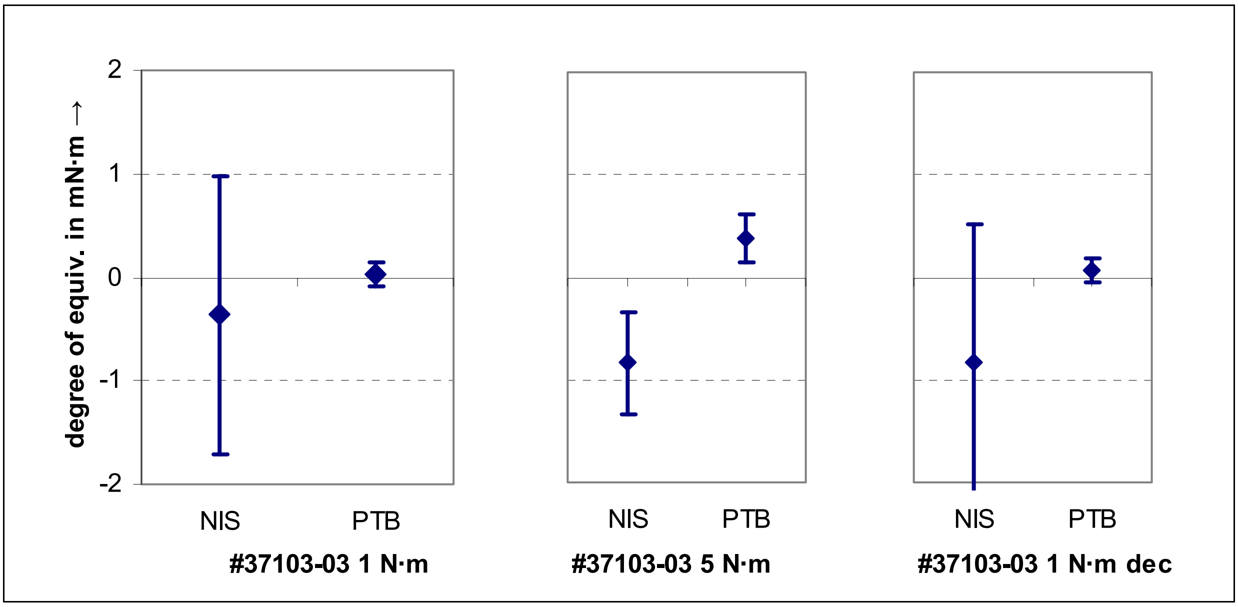

Figure A17. Degrees of equivalence for all measurements made by the participating laboratories with transducer D at clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

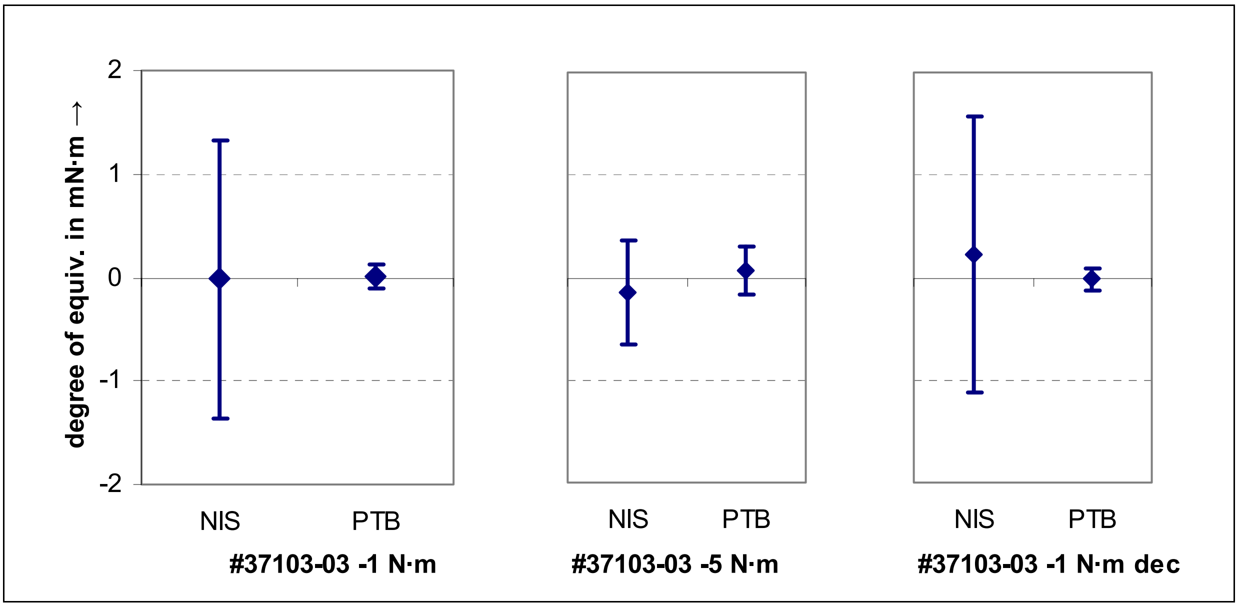

Figure A18. Degrees of equivalence for all measurements made by the participating laboratories with transducer D at anti-clockwise torque (dot = d_i, uncertainty bar = $U(d_i)$)

Table A14 shows the degrees of equivalence ($d_{i,j}$, $U(d_{i,j})$) between the corrected values from the participants considering the last as pairs (i, j) for each of the transducers and both steps. The value in a cell was calculated as the difference between the result of the participant in the corresponding row and the result of the participant in the corresponding column. For example, the value -44.8 nV/V in the second column is the difference result(P) – result(E), 44.8 nV/V in the second row is the difference result(E) – result(B), respectively.

Table A13: Degrees of equivalence (d_i, $U(d_i)$) in mN·m between the corrected values from the participants and the corresponding comparison reference value

	A – cw			**A – acw**		
	500 N·m	1000 N·m	500 N·m *	-500 N·m	-1000 N·m	-500 N·m *
E	(40,2; 285,1)	(95,6; 570,0)	(33,8; 284,3)	(-23,2; 289,6)	(-24,5; 579,0)	(-16,1; 288,8)
P	(-4,6; 32,6)	(-10,9; 65,1)	(-4,1; 34,3)	(2,7; 33,2)	(2,8; 66,3)	(1,9; 34,9)
	B – cw			**B – acw**		
	50 N·m	200 N·m	50 N·m *	-50 N·m	-200 N·m	-50 N·m *
E	(-2,8; 28,5)	(4,1; 113,9)	(-3,1; 28,5)	(1,0; 28,5)	(-3,3; 113,9)	(0,0; 28,5)
P	(0,3; 3,2)	(-0,5; 12,7)	(0,4; 3,2)	(-0,1; 3,2)	(0,4; 12,7)	(0,0; 3,2)
	C – cw			**C – acw**		
	5 N·m	10 N·m	5 N·m *	-5 N·m	-10 N·m	-5 N·m *
E	(0,2; 2,5)	(0,6; 5,0)	(-0,3; 2,5)	(0,1; 2,6)	(-0,2; 5,1)	(0,5; 2,6)
P	(-0,1; 1,1)	(-0,3; 2,2)	(0,1; 1,1)	(0,0; 1,1)	(0,1; 2,2)	(-0,2; 1,1)
	D – cw			**D – acw**		
	1 N·m	5 N·m	1 N·m *	-1 N·m	-5 N·m	-1 N·m *
E	(-0,4; 1,3)	(-4,2; 2,5)	(-0,8; 1,3)	(0,0; 1,3)	(-0,7; 2,5)	(0,2; 1,3)
P	(0,0; 0,1)	(1,9; 1,1)	(0,1; 0,1)	(0,0; 0,1)	(0,3; 1,1)	(0,0; 0,1)

Table A14: Degrees of equivalence ($d_{i,j}$, $U(d_{i,j})$) in mN·m between the corrected values from the participants, * - decremental torque

	E			P		
E	A, 500 N·m	A, 1000 N·m	A, 500 N·m*	(44,8; 317,7)	(106,5; 635,1)	(37,9; 318,6)
	A, -500 N·m	A, -1000 N·m	A, -500 N·m*	(-25,9; 322,8)	(-27,3; 645,3)	(-18,0; 323,7)
	B, 50 N·m	B, 200 N·m	B, 50 N·m*	(-3,1; 31,7)	(4,6; 126,5)	(-3,5; 31,7)
	B, -50 N·m	B, -200 N·m	B, -50 N·m*	(1,1; 31,7)	(-3,6; 126,6)	(0,0; 31,7)
	C, 5 N·m	C, 10 N·m	C, 5 N·m*	(0,3; 3,6)	(0,9; 7,2)	(-0,4; 3,6)
	C, -5 N·m	C, -10 N·m	C, -5 N·m*	(0,1; 3,7)	(-0,3; 7,3)	(0,7; 3,7)
	D, 1 N·m	D, 5 N·m	D, 1 N·m*	(-0,4; 1,5)	(-6,1; 3,6)	(-0,9; 1,5)
	D, -1 N·m	D, -5 N·m	D, -1 N·m*	(0,0; 1,5)	(-1,1; 3,6)	(0,2; 1,5)
P	(-44,8; 317,7)	(-106,5; 635,1)	(-37,9; 318,6)	A, 500 N·m	A, 1000 N·m	A, 500 N·m*
	(25,9; 322,8)	(27,3; 645,3)	(18,0; 323,7)	A, -500 N·m	A, -1000 N·m	A, -500 N·m*
	(3,1; 31,7)	(-4,6; 126,5)	(3,5; 31,7)	B, 50 N·m	B, 200 N·m	B, 50 N·m*
	(-1,1; 31,7)	(3,6; 126,6)	(0,0; 31,7)	B, -50 N·m	B, -200 N·m	B, -50 N·m*
	(-0,3; 3,6)	(-0,9; 7,2)	(0,4; 3,6)	C, 5 N·m	C, 10 N·m	C, 5 N·m*
	(-0,1; 3,7)	(0,3; 7,3)	(-0,7; 3,7)	C, -5 N·m	C, -10 N·m	C, -5 N·m*
	(0,4; 1,5)	(6,1; 3,6)	(0,9; 1,5)	D, 1 N·m	D, 5 N·m	D, 1 N·m*
	(0,0; 1,5)	(1,1; 3,6)	(-0,2; 1,5)	D, -1 N·m	D, -5 N·m	D, -1 N·m*