

Final Report on the Torque Key Comparison CCM.T-K1.1 Measurand Torque: 0 N·m, 500 N·m, 1000 N·m

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1. General information about the CCM.T-K1.1

The CCM.T-K1.1 comparison is a follow-up comparison to the CCM.T-K1 torque key comparison. It is a bilateral comparison between National Physical Laboratory (NPL) of India and the pilot laboratory of the CCM.T-K1 (PTB) again as pilot, thus providing linkage to CCM.T-K1 (see Table 1). The measurements were carried out between January and July 2007. The results of the CCM.T-K1 were published in February 2009 [1]. As usual for follow-up comparisons, the results of this bilateral comparison were not used to calculate the key comparison reference value (KCRV) for CCM.T-K1, but the KCRV of CCM.T-K1 will be used here as reference value. The measurement procedure as well as the travelling standards, transportation boxes and temperature/humidity sensors were the same for both comparisons. Therefore, the technical protocol of the CCM.T-K1 and the corresponding Excel data file templates could be applied to the CCM.T-K1.1.

Table 1: Participants in the CCM.T-K1.1 torque key comparison: countries, institutes and code numbers used in the report

Country	Institute	Code letter
India	NPL	I
Germany (pilot)	PTB	H

2. Principles of the comparison

The purpose of key comparisons 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 standard machines of the participants following a strict measurement protocol and using similar amplifiers. The following loading scheme was agreed:

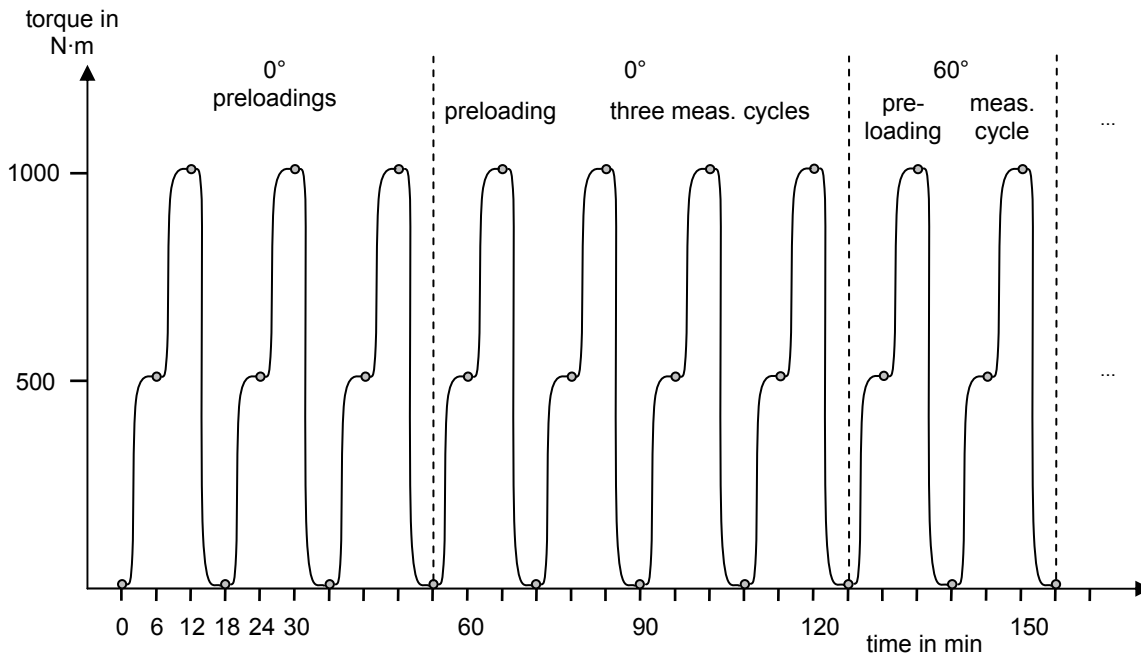


Figure 1. Diagram of the measurement sequence of the CCM.T-K1.1

The torque transducer was rotated from 0° to 720° with 60° steps. Except the first mounting position with seven load cycles—four for stabilization and three for the repeatability measurement - in all other positions one preload and one measurement cycle (as shown for the 60° position in figure 1) were carried out, i.e. at transducer positions of 120°, 180°, 240°, 300°, 360°, 420°, 480°, 540°, 600°, 660° and 720°.

The comparison measurements had to be done with each of two torque transducers having nominal capacities of 1 kN·m. The first transducer is a TB2 torque measuring flange with adaptors at both ends. The second transducer is a TT1 transducer 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 diameter and a suitable length fitting for an ETP-50 hydraulic coupling. The transducers had been selected for their very stable characteristics and their known history.

3. Realisation of the comparison

For this key comparison a star type formation had been chosen. That means that the transducers were returned to the pilot laboratory after the measurement at the participant. The pilot repeated all measurements. One complete measurement cycle (pilot—participating laboratory—pilot) is called a loop. The first measurement by the pilot is called “PTB11”, the second measurement by the pilot after the participating laboratory is called “PTB12”.

4. Limitations of the comparison

In 6 it will be shown, that the travelling standards (transducers TB2 and TT1) used in this key comparison were very stable, especially the hermetically closed TB2 [2]. Nevertheless, in order to get comparable results some known effects should be taken into account. These are possible deviations of the amplifiers (DMP40) of the participating laboratories, the creep influence due to different loading times in the machines and the environmental conditions on site. 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 laboratory against an absolute reference standard. The uniformity of the different DMP40s was confirmed with reference to a BN100 bridge standard. Each participating laboratory measured the indication of its own DMP40 against the signal of the pilot's BN100, which was delivered together with the transducers. The pilot monitored the signal

of the same BN100 against two DMP40 amplifiers in the pilot laboratory additionally each time when the equipment was back from a participant. The sensitivities of the transducers at nominal torque were 1.000 mV/V (TB2) and 1.342 mV/V (TT1). The measurements with the BN100 were carried out with suitably selected voltage ratios near the signals of the transducers for 500 N·m and 1 kN·m. Therefore, figure 2 shows two lines for positive and two lines for negative voltage ratios for each of the participants.

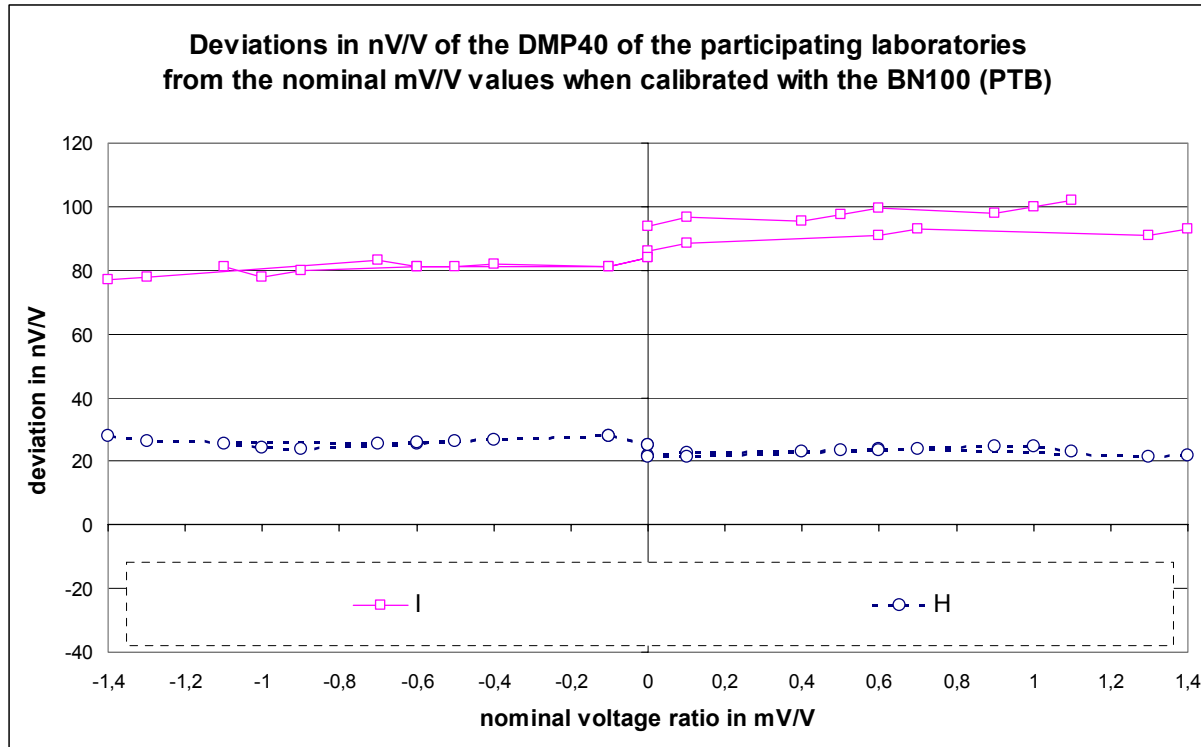


Figure 2. Deviations in nV/V of the DMP40 indication of the participating laboratories from the nominal mV/V values when calibrated with the pilot's BN100 (averaged values from two measurements, for the pilot H averaged over 26 measurements)

These measurements show that there are quite large deviations of up to 80 nV/V between the different DMPs. But the measurement result is a difference between two readings, that means an offset of the DMP's indication as shown in figure 2 will not affect the results as long as there is no inclination of these functions. The relative deviations of the voltage ratio differences (referred to the signal at nominal zero given by the BN100) from their nominal value are shown for all DMPs in table 2.

Table 2: Relative deviations d_i of the zero-related voltage ratio differences of the participants' DMPs from their nominal values

	nominal voltage ratio difference in mV/V	relative voltage ratio difference* d_i related to nominal value for lab...	
		.A in ppm	.H in ppm
TB2 cw**	0.5	7.0	3.2
	1	6.0	2.6
TB2 acw**	-0.5	6.0	-2.7
	-1	6.0	0.5
TT1 cw	0.67***	9.6	3.1
	1.34***	4.3	0.0
TT1 acw	-0.67***	2.4	-0.9
	-1.34***	4.8	-1.4

* related to nominal 0 mV/V, ** cw–clockwise, acw–anti-clockwise, *** interpolated

Using the values $d_i(V/V_S)$ given in table 2 for each of the participants i and the corresponding voltage ratios V/V_S , the deflections calculated from the participant's calibration results can be corrected using (1):

$$Y'_i = Y_i \cdot (1 - d_i(V/V_S)) \quad (1)$$

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

6. Characteristics of the transducers

Creep effect

To minimize the influence of the creep, a relatively long cycle time of 6 minutes was agreed. This time includes the loading/unloading and the waiting time before the reading. The creep effect should be small enough to eliminate the uncertainty of the time of reading and the same for every loading.

Both transducers had a nearly constant creep after approx. 3 min, i.e. the values showed a quite linear dependence on the time. The relative change of the indication due to creep for a period from the 4th, resp. the 5th, to the 6th minute after the torque application is given in table 3 for both transducers. The values indicate that a change in the reading time by some seconds is not significant to the uncertainty of measurement.

Table 3: Relative change of indication due to creep

Time after start of load application	Relative change of indication due to creep	
	TB2, S/N #044430025/1 kN·m	TT1, S/N 36079-00
4 th to 6 th minute after applying the load	$4 \cdot 10^{-6}$	$4 \cdot 10^{-6}$
5 th to 6 th minute after applying the load	$2 \cdot 10^{-6}$	$2 \cdot 10^{-6}$

The aim was to have an equal loading schedule for each laboratory, but this could not be realized due to the different designs and capabilities of the machines. The loading times varied from 25 s to 150 s. The shortest time for taking the readings after finishing the torque application was 3.5 min. The pilot checked the loading time with the transducer TB2, S/N #044430025/1 kN·m. The difference between loading times of 23 s and 42 s in the PTB's 1 kN·m torque standard machine gave a difference after the 6 min of only $1 \cdot 10^{-6}$, which is less than any measurement uncertainty. Table 4 shows the time needed for the torque application (from 0 N·m to 500 N·m, respectively from 500 N·m to 1 kN·m) in the different standard machines of the participants. A long torque application time and a fast loading speed mean, that the load is applied in a short time after a longer waiting time (for collecting the weights, for example). A slow loading speed means, that the quite long torque application time is needed to apply the weights one by one.

Depending on the loading profile (time and speed) of the machines, different correction factors are proposed and should be used in order to reduce the creep influence on the result.

Table 4: Time needed for the application of the torque step (maximum value)

Participant	Time for torque application		Time difference to the pilot		Loading speed	Correction factor c_i
	in s	in min	in s	in min		
I	25	0.42	0	0	fast	1
H	25	0.42	-	-	fast	1

Using the values c_i given in table 4 for each of the participants, the deflections calculated from the participant's calibration results can be corrected using (2):

$$Y_i'' = Y_i' \cdot c_i \quad (2)$$

with Y_i' being the uncorrected and Y_i'' the corrected deflections.

Humidity and temperature influences on the sensitivity

Humidity and temperature effects on the sensitivity can be important factors if the environmental conditions at the participating laboratory are not the same as that at the pilot. The humidity and temperature sensitivities e_{TH} and e_T of each transducer were determined for the CCM.T-K1 [1]. The values obtained there are also used here (see Table 5).

It is considered that the humidity and temperature sensitivities have the same absolute value for clockwise and anti-clockwise torque, therefore only clockwise measurements have been carried out. All measurements at the pilot as participant together with the additional measurements at higher temperature, respectively humidity were used to calculate the corresponding sensitivities of the transducers for both torque steps.

For this purpose, a linear regression according to (3) was used.

$$S_i = S_0 + e_{TH} \cdot \Delta rH_i + e_T \cdot \Delta T_i \quad (3)$$

with S_0 being the deflection at reference conditions and S_i the deflection at conditions changed by ΔrH_i and ΔT_i .

Table 5: Calculated humidity coefficients e_{rH} of the transfer transducers (from measurements only in clockwise direction)

	500 N·m	1000 N·m	-500 N·m	-1000 N·m
	Air humidity coefficient and expanded uncertainty ($k = 2$) in (nV/V)/%			
TB2, S/N #044430025/1 kN·m	0.2 ± 0.5	0.2 ± 0.8	-0.2 ± 0.5	-0.2 ± 0.8
TT1, S/N 36079-00	-2.5 ± 2.5	-5.1 ± 5.5	2.5 ± 2.5	5.1 ± 5.5
	Temperature coefficient and expanded uncertainty ($k = 2$) in (nV/V)/K			
TB2, S/N #044430025/1 kN·m	0.5 ± 0.6	0.8 ± 1.0	-0.5 ± 0.6	-0.8 ± 1.0
TT1, S/N 36079-00	0.4 ± 2.7	1.5 ± 6.1	-0.4 ± 2.7	-1.5 ± 6.1

The figures 3 show the environmental conditions (temperature and humidity of the ambient air) in the participating laboratory as recorded by the data logger Hobo. The date and time shown in the diagrams is the local time in the pilot laboratory. The time difference between pilot and participant is not taken into account. Due to a long delay between the delivery of the transducers and the start of the measurements the recording time of the Hobo was finished before the calibration of the TT1 was started. Although the maximum temperature during transportation was about 34°C, the maximum relative humidity was stable enough and not higher than 45%.

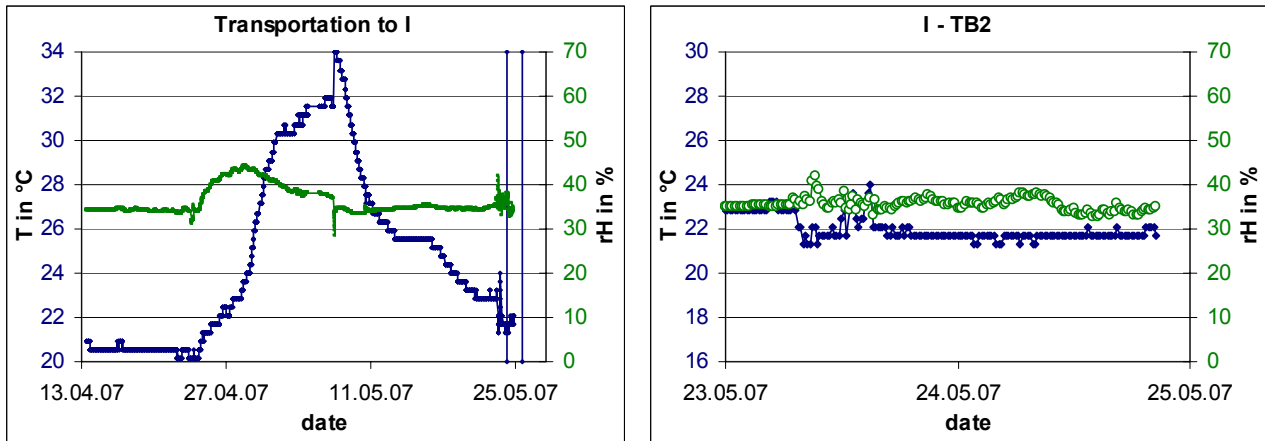


Figure 3. Environmental conditions during the transportation of the equipment to participant I (left diagram) and during the calibration of the TB2 (right diagram) by I (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate)

Using the values e_{rH} and e_T given in table 5, for each of the participants the deflections can be corrected taking into account the corresponding deviations Δ from the ideal environmental conditions ($T = 20^\circ\text{C}$, $rH = 40\%$) according to (4):

$$Y_i''' = Y_i'' - e_{rH} \cdot \Delta rH - e_T \cdot \Delta T \quad (4)$$

with Y_i'' being the uncorrected and Y_i''' the corrected deflections. The temperature and relative humidity values reported by the participants were taken to calculate the corrected results in table 11.

Stability of the transfer transducers

a) Stability of the sensitivity over the period of the key comparison

Based on the fact that the quality of the comparison substantially depends on the three measurements during the loop, the stability of the transducers is extremely important. The figures 19 to 26 show the stability of the transducers, which is determined as the relative deviations of the resulting deflections for all measurements made by the pilot from their arithmetical mean value. The chronological order of the calibrations in the pilot and the participating laboratories is given in table 6.

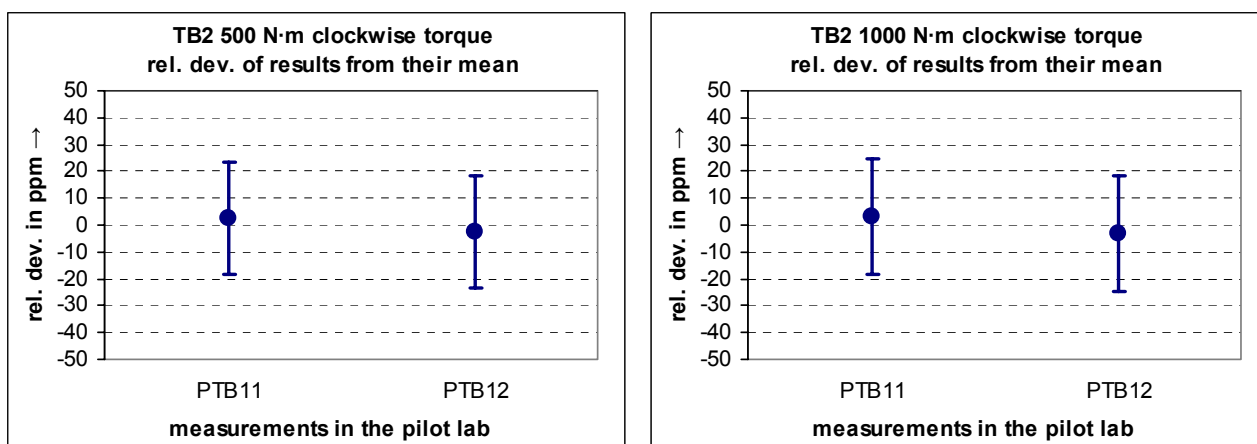


Figure 4. Relative deviations of the deflections for all measurements made by the pilot from their mean values (0.500252 mV/V at 500 N·m—left, and 1.000560 mV/V at 1000 N·m—right, both clockwise torque) for transducer TB2 and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity

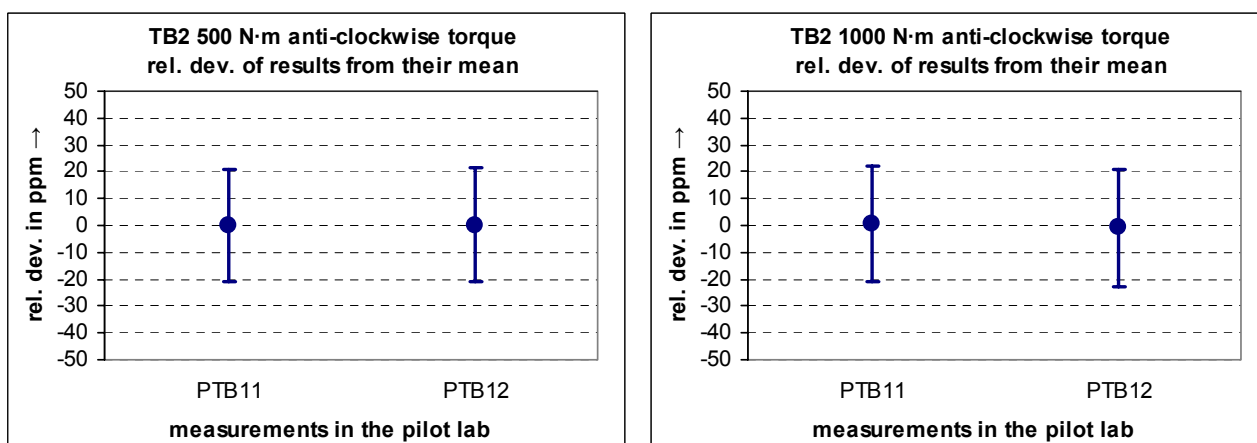


Figure 5. Relative deviations of the deflections for all measurements made by the pilot from their mean values (-0.500248 mV/V at 500 N·m—left, and -1.000530 mV/V at 1000 N·m—right, both anti-clockwise torque) for transducer TB2 and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity

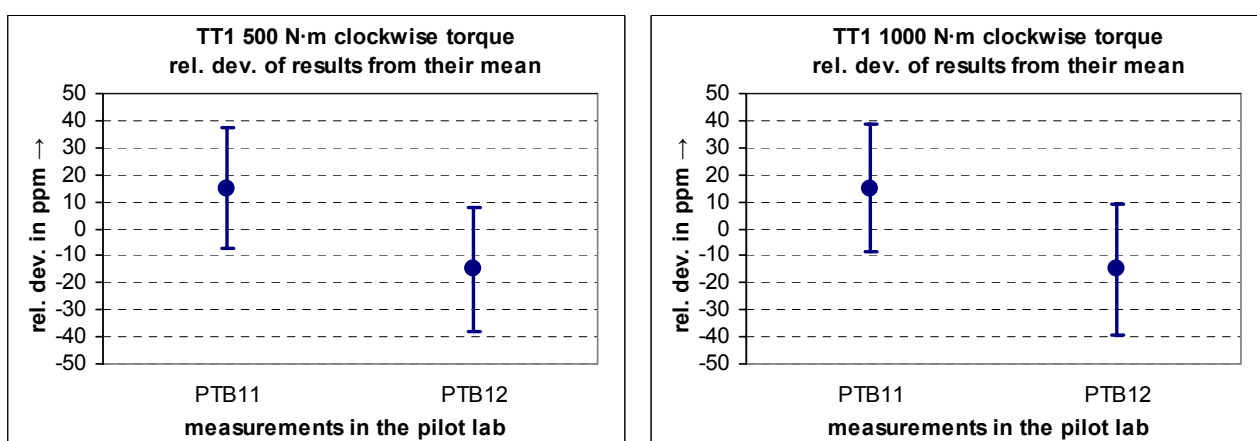


Figure 6. Relative deviations of the deflections for all measurements made by the pilot from their mean values (0.670880 mV/V at 500 N·m—left, and 1.341877 mV/V at 1000 N·m—right, both clockwise torque) for transducer TT1 and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity

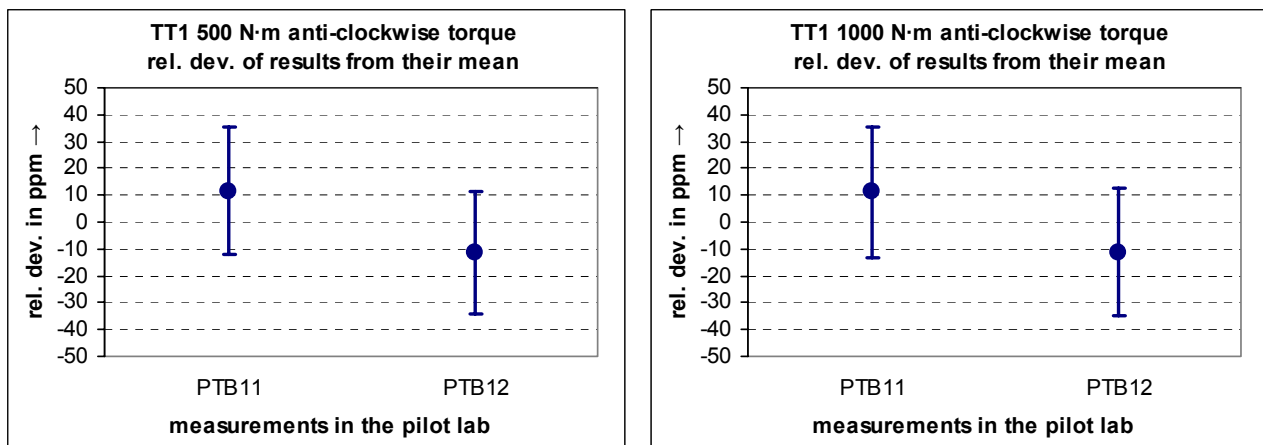


Figure 7. Relative deviations of the deflections for all measurements made by the pilot from their mean value (-0.670862 mV/V at 500 N·m – left, and 1.341810 mV/V at 1000 N·m – right, both anti-clockwise torque) for transducer TT1 and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity

Table 6: Chronological order of the calibrations during the key comparison

Measurement	TB2		TT1	
	cw	acw	cw	acw
PTB11	22.01.2007	23.01.2007	24.01.2007	24.01.2007
I	24.05.2007	25.05.2007	28.05.2007	30.05.2007
PTB12	23.07.2007	24.07.2007	25.07.2007	26.07.2007

b) Stability in the loop

The measurements in the pilot laboratory (see figures 4 to 7) demonstrate that the stability of the travelling standards is sufficiently good compared with the uncertainty of measurement and there is no evidence for a drift. In CCM.T-K1, the deviations from the mean showed a stochastic behaviour. Therefore it was not necessary to use drift corrections for the results from the participants in the loop. That means, that the single loops don't need to be considered as independent of each other and their numerical (corrected) values can be compared. However, a correction for the different environmental condition in the participating laboratories has to be used to calculate the results.

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 creep influence due to different loading regimes in the machines according to 6 (section "Creep effect") and - also in addition -
- 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.

The calculation of the weighted mean and a χ^2 test is given in the annex A.1 according to procedure A in [3]. The parts A.2 and A.3 contain the calculation of the relative deviations of the deflections from the corresponding KCRV and of the degrees of equivalence.

The following designations are used in the tables 7 to 10:

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

Table 7: Uncorrected deflections in mV/V and uncertainties as reported by the participants

Participant	TB2 - cw				TT1 - cw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}
PTB11	0.500255	$2.0 \cdot 10^{-5}$	1.000565	$2.0 \cdot 10^{-5}$	0.670895	$2.0 \cdot 10^{-5}$	1.341902	$2.0 \cdot 10^{-5}$
I	0.500266	$1.0 \cdot 10^{-4}$	1.000592	$1.0 \cdot 10^{-4}$	0.670878	$1.0 \cdot 10^{-4}$	1.341882	$1.0 \cdot 10^{-4}$
PTB12	0.500253	$2.0 \cdot 10^{-5}$	1.000560	$2.0 \cdot 10^{-5}$	0.670870	$2.0 \cdot 10^{-5}$	1.341852	$2.0 \cdot 10^{-5}$
Participant	TB2 - acw				TT1-acw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}	X_{P-Rep}	W_{P-Rep}
PTB11	-0.500246	$2.0 \cdot 10^{-5}$	-1.000531	$2.0 \cdot 10^{-5}$	-0.670872	$2.0 \cdot 10^{-5}$	-1.341830	$2.0 \cdot 10^{-5}$
I	-0.500255	$1.0 \cdot 10^{-4}$	-1.000552	$1.0 \cdot 10^{-4}$	-0.670867	$1.0 \cdot 10^{-4}$	-1.341818	$1.0 \cdot 10^{-4}$
PTB12	-0.500247	$2.0 \cdot 10^{-5}$	-1.000530	$2.0 \cdot 10^{-5}$	-0.670850	$2.0 \cdot 10^{-5}$	-1.341787	$2.0 \cdot 10^{-5}$

Table 8: Deflections from table 7 in mV/V, corrected for the influence of the DMP40, and corresponding uncertainties

Participant	TB2 - cw				TT1 - cw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}
PTB11	0.500253	$2.1 \cdot 10^{-5}$	1.000563	$2.2 \cdot 10^{-5}$	0.670893	$2.1 \cdot 10^{-5}$	1.341902	$2.2 \cdot 10^{-5}$
I	0.500262	$1.0 \cdot 10^{-4}$	1.000586	$1.0 \cdot 10^{-4}$	0.670872	$1.0 \cdot 10^{-4}$	1.341876	$1.0 \cdot 10^{-4}$
PTB12	0.500251	$2.1 \cdot 10^{-5}$	1.000557	$2.2 \cdot 10^{-5}$	0.670868	$2.1 \cdot 10^{-5}$	1.341852	$2.2 \cdot 10^{-5}$
Participant	TB2 - acw				TT1-acw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}	X_{P-DMP}	W_{P-DMP}
PTB11	-0.500248	$2.1 \cdot 10^{-5}$	-1.000530	$2.2 \cdot 10^{-5}$	-0.670873	$2.1 \cdot 10^{-5}$	-1.341832	$2.2 \cdot 10^{-5}$
I	-0.500252	$1.0 \cdot 10^{-4}$	-1.000546	$1.0 \cdot 10^{-4}$	-0.670865	$1.0 \cdot 10^{-4}$	-1.341812	$1.0 \cdot 10^{-4}$
PTB12	-0.500248	$2.1 \cdot 10^{-5}$	-1.000529	$2.2 \cdot 10^{-5}$	-0.670851	$2.1 \cdot 10^{-5}$	-1.341789	$2.2 \cdot 10^{-5}$

Table 9: Deflections from table 8 in mV/V, additionally corrected for the influence of the creep, and corresponding uncertainties

Participant	TB2 - cw				TT1 - cw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$
PTB11	0.500253	$2.1 \cdot 10^{-5}$	1.000563	$2.2 \cdot 10^{-5}$	0.670893	$2.1 \cdot 10^{-5}$	1.341902	$2.2 \cdot 10^{-5}$
I	0.500262	$1.0 \cdot 10^{-4}$	1.000586	$1.0 \cdot 10^{-4}$	0.670872	$1.0 \cdot 10^{-4}$	1.341876	$1.0 \cdot 10^{-4}$
PTB12	0.500251	$2.1 \cdot 10^{-5}$	1.000557	$2.2 \cdot 10^{-5}$	0.670868	$2.1 \cdot 10^{-5}$	1.341852	$2.2 \cdot 10^{-5}$
Participant	TB2 - acw				TT1-acw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$	$X_{P-Creep}$	$W_{P-Creep}$
PTB11	-0.500248	$2.1 \cdot 10^{-5}$	-1.000530	$2.2 \cdot 10^{-5}$	-0.670873	$2.1 \cdot 10^{-5}$	-1.341832	$2.2 \cdot 10^{-5}$
I	-0.500252	$1.0 \cdot 10^{-4}$	-1.000546	$1.0 \cdot 10^{-4}$	-0.670865	$1.0 \cdot 10^{-4}$	-1.341812	$1.0 \cdot 10^{-4}$
PTB12	-0.500248	$2.1 \cdot 10^{-5}$	-1.000529	$2.2 \cdot 10^{-5}$	-0.670851	$2.1 \cdot 10^{-5}$	-1.341789	$2.2 \cdot 10^{-5}$

Table 10: Deflections from table 9 in mV/V, additionally corrected for the influence of the environment, and corresponding uncertainties

Participant	TB2 - cw				TT1 - cw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$
PTB11	0.500253	$2.1 \cdot 10^{-5}$	1.000563	$2.2 \cdot 10^{-5}$	0.670890	$2.3 \cdot 10^{-5}$	1.341896	$2.3 \cdot 10^{-5}$
I	0.500261	$1.0 \cdot 10^{-4}$	1.000585	$1.0 \cdot 10^{-4}$	0.670870	$1.0 \cdot 10^{-4}$	1.341872	$1.0 \cdot 10^{-4}$
PTB12	0.500251	$2.1 \cdot 10^{-5}$	1.000556	$2.2 \cdot 10^{-5}$	0.670870	$2.3 \cdot 10^{-5}$	1.341856	$2.4 \cdot 10^{-5}$
Participant	TB2 - acw				TT1-acw			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$	$X_{P-Envir}$	$W_{P-Envir}$
PTB11	-0.500248	$2.1 \cdot 10^{-5}$	-1.000530	$2.2 \cdot 10^{-5}$	-0.670868	$2.2 \cdot 10^{-5}$	-1.341822	$2.3 \cdot 10^{-5}$
I	-0.500251	$1.0 \cdot 10^{-4}$	-1.000544	$1.0 \cdot 10^{-4}$	-0.670864	$1.0 \cdot 10^{-4}$	-1.341807	$1.0 \cdot 10^{-4}$
PTB12	-0.500248	$2.1 \cdot 10^{-5}$	-1.000528	$2.2 \cdot 10^{-5}$	-0.670853	$2.2 \cdot 10^{-5}$	-1.341792	$2.3 \cdot 10^{-5}$

8. Summary

The results of the measurements (deflections and uncertainties) reported by the participants of the CIPM key comparison CCM.T-K1.1 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, the creep influence due to different loading times in the machines and the environmental conditions on site were calculated.

The Annex contains the key comparison reference values for CCM.T-K1, 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, 2009 *Metrologia* **46** 07002, http://www.bipm.org/utis/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 Key Comparison CCM.T-K1.1

Measurand Torque: 0 N·m, 500 N·m, 1000 N·m

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

The weighted means and their corresponding uncertainties were calculated according to procedure A in [3] for all participants of CCM.T-K1 and the new participant of CCM.T-K1.1. 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 A11 were obtained. For the anti-clockwise torque, the results shown in table A12 were obtained. According to [1], the anti-clockwise results of participant F were not taken into account. The χ^2 test showed, that the corrected values of participant I of CCM.T-K1.1 can be considered to be consistent with the results of the participants of CCM.T-K1.

Table A11: Results of a χ^2 test on the corrected clockwise values from all participants (ν - degree of freedom = number of participants - 1)

	TB2		TT1	
	500 N·m cw	1000 N·m cw	500 N·m cw	1000 N·m cw
χ^2_{obs}	6.79	11.09	8.59	8.97
ν	8	8	8	8
$\chi^2(\nu), P = 0,05$	15.51	15.51	15.51	15.51
Result	Test passed	Test passed	Test passed	Test passed

Table A12: Results of a χ^2 test on the corrected anti-clockwise values from all participants, except participant F (ν - degree of freedom = number of participants - 1)

	TB2		TT1	
	500 N·m acw	1000 N·m acw	500 N·m acw	1000 N·m acw
χ^2_{obs}	7.61	12.34	9.81	6.69
ν	7	7	7	7
$\chi^2(\nu), P = 0,05$	14.07	14.07	14.07	14.07
Result	Test passed	Test passed	Test passed	Test passed

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

The CCM.T-K1 key comparison reference values—given in table A13 in mV/V as well as in N·m [1]—and the corresponding uncertainties were used to calculate relative deviations and degrees of equivalence. The figures A8 to A15 show the resulting deviations from the KCRVs and the uncertainties. Table A14 contains the participants of CCM.T-K1.

Table A13: Key comparison reference values (KCRV, x_{ref}) and corresponding standard uncertainties $u(x_{\text{ref}})$

	TB2 cw		TB2 acw		TT1 cw		TT1 acw	
	x_{ref} in mV/V	$u(x_{\text{ref}})$ in nV/V	x_{ref} in mV/V	$u(x_{\text{ref}})$ in nV/V	x_{ref} in mV/V	$u(x_{\text{ref}})$ in nV/V	x_{ref} in mV/V	$u(x_{\text{ref}})$ in nV/V
500 N·m	0.500258	2.9	-0.500252	3.0	0.670866	5.2	-0.670849	4.8
1000 N·m	1.000578	5.5	-1.000547	5.8	1.341850	10.9	-1.341788	10.0
	x_{ref} in N·m	$u(x_{\text{ref}})$ in mN·m	x_{ref} in N·m	$u(x_{\text{ref}})$ in mN·m	x_{ref} in N·m	$u(x_{\text{ref}})$ in mN·m	x_{ref} in N·m	$u(x_{\text{ref}})$ in mN·m
500 N·m	500.000	2.9	-500.000	3.0	500.000	3.9	-500.000	3.6
1000 N·m	1000.000	5.5	-1000.000	5.8	1000.000	8.1	-1000.000	7.5

Table A14: Participants in the CCM.T-K1 torque key comparison: countries, institutes and code numbers used in the report

Country	Brazil	Germany	Japan	Korea	Mexico	Spain	Switzer- land	United Kingdom
Institute	INMETRO	PTB	NMIJ	KRISS	CENAM	CEM	METAS	NPL
Code letter	E	H	D	C	F	B	A	G

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

$$Y_{P-N\cdot m} = \frac{x_{ref}}{x'_{ref}} \cdot Y_{P-Envir} \quad (5)$$

and are given in table A15. The relative uncertainties W don't need to be converted.

Table A15: Deflections from table 10 for participant I converted to torque units in N·m and corresponding expanded relative uncertainties ($k = 2$)

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	500 N·m		1000 N·m		500 N·m		1000 N·m	
	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$
I	500.004	$1.0 \cdot 10^{-4}$	1000.007	$1.0 \cdot 10^{-4}$	500.003	$1.0 \cdot 10^{-4}$	1000.016	$1.0 \cdot 10^{-4}$
Participant	TB2 - anti-clockwise torque				TT1 – anti-clockwise torque			
	-500 N·m		-1000 N·m		-500 N·m		-1000 N·m	
	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$	$Y_{P-N\cdot m}$	$W_{P-N\cdot m}$
I	-499.999	$1.0 \cdot 10^{-4}$	-999.997	$1.0 \cdot 10^{-4}$	-500.011	$1.0 \cdot 10^{-4}$	-1000.014	$1.0 \cdot 10^{-4}$

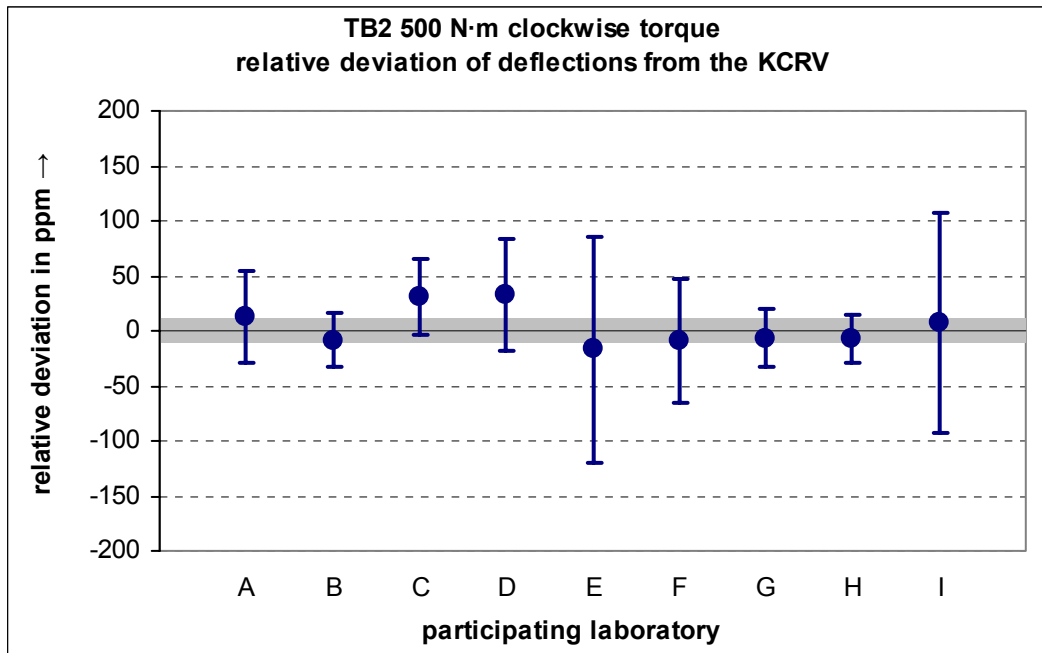


Figure A8. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TB2 at 500 N·m clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

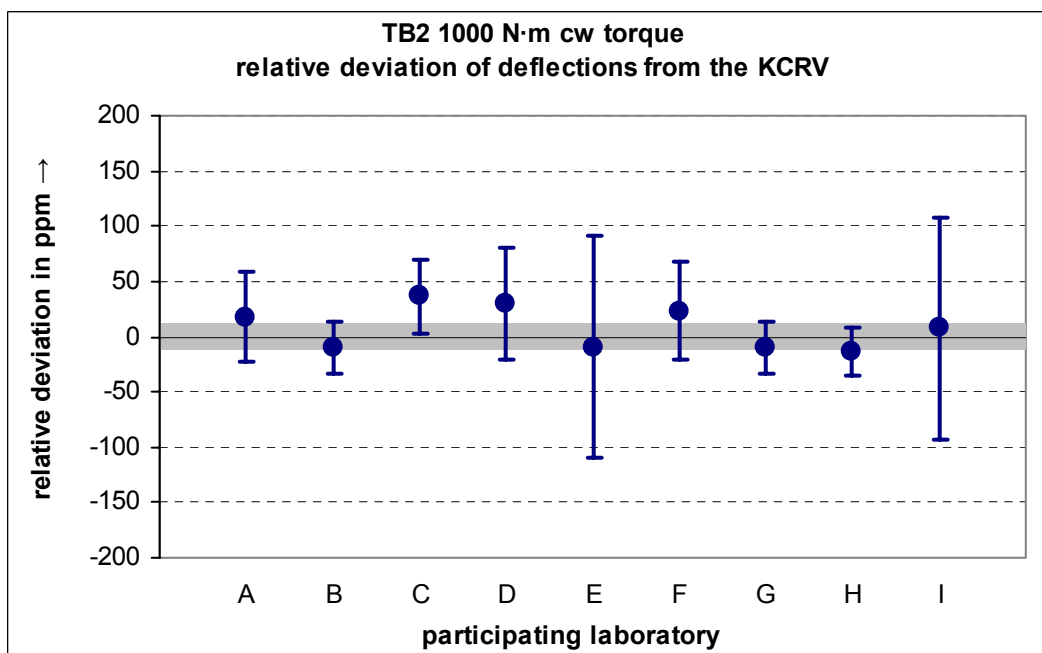


Figure A9. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TB2 at 1000 N·m clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

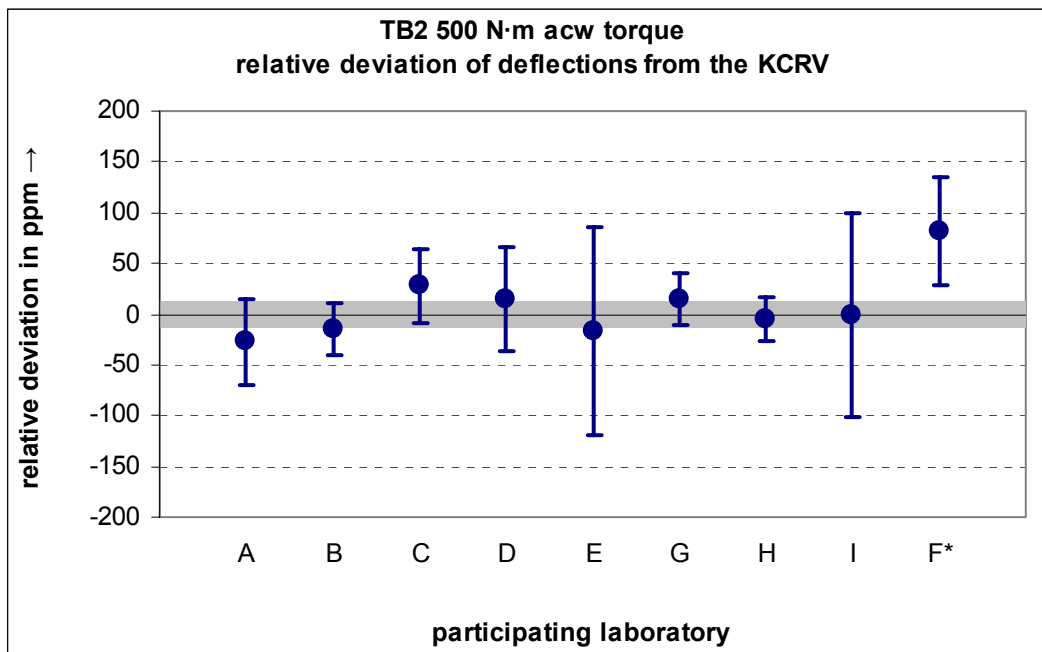


Figure A10. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (* grey band = relative expanded uncertainty, $k = 2$, calculated without F) for transducer TB2 at 500 N-m anti-clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

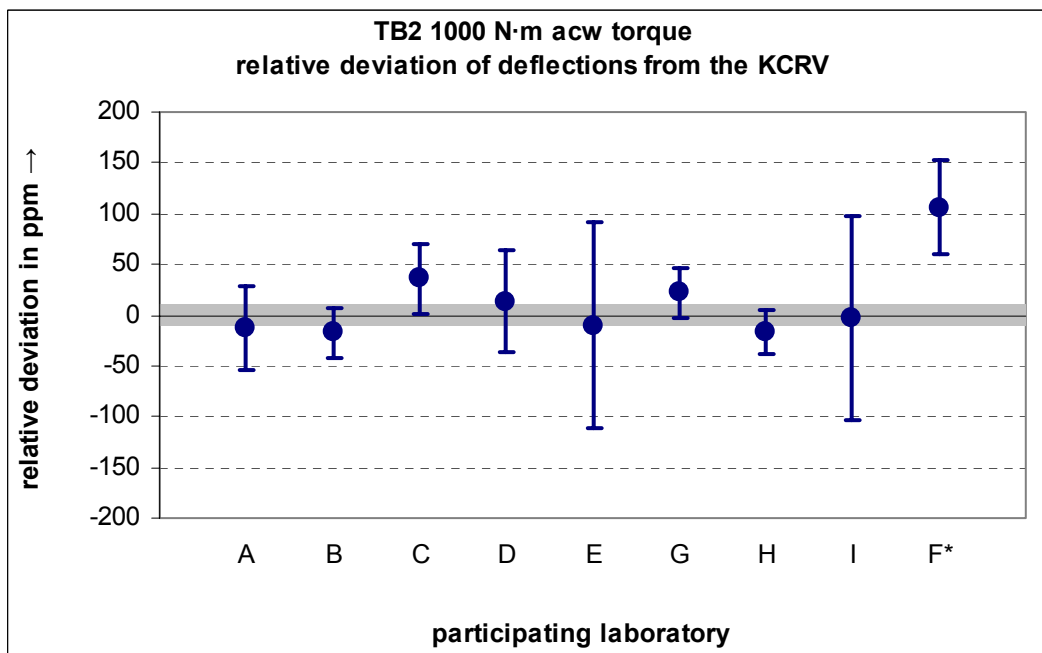


Figure A11. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (* grey band = relative expanded uncertainty, $k = 2$, calculated without F) for transducer TB2 at 1000 N-m anti-clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

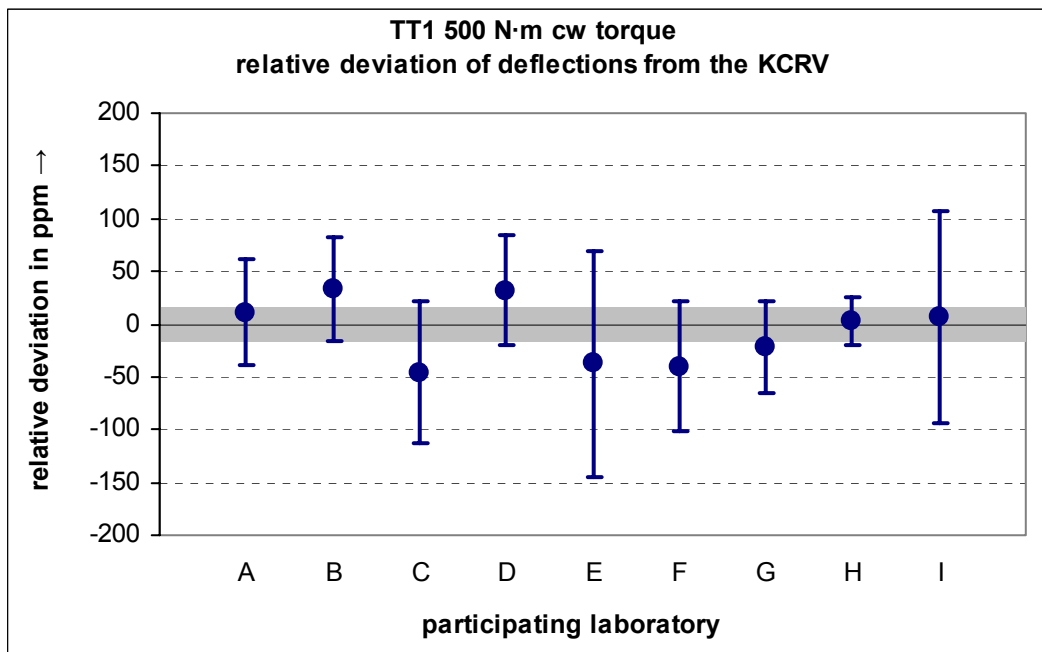


Figure A12. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TT1 at 500 N·m clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

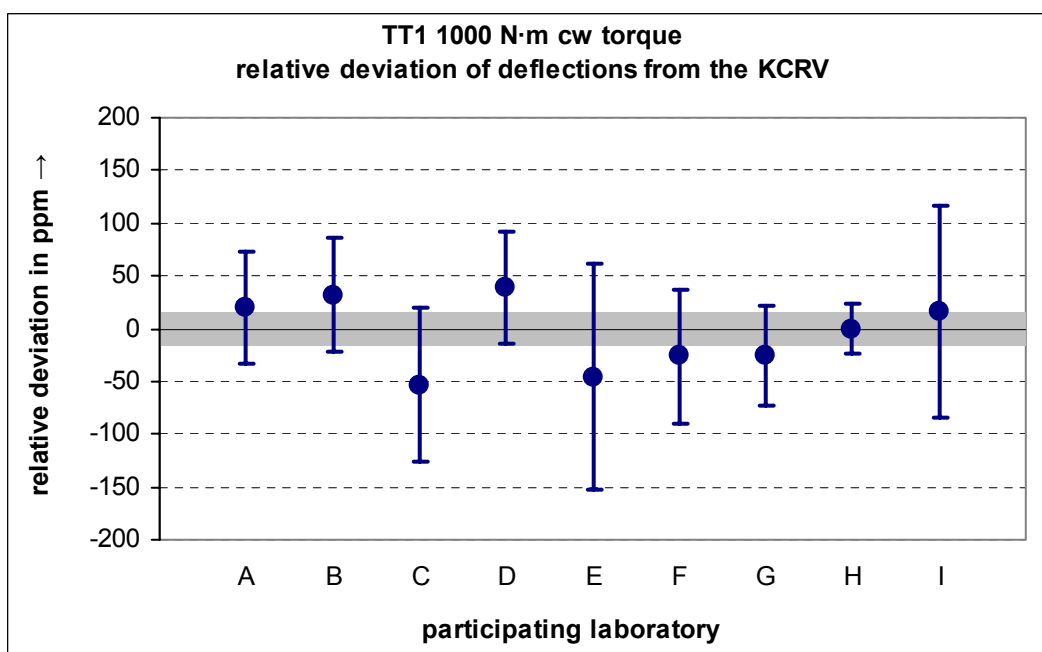


Figure A13. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (grey band = relative expanded uncertainty, $k = 2$) for transducer TT1 at 1000 N·m clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

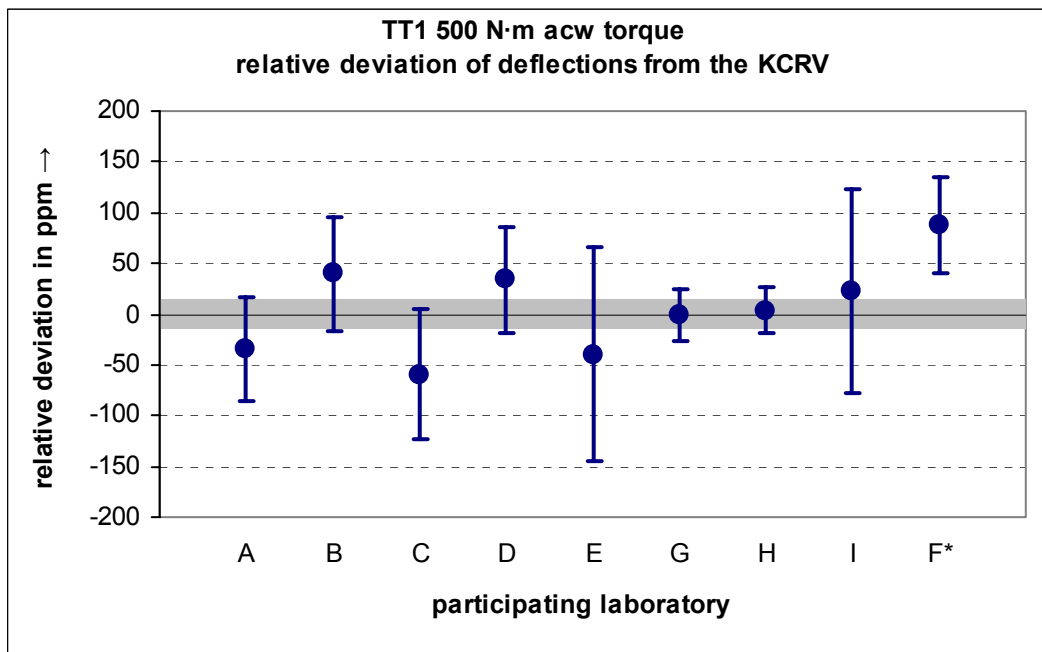


Figure A14. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (* grey band = relative expanded uncertainty, $k = 2$, calculated without F) for transducer TT1 at 500 N·m anti-clockwise torque and relative expanded ($k = 2$) measurement uncertainties (uncertainty bars)

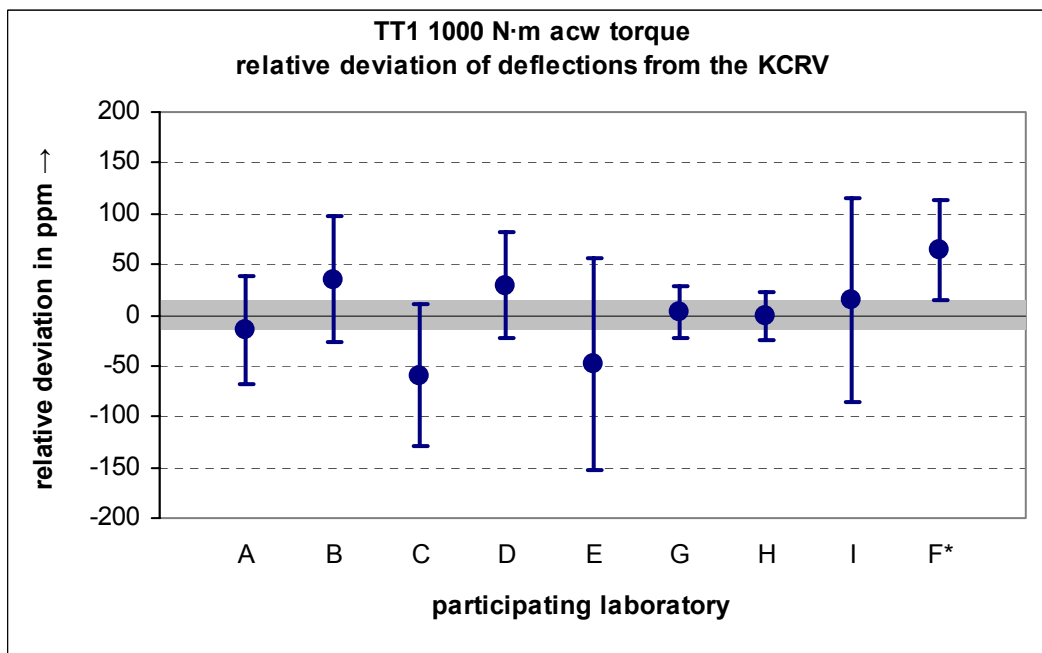


Figure A15. Relative deviations of the corrected deflections for the participating laboratories from the corresponding CCM.T-K1-KCRV (* grey band = relative expanded uncertainty, $k = 2$, calculated without F) for transducer TT1 at 1000 N·m anti-clockwise torque and relative expanded ($k = 2$) measurement 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 key comparison reference values were calculated according to procedure A in [3]. The figures A16 to A23 show the results, the values are given in the table A16.

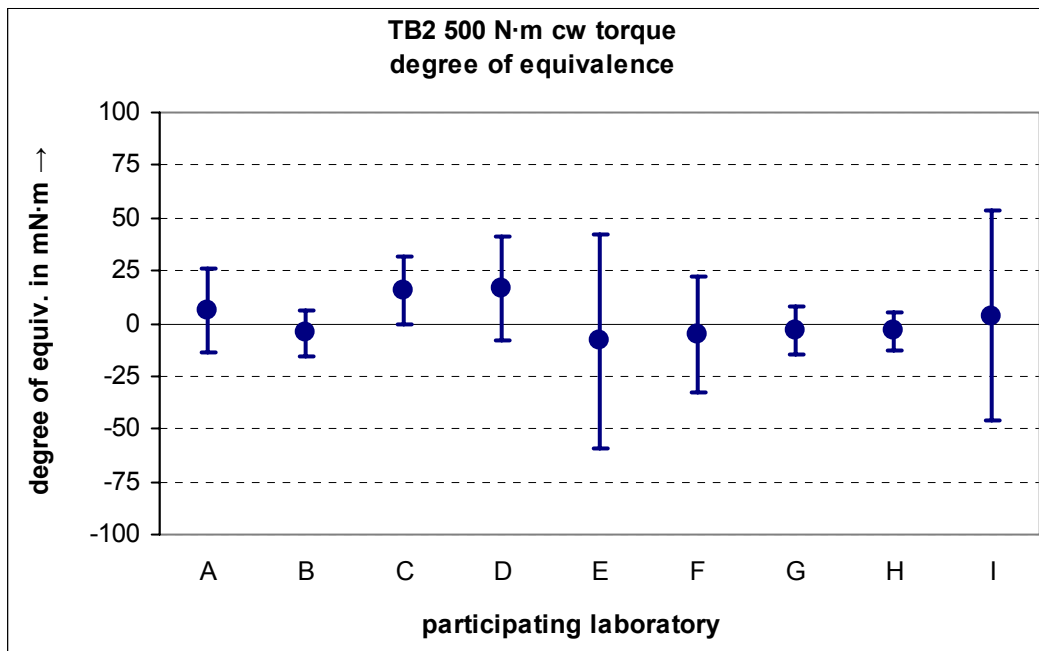


Figure A16. Degrees of equivalence for all measurements made by the participating laboratories with transducer TB2 at 500 N·m clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$)

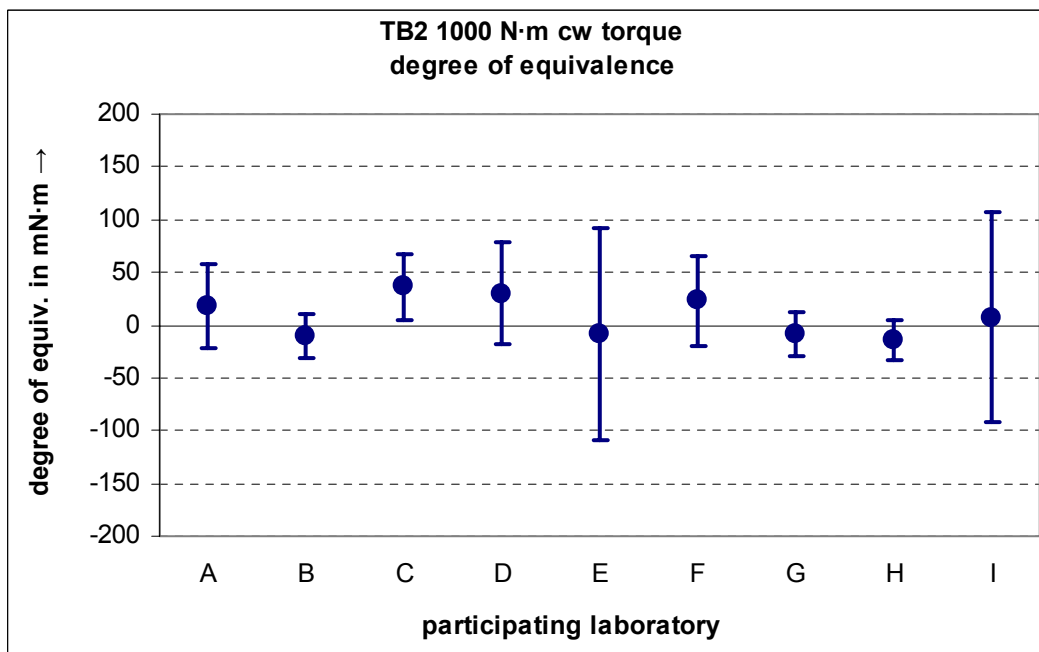


Figure A17. Degrees of equivalence for all measurements made by the participating laboratories with transducer TB2 at 1000 N·m clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$)

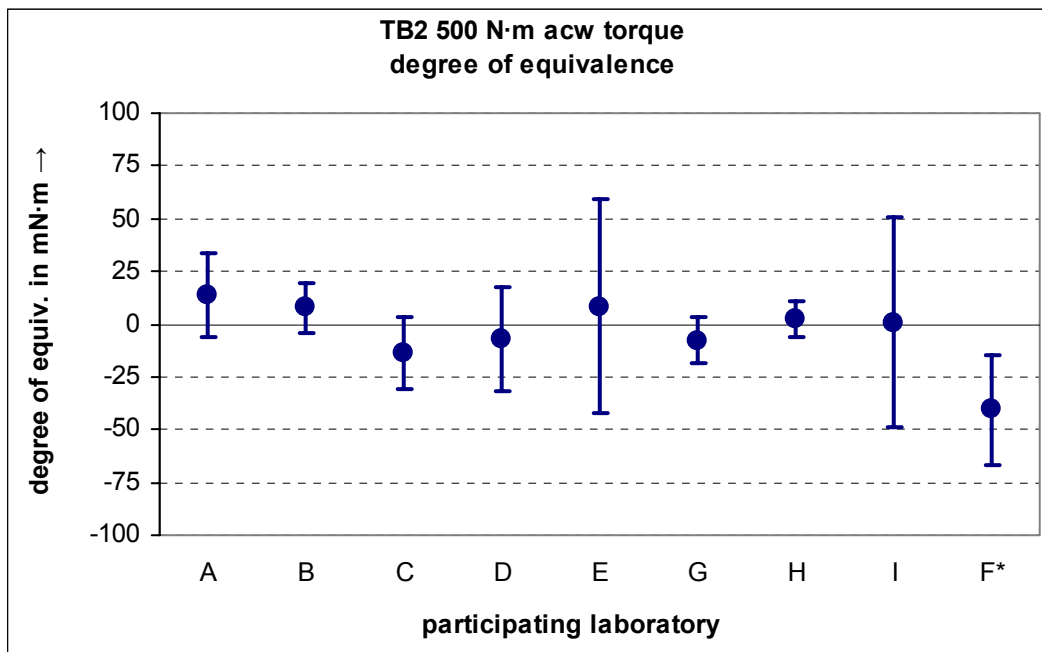


Figure A18. Degrees of equivalence for all measurements made by the participating laboratories with transducer TB2 at 500 N·m anti-clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$),
* KCRV calculated without F

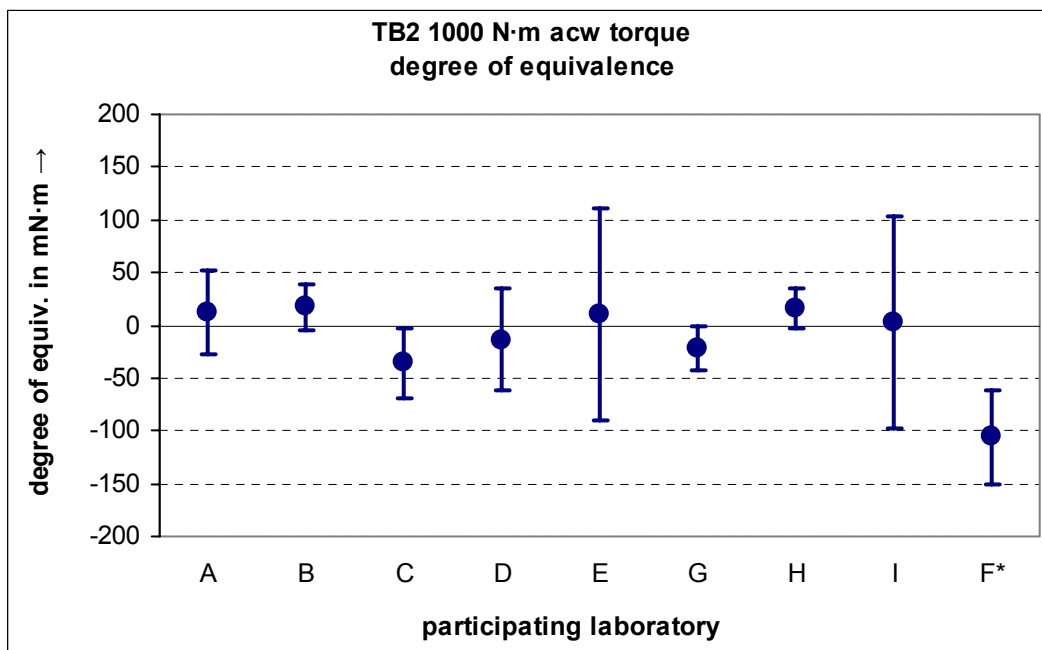


Figure A19. Degrees of equivalence for all measurements made by the participating laboratories with transducer TB2 at 1000 N·m anti-clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$),
* KCRV calculated without F

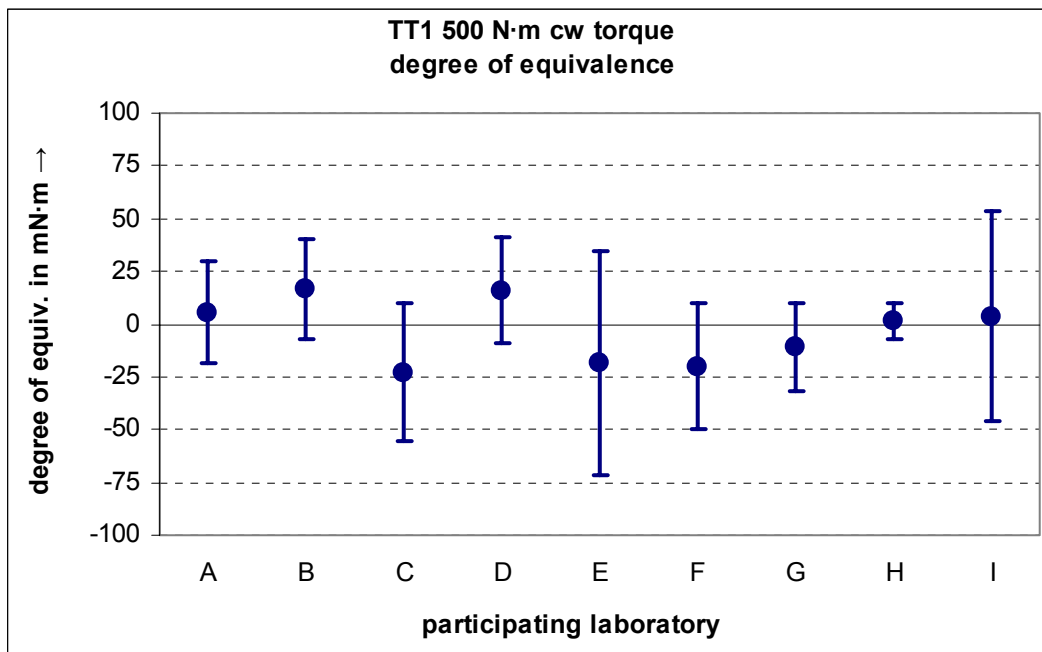


Figure A20. Degrees of equivalence for all measurements made by the participating laboratories with transducer TT1 at 500 N·m clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$)

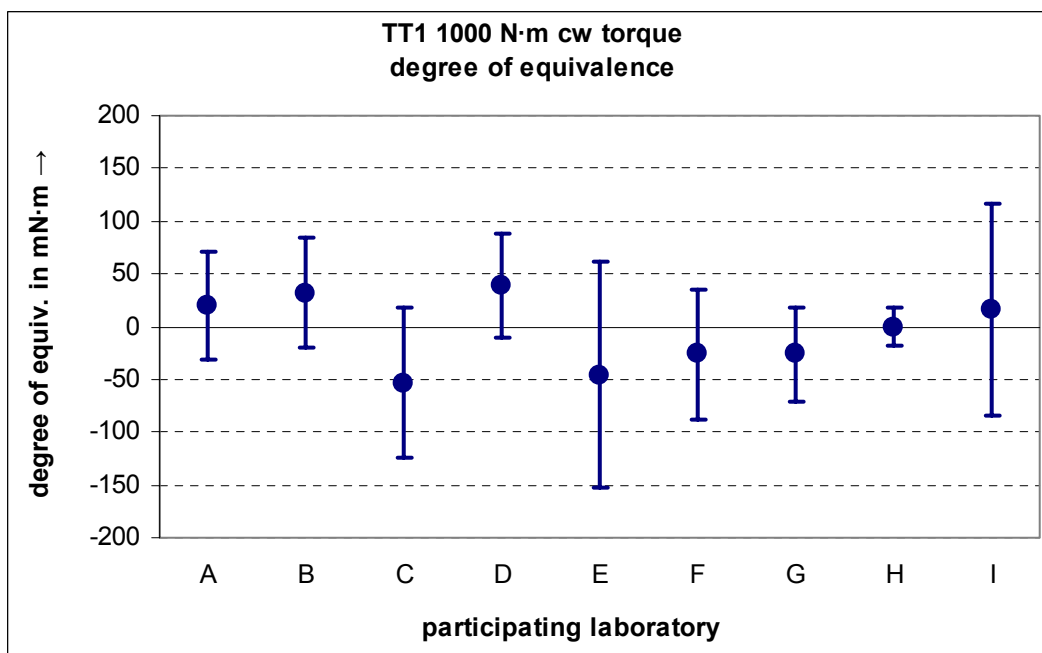


Figure A21. Degrees of equivalence for all measurements made by the participating laboratories with transducer TT1 at 1000 N·m clockwise torque (dot = d_i , uncertainty bar = $U(d_i)$)

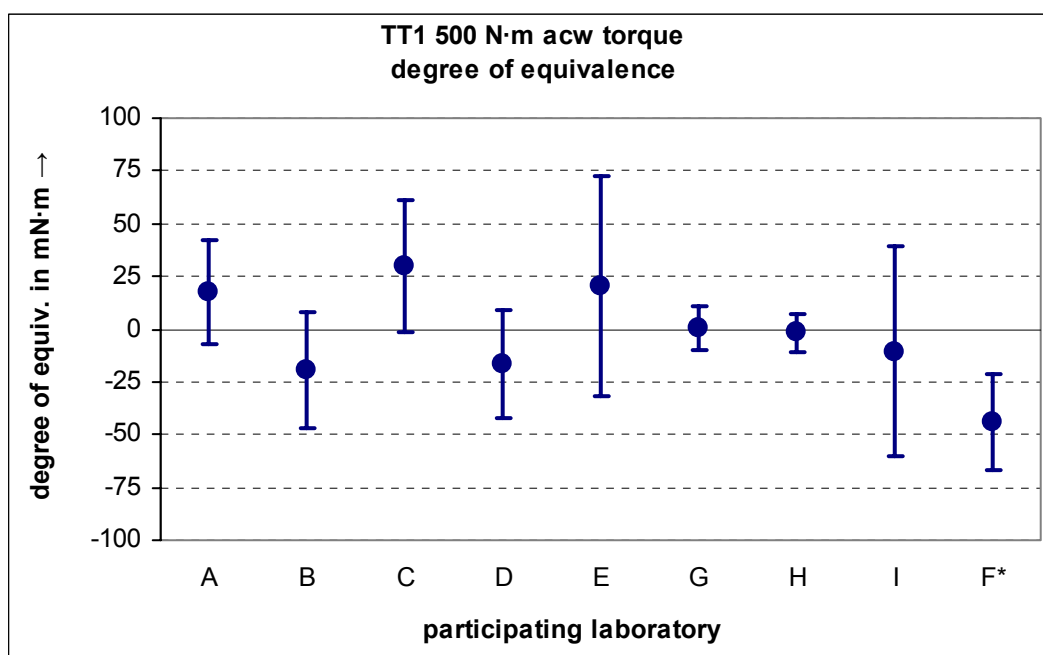


Figure A22. Degrees of equivalence for all measurements made by the participating laboratories with transducer TT1 at 500 N·m anti-clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$),
* KCRV calculated without F

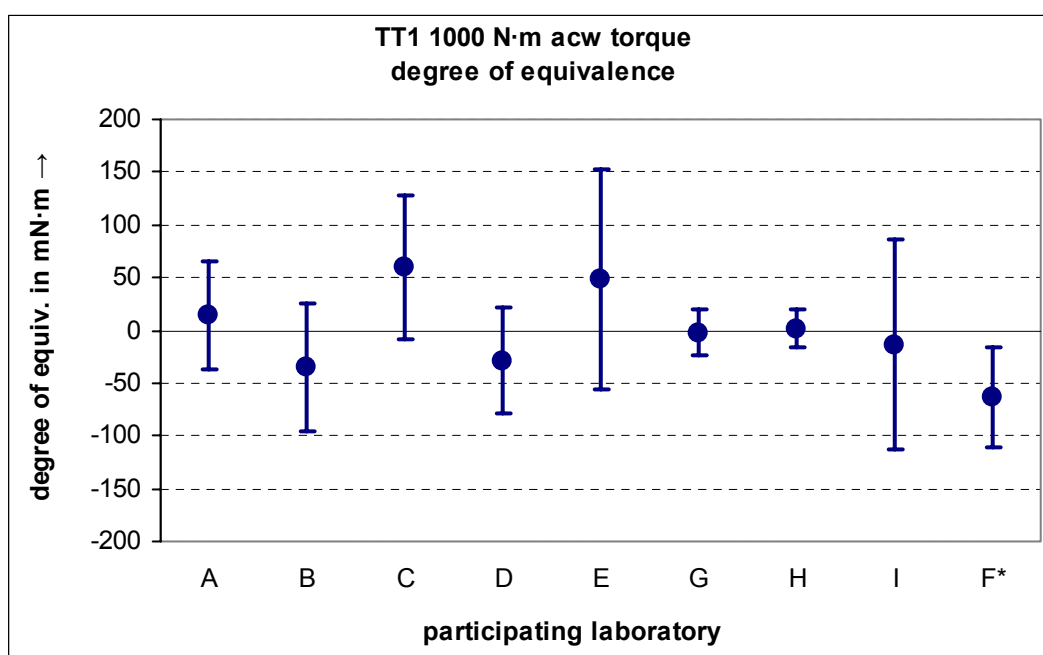


Figure A23. Degrees of equivalence for all measurements made by the participating laboratories with transducer TT1 at 1000 N·m anti-clockwise torque (dot = D_i , uncertainty bar = $U(D_i)$),
* KCRV calculated without F

Table A17 shows the degrees of equivalence (D_{ij} , $U(D_{ij})$) 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 -10.6 mN·m in the second column is the difference result(B)–result(A), 10.6 mN·m in the second row is the difference result(A)–result(B), respectively.

Table A16: Degrees of equivalence (D_i , $U(D_i)$) in mN·m between the corrected values from the participants and the corresponding key comparison reference value (* anti-clockwise result not used for the calculation of the KCRV)

$(D_i, U(D_i))$ in mN·m	TB2 cw		TB2 acw	
	500 N·m	1000 N·m	500 N·m	1000 N·m
A	(6.2, 20.0)	(18.0, 39.9)	(13.8, 19.9)	(12.6, 39.8)
B	(-4.4, 10.9)	(-10.6, 21.0)	(7.6, 11.5)	(17.4, 21.7)
C	(15.5, 16.4)	(36.3, 31.8)	(-13.9, 17.1)	(-35.8, 32.6)
D	(16.8, 24.8)	(30.3, 49.1)	(-7.2, 24.7)	(-13.3, 49.0)
E	(-8.5, 50.7)	(-9.1, 100.6)	(8.3, 50.7)	(10.0, 100.5)
F *	(-4.9, 27.5)	(23.1, 43.1)	(-40.7, 25.8)	(-106.0, 45.2)
G	(-3.4, 11.7)	(-9.2, 20.7)	(-7.7, 11.2)	(-21.9, 21.7)
H	(-3.7, 8.8)	(-14.0, 18.7)	(2.3, 8.7)	(16.1, 18.4)
I	(3.6, 49.8)	(7.3, 99.8)	(0.6, 49.8)	(2.9, 99.7)
$(D_i, U(D_i))$ in mN·m	TT1 cw		TT1 acw	
	500 N·m	1000 N·m	500 N·m	1000 N·m
A	(5.7, 24.2)	(19.7, 50.5)	(17.4, 24.4)	(14.3, 50.9)
B	(16.8, 23.6)	(32.2, 52.0)	(-19.6, 27.3)	(-34.6, 60.2)
C	(-23.0, 32.7)	(-53.4, 71.4)	(30.1, 31.1)	(59.5, 67.9)
D	(16.1, 25.1)	(39.0, 49.9)	(-16.6, 25.2)	(-29.0, 50.2)
E	(-18.6, 53.0)	(-45.5, 106.4)	(20.1, 52.0)	(48.8, 104.0)
F *	(-20.0, 30.2)	(-25.9, 61.7)	(-43.8, 22.7)	(-64.1, 47.2)
G	(-10.9, 20.8)	(-26.0, 44.6)	(0.4, 10.6)	(-2.4, 21.8)
H	(1.3, 8.5)	(-0.2, 17.4)	(-1.7, 8.9)	(1.5, 18.5)
I	(3.4, 49.8)	(16.1, 99.7)	(-10.8, 49.8)	(-13.8, 99.6)

Table A17: Degrees of equivalence (D_{ij} , $U(D_{ij})$) in mN·m between the corrected values from the participants
 –to be continued on the next page

	A		B		C	
A	TB2, 500 N·m	TB2, -500 N·m	(10,6; 24,2)	(6,2; 24,4)	(-9,3; 27,1)	(27,7; 27,5)
	TB2, 1000 N·m	TB2, -1000 N·m	(28,5; 47,7)	(-4,8; 48,2)	(-18,4; 53,3)	(48,4; 54,0)
	TT1, 500 N·m	TT1, -500 N·m	(-11,2; 35,5)	(37,0; 38,0)	(28,7; 42,1)	(-12,7; 40,8)
	TT1, 1000 N·m	TT1, -1000 N·m	(-12,4; 76,0)	(48,9; 81,6)	(73,1; 90,3)	(-45,2; 87,4)
B	(-10,6; 24,2)	(-6,2; 24,4)	TB2, 500 N·m	TB2, -500 N·m	(-19,9; 21,3)	(21,6; 22,3)
	(-28,5; 47,7)	(4,8; 48,2)	TB2, 1000 N·m	TB2, -1000 N·m	(-46,9; 41,1)	(53,2; 42,4)
	(11,2; 35,5)	(-37,0; 38,0)	TT1, 500 N·m	TT1, -500 N·m	(39,8; 41,7)	(-49,7; 42,6)
	(12,4; 76,0)	(-48,9; 81,6)	TT1, 1000 N·m	TT1, -1000 N·m	(85,6; 91,2)	(-94,1; 93,1)
C	(9,3; 27,1)	(-27,7; 27,5)	(19,9; 21,3)	87,3783292	TB2, 500 N·m	TB2, -500 N·m
	(18,4; 53,3)	(-48,4; 54,0)	(46,9; 41,1)	125,964123	TB2, 1000 N·m	TB2, -1000 N·m
	(-28,7; 42,1)	(12,7; 40,8)	(-39,8; 41,7)	(49,7; 42,6)	TT1, 500 N·m	TT1, -500 N·m
	(-73,1; 90,3)	(45,2; 87,4)	(-85,6; 91,2)	(94,1; 93,1)	TT1, 1000 N·m	TT1, -1000 N·m
D	(10,5; 32,8)	(-20,9; 32,8)	(21,1; 28,2)	(-14,8; 28,5)	(1,3; 30,8)	(6,8; 31,2)
	(12,3; 65,2)	(-25,9; 65,2)	(40,9; 55,6)	(-30,7; 56,0)	(-6,0; 60,5)	(22,5; 61,1)
	(10,4; 36,5)	(-33,9; 36,5)	(-0,8; 36,1)	(3,0; 38,5)	(39,1; 42,6)	(-46,7; 41,3)
	(19,2; 74,5)	(-43,3; 74,5)	(6,8; 75,5)	(5,6; 81,2)	(92,3; 90,0)	(-88,5; 87,0)
E	(-14,7; 55,1)	(-5,5; 55,1)	(-4,1; 52,5)	(0,7; 52,7)	(-24,0; 53,9)	(22,2; 54,2)
	(-27,0; 109,3)	(-2,6; 109,4)	(1,5; 103,9)	(-7,4; 104,1)	(-45,4; 106,6)	(45,8; 107,0)
	(-24,3; 59,2)	(2,8; 58,3)	(-35,5; 59,0)	(39,7; 59,6)	(4,4; 63,2)	(-10,0; 61,4)
	(-65,3; 120,0)	(34,5; 117,7)	(-77,7; 120,6)	(83,4; 122,0)	(7,8; 130,1)	(-10,7; 126,0)
F	(-11,1; 34,9)	(-54,5; 33,6)	(-0,5; 30,6)	(-48,3; 29,4)	(-20,3; 33,0)	(-26,7; 32,1)
	(5,1; 60,7)	(-118,6; 62,4)	(33,7; 50,4)	(-123,3; 52,8)	(-13,3; 55,7)	(-70,2; 58,1)
	(-25,6; 40,2)	(-61,1; 34,8)	(-36,8; 39,8)	(-24,2; 36,9)	(3,0; 45,8)	(-73,8; 39,8)
	(-45,6; 82,9)	(-78,4; 72,5)	(-58,1; 83,8)	(-29,5; 79,3)	(27,5; 97,1)	(-123,5; 85,3)
G	(-9,6; 24,6)	(-21,4; 24,3)	(1,0; 17,9)	(-15,3; 18,1)	(-18,9; 21,7)	(6,3; 22,1)
	(-27,2; 47,6)	(-34,5; 48,2)	(1,4; 33,3)	(-39,2; 34,8)	(-45,5; 41,0)	(13,9; 42,4)
	(-16,6; 33,7)	(-17,0; 28,4)	(-27,7; 33,3)	(20,0; 31,0)	(12,1; 40,2)	(-29,7; 34,4)
	(-45,7; 71,1)	(-16,7; 59,2)	(-58,2; 72,2)	(32,2; 67,4)	(27,4; 87,2)	(-61,9; 74,3)
H	(-9,9; 23,3)	(-11,5; 23,2)	(0,7; 16,2)	(-5,3; 16,7)	(-19,2; 20,3)	(16,2; 21,0)
	(-31,9; 46,7)	(3,5; 46,8)	(-3,4; 32,1)	(-1,3; 32,8)	(-50,3; 40,0)	(51,9; 40,8)
	(-4,4; 27,8)	(-19,1; 27,8)	(-15,5; 27,3)	(17,9; 30,5)	(24,3; 35,5)	(-31,8; 33,9)
	(-19,9; 58,0)	(-12,8; 58,1)	(-32,4; 59,3)	(36,1; 66,4)	(53,2; 76,9)	(-58,0; 73,4)
I	(-2,6; 54,3)	(-13,2; 54,2)	(8,0; 51,7)	(-7,0; 51,8)	(-11,9; 53,1)	(14,5; 53,3)
	(-10,7; 108,6)	(-9,7; 108,6)	(17,9; 103,2)	(-14,5; 103,4)	(-29,0; 105,9)	(38,7; 106,2)
	(-2,2; 56,4)	(-28,1; 56,3)	(-13,4; 56,2)	(8,8; 57,7)	(26,4; 60,5)	(-40,9; 59,6)
	(-3,6; 114,1)	(-28,1; 113,8)	(-16,0; 114,7)	(20,8; 118,2)	(69,5; 124,7)	(-73,3; 122,3)

Table A17 - continued: Degrees of equivalence (D_{ij} , $U(D_{ij})$) in mN·m between the corrected values from the participants—to be continued on the next page

	D		E		F	
A	(-10,5; 32,8)	(20,9; 32,8)	(14,7; 55,1)	(5,5; 55,1)	(11,1; 34,9)	(54,5; 33,6)
	(-12,3; 65,2)	(25,9; 65,2)	(27,0; 109,3)	(2,6; 109,4)	(-5,1; 60,7)	(118,6; 62,4)
	(-10,4; 36,5)	(33,9; 36,5)	(24,3; 59,2)	(-2,8; 58,3)	(25,6; 40,2)	(61,1; 34,8)
	(-19,2; 74,5)	(43,3; 74,5)	(65,3; 120,0)	(-34,5; 117,7)	(45,6; 82,9)	(78,4; 72,5)
B	(-21,1; 28,2)	(14,8; 28,5)	(4,1; 52,5)	(-0,7; 52,7)	(0,5; 30,6)	(48,3; 29,4)
	(-40,9; 55,6)	(30,7; 56,0)	(-1,5; 103,9)	(7,4; 104,1)	(-33,7; 50,4)	(123,3; 52,8)
	(0,8; 36,1)	(-3,0; 38,5)	(35,5; 59,0)	(-39,7; 59,6)	(36,8; 39,8)	(24,2; 36,9)
	(-6,8; 75,5)	(-5,6; 81,2)	(77,7; 120,6)	(-83,4; 122,0)	(58,1; 83,8)	(29,5; 79,3)
C	(-1,3; 30,8)	(-6,8; 31,2)	(24,0; 53,9)	(-22,2; 54,2)	(20,3; 33,0)	(26,7; 32,1)
	(6,0; 60,5)	(-22,5; 61,1)	(45,4; 106,6)	(-45,8; 107,0)	(13,3; 55,7)	(70,2; 58,1)
	(-39,1; 42,6)	(46,7; 41,3)	(-4,4; 63,2)	(10,0; 61,4)	(-3,0; 45,8)	(73,8; 39,8)
	(-92,3; 90,0)	(88,5; 87,0)	(-7,8; 130,1)	(10,7; 126,0)	(-27,5; 97,1)	(123,5; 85,3)
D	TB2, 500 N·m	TB2, -500 N·m	(25,3; 57,0)	(-15,4; 57,1)	(21,6; 37,8)	(33,5; 36,7)
	TB2, 1000 N·m	TB2, -1000 N·m	(39,4; 113,0)	(-23,3; 113,0)	(7,2; 67,1)	(92,6; 68,7)
	TT1, 500 N·m	TT1, -500 N·m	(34,7; 59,6)	(-36,7; 58,7)	(36,0; 40,7)	(27,2; 35,4)
	TT1, 1000 N·m	TT1, -1000 N·m	(84,5; 119,7)	(-77,8; 117,4)	(64,8; 82,5)	(35,1; 72,0)
E	(-25,3; 57,0)	(15,4; 57,1)	TB2, 500 N·m	TB2, -500 N·m	(-3,7; 58,2)	(48,9; 57,5)
	(-39,4; 113,0)	(23,3; 113,0)	TB2, 1000 N·m	TB2, -1000 N·m	(-32,1; 110,5)	(115,9; 111,5)
	(-34,7; 59,6)	(36,7; 58,7)	TT1, 500 N·m	TT1, -500 N·m	(1,3; 61,9)	(63,9; 57,6)
	(-84,5; 119,7)	(77,8; 117,4)	TT1, 1000 N·m	TT1, -1000 N·m	(-19,6; 125,1)	(112,9; 116,2)
F	(-21,6; 37,8)	(-33,5; 36,7)	(3,7; 58,2)	(-48,9; 57,5)	TB2, 500 N·m	TB2, -500 N·m
	(-7,2; 67,1)	(-92,6; 68,7)	(32,1; 110,5)	(-115,9; 111,5)	TB2, 1000 N·m	TB2, -1000 N·m
	(-36,0; 40,7)	(-27,2; 35,4)	(-1,3; 61,9)	(-63,9; 57,6)	TT1, 500 N·m	TT1, -500 N·m
	(-64,8; 82,5)	(-35,1; 72,0)	(19,6; 125,1)	(-112,9; 116,2)	TT1, 1000 N·m	TT1, -1000 N·m
G	(-20,2; 28,6)	(-0,5; 28,4)	(5,1; 52,7)	(-15,9; 52,6)	(1,4; 30,9)	(33,0; 29,3)
	(-39,5; 55,5)	(-8,5; 56,0)	(-0,2; 103,9)	(-31,8; 104,1)	(-32,3; 50,2)	(84,1; 52,8)
	(-27,0; 34,3)	(17,0; 29,1)	(7,7; 57,9)	(-19,7; 54,0)	(9,1; 38,2)	(44,1; 27,0)
	(-64,9; 70,6)	(26,6; 58,6)	(19,6; 117,6)	(-51,2; 108,3)	(-0,1; 79,5)	(61,6; 56,0)
H	(-20,4; 27,5)	(9,4; 27,5)	(4,9; 52,1)	(-6,0; 52,2)	(1,2; 30,0)	(43,0; 28,5)
	(-44,3; 54,8)	(29,4; 54,8)	(-4,9; 103,5)	(6,1; 103,5)	(-37,1; 49,4)	(122,1; 51,5)
	(-14,7; 28,6)	(14,9; 28,6)	(19,9; 54,7)	(-21,8; 53,7)	(21,3; 33,2)	(42,0; 26,4)
	(-39,1; 57,4)	(30,5; 57,5)	(45,4; 110,2)	(-47,3; 107,7)	(25,7; 68,0)	(65,6; 54,9)
I	(-13,1; 56,2)	(7,7; 56,2)	(12,1; 71,6)	(-7,7; 71,6)	(8,5; 57,5)	(41,3; 56,7)
	(-23,0; 112,3)	(16,2; 112,3)	(16,3; 142,6)	(-7,1; 142,6)	(-15,8; 109,8)	(108,8; 110,7)
	(-12,6; 56,8)	(5,8; 56,7)	(22,1; 73,5)	(-30,9; 72,7)	(23,4; 59,2)	(33,0; 55,6)
	(-22,8; 113,8)	(15,2; 113,5)	(61,7; 147,6)	(-62,6; 145,5)	(42,0; 119,4)	(50,3; 112,2)

Table A17 - continued: Degrees of equivalence (D_{ij} , $U(D_{ij})$) in mN·m between the corrected values from the participants

	G		H		I	
A	(9,6; 24,6)	(21,4; 24,3)	(9,9; 23,3)	(11,5; 23,2)	(2,6; 54,3)	(13,2; 54,2)
	(27,2; 47,6)	(34,5; 48,2)	(31,9; 46,7)	(-3,5; 46,8)	(10,7; 108,6)	(9,7; 108,6)
	(16,6; 33,7)	(17,0; 28,4)	(4,4; 27,8)	(19,1; 27,8)	(2,2; 56,4)	(28,1; 56,3)
	(45,7; 71,1)	(16,7; 59,2)	(19,9; 58,0)	(12,8; 58,1)	(3,6; 114,1)	(28,1; 113,8)
B	(-1,0; 17,9)	(15,3; 18,1)	(-0,7; 16,2)	(5,3; 16,7)	(-8,0; 51,7)	(7,0; 51,8)
	(-1,4; 33,3)	(39,2; 34,8)	(3,4; 32,1)	(1,3; 32,8)	(-17,9; 103,2)	(14,5; 103,4)
	(27,7; 33,3)	(-20,0; 31,0)	(15,5; 27,3)	(-17,9; 30,5)	(13,4; 56,2)	(-8,8; 57,7)
	(58,2; 72,2)	(-32,2; 67,4)	(32,4; 59,3)	(-36,1; 66,4)	(16,0; 114,7)	(-20,8; 118,2)
C	(18,9; 21,7)	(-6,3; 22,1)	(19,2; 20,3)	(-16,2; 21,0)	(11,9; 53,1)	(-14,5; 53,3)
	(45,5; 41,0)	(-13,9; 42,4)	(50,3; 40,0)	(-51,9; 40,8)	(29,0; 105,9)	(-38,7; 106,2)
	(-12,1; 40,2)	(29,7; 34,4)	(-24,3; 35,5)	(31,8; 33,9)	(-26,4; 60,5)	(40,9; 59,6)
	(-27,4; 87,2)	(61,9; 74,3)	(-53,2; 76,9)	(58,0; 73,4)	(-69,5; 124,7)	(73,3; 122,3)
D	(20,2; 28,6)	(0,5; 28,4)	(20,4; 27,5)	(-9,4; 27,5)	(13,1; 56,2)	(-7,7; 56,2)
	(39,5; 55,5)	(8,5; 56,0)	(44,3; 54,8)	(-29,4; 54,8)	(23,0; 112,3)	(-16,2; 112,3)
	(27,0; 34,3)	(-17,0; 29,1)	(14,7; 28,6)	(-14,9; 28,6)	(12,6; 56,8)	(-5,8; 56,7)
	(64,9; 70,6)	(-26,6; 58,6)	(39,1; 57,4)	(-30,5; 57,5)	(22,8; 113,8)	(-15,2; 113,5)
E	(-5,1; 52,7)	(15,9; 52,6)	(-4,9; 52,1)	(6,0; 52,2)	(-12,1; 71,6)	(7,7; 71,6)
	(0,2; 103,9)	(31,8; 104,1)	(4,9; 103,5)	(-6,1; 103,5)	(-16,3; 142,6)	(7,1; 142,6)
	(-7,7; 57,9)	(19,7; 54,0)	(-19,9; 54,7)	(21,8; 53,7)	(-22,1; 73,5)	(30,9; 72,7)
	(-19,6; 117,6)	(51,2; 108,3)	(-45,4; 110,2)	(47,3; 107,7)	(-61,7; 147,6)	(62,6; 145,5)
F	(-1,4; 30,9)	(-33,0; 29,3)	(-1,2; 30,0)	(-43,0; 28,5)	(-8,5; 57,5)	(-41,3; 56,7)
	(32,3; 50,2)	(-84,1; 52,8)	(37,1; 49,4)	(-122,1; 51,5)	(15,8; 109,8)	(-108,8; 110,7)
	(-9,1; 38,2)	(-44,1; 27,0)	(-21,3; 33,2)	(-42,0; 26,4)	(-23,4; 59,2)	(-33,0; 55,6)
	(0,1; 79,5)	(-61,6; 56,0)	(-25,7; 68,0)	(-65,6; 54,9)	(-42,0; 119,4)	(-50,3; 112,2)
G	TB2, 500 N·m	TB2, 500 N·m	(0,3; 16,8)	(-9,9; 16,4)	(-7,0; 51,8)	(-8,2; 51,7)
	TB2, 1000 N·m	TB2, 1000 N·m	(4,8; 31,9)	(-38,0; 32,8)	(-16,5; 103,1)	(-24,7; 103,4)
	TT1, 500 N·m	TT1, 500 N·m	(-12,2; 24,9)	(2,1; 17,1)	(-14,3; 55,0)	(11,2; 51,9)
	TT1, 1000 N·m	TT1, 1000 N·m	(-25,8; 53,0)	(-3,9; 35,4)	(-42,1; 111,6)	(11,4; 104,1)
H	(-0,3; 16,8)	(9,9; 16,4)	TB2, 500 N·m	TB2, -500 N·m	(-7,3; 51,3)	(1,7; 54,6)
	(-4,8; 31,9)	(38,0; 32,8)	TB2, 1000 N·m	TB2, -1000 N·m	(-21,3; 102,7)	(13,2; 102,7)
	(12,2; 24,9)	(-2,1; 17,1)	TT1, 500 N·m	TT1, -500 N·m	(-2,1; 51,7)	(9,1; 51,9)
	(25,8; 53,0)	(3,9; 35,4)	TT1, 1000 N·m	TT1, -1000 N·m	(-16,3; 103,7)	(15,3; 103,4)
I	(7,0; 51,8)	(8,2; 51,7)	(7,3; 51,3)	(-1,7; 54,6)	TB2, 500 N·m	TB2, -500 N·m
	(16,5; 103,1)	(24,7; 103,4)	(21,3; 102,7)	(-13,2; 102,7)	TB2, 1000 N·m	TB2, -1000 N·m
	(14,3; 55,0)	(-11,2; 51,9)	(2,1; 51,7)	(-9,1; 51,9)	TT1, 500 N·m	TT1, -500 N·m
	(42,1; 111,6)	(-11,4; 104,1)	(16,3; 103,7)	(-15,3; 103,4)	TT1, 1000 N·m	TT1, -1000 N·m