Final Report on the Torque Key Comparison CCM.T-K2
Measurand Torque: 0 kN·m, 10 kN·m, 20 kN·m
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This report includes the following sections:

1. General information about the CCM.T-K2

In March 2004 in Pretoria (South Africa) the CCM force working group, chaired at that time by Prof. Manfred Peters (PTB), decided to carry out CIPM torque key comparisons. Two ranges were agreed – 1 kN·m and 20 kN·m. As pilot laboratory for both inter-comparisons the torque working group of PTB was appointed [1]. This is the report for the 20 kN·m key comparison denoted as CCM.T-K2. Six laboratories - including the pilot – should take part in the key comparison (see table 1).

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Table1: Participants in the CCM.T-K2 torque key comparisons: countries, institutes, code numbers used in the report and machine types

Country (alphabetical order)	Institute (designated institute)	Code letter	Machine type	Expanded relative uncertainty (k = 2)
China	NIM (SMERI)	C	Multi-beam dead-weight machine	5×10^{-4} (k = 3)
Finland	VTT (Lahti Precision Oy, former Raute Precision Oy)	B	Reference machine with torque transducer	5×10^{-4}
France	LNE	F	-	-
Germany	PTB	D	Dead-weight machine	2×10^{-5}
Japan	NMIJ	A	Dead-weight machine	6.57×10^{-5}
Mexico	CENAM	E	Reference machine with torque transducer	9×10^{-5} (10 kN·m) 6×10^{-5} (20 kN·m)

One participant (F) cancelled the participation in the comparison because of a tragic occurrence. The person in charge of the measurements died in a traffic accident. Another participant (E) took part, but the results could not be used for calculating good mean values due to problems with the new and not well investigated machine and its control. It is planned to set-up a subsequent follow-up comparison with participant E when the problems with the machine are solved. Nevertheless, the results of participants E are given in this report, but they have not been used for the calculation of the key comparison reference values in mV/V.

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:

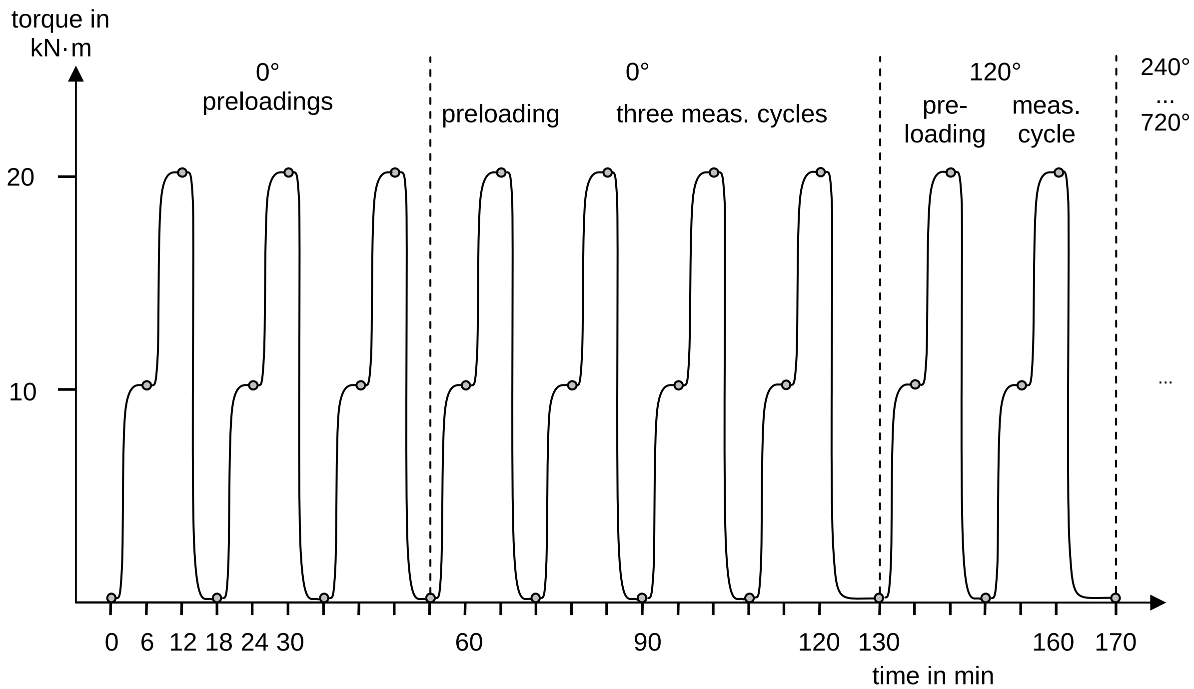

Figure 1 Measurement sequence of the CCM.T-K2

The torque transducer was rotated from 0° to 720° with 120° 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 120° position in figure 1) were carried out, i.e. at transducer positions of 240°, 360°, 480°, 600°, and 720°.

The comparison measurements had to be done with each of two torque transducers. The first transducer is a TB2 torque measuring flange (S/N #112330004) with adaptors at both ends and a nominal capacity of 10 kN·m. It can be used up to 20 kN·m because of it's elastic properties, the output signal at 10 kN·m is only 1 mV/V. The second transducers is a TT1 transducer of shaft type (S/N 37365-04) with a nominal capacity of 20 kN·m. The construction principles of the two transducer types are different, but the mechanical interface is the same – round shafts with 110 mm diameter and a suitable length fitting for an ETP-Hyloc or ETP-T 110 hydraulic coupling. The transducers had been selected for their very good characteristics.

3. Realization of the comparison

For this key comparison a star type formation had been chosen. That means the transducers were returned to the pilot laboratory after the measurement at each participant. The pilot repeated all measurements before sending the instruments to the next participant. One complete measurement cycle (pilot – participating laboratory – pilot) is called a loop. The first measurement carried out by the pilot is called the “D1” measurement, the second measurement by the pilot after the participating laboratory is called the “D2” measurement. In general, a “D2” measurement for one participant is the “D1” measurement for the next participant, if there is one. In the case of a long time span between the measurements at participants, an new “D1” measurement was followed by the preceding “D2” measurement in order to reveal possible drifts of the travelling standards.

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 considered. 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 in the participating laboratories.
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 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 20 kN·m were 2.000 mV/V (TB2) and 1.314 mV/V (TT1). The measurements with the BN100 were carried out with suitably selected voltage ratios near the signals of the transducers for 10 kN·m and 20 kN·m. Therefore, figure 2 shows two lines for positive and two lines for negative voltage ratios for each of the participants.

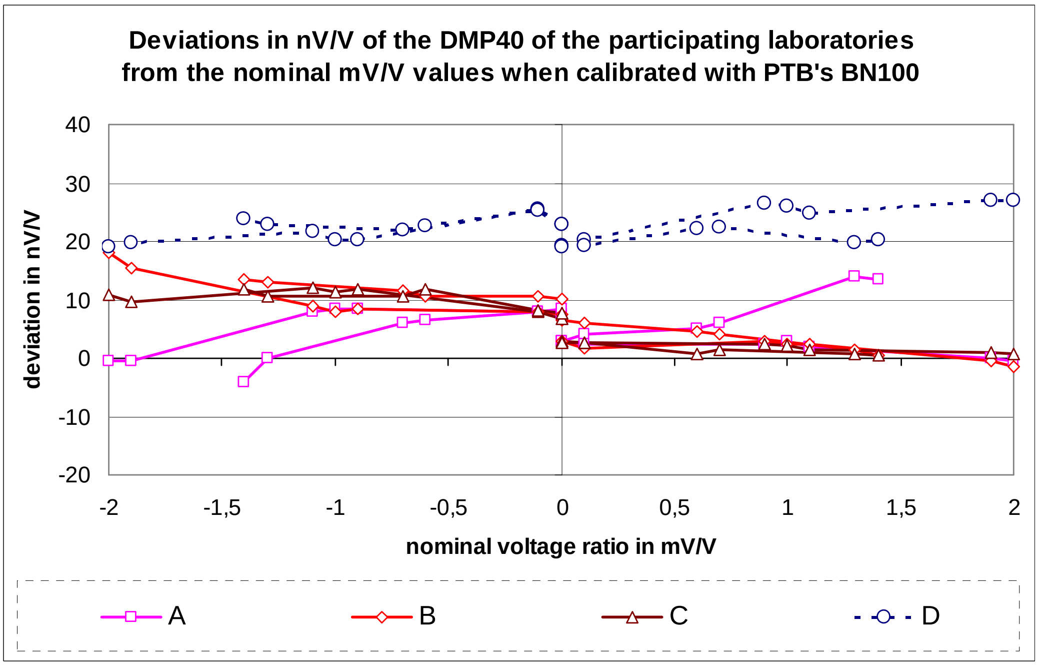

Figure 2 Deviations in nV/V of the DMP40 indication of the participating laboratories from the nominal mV/V values when calibrated with the pilot's BN100 (averaged values from two measurements, for the pilot D averaged over 15 measurements)

These measurements show that there are quite large deviations of up to 28 nV/V between different DMPs. But the measurement result is the difference of two readings, i.e. 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.
Using the values $d_i(V/V_S)$ given in table 2 for each of the participants 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.

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

	nominal voltage ratio in mV/V	relative voltage ratio difference* d_i related to nominal value for lab …			
		… A in ppm	… B in ppm	… C in ppm	… D in ppm
TB2 cw**	1	0.0	-0.5	-0.9	6.8
	2	-1.8	-2.2	-1.1	3.9
TB2 acw**	-1	-1.0	-0.5	-4.5	2.8
	-2	4.0	-5.2	-2.0	2.0
TT1 cw	0.657***	3.9	-3.5	-2.4	4.8
	1.314***	8.3	-3.9	-1.5	0.5
TT1 acw	-0.657***	3.5	-1.6	-5.1	1.1
	-1.314***	6.9	-2.3	-2.4	0.0

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

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. When the mounting position has to be changed, the waiting time is 10 minutes. The creep effect should be small enough then to eliminate the uncertainty of the time of reading for every loading.

Both transducers had a nearly constant creep after approx. 4 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 at 20 kN·m torque. 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 at 20 kN·m

	Relative change of indication due to creep	
Time after start of load application	TB2, S/N #112330004	TT1, S/N 37365-04
4th to 6th minute after applying the load	$6\cdot10^{-6}$	$5\cdot10^{-6}$
5th to 6th minute after applying the load	$2\cdot10^{-6}$	$2\cdot10^{-6}$

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. On the other hand, only the two dead-weight machines of participants A and D have a sufficiently small uncertainty, so that this effect must be considered. The loading times varied from 25 s to 70 s. Table 4 shows the time needed for the torque application (from 0 kN·m to 10 kN·m, respectively from 10 kN·m to 20 kN·m) in the different standard machines of the participants. A long torque application time means that this 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 and correction factors

Participant	Torque application time		Time difference to pilot cw		Correction factor c_i for	
	in s	in min	in s	in min	10 kN·m	20 kN·m
A - clockwise	70	1.17	50	0.83	$1 + 4\cdot10^{-6}$	$1 + 2\cdot10^{-6}$
D - clockwise	20	0.33	-	-	1	1
A - anti-clockwise	70	1.17	40	0.67	$1 + 3\cdot10^{-6}$	$1 + 1.5\cdot10^{-6}$
D - anti-clockwise	30	0.50	-	-	1	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

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. For determining the humidity sensitivity e_{rH} of each transducer, measurements at a 5%rH higher humidity level have been carried out in clockwise direction.

The temperature effect on the sensitivity can also be an important factor if the environmental temperature in the participating laboratory is not the same as that at the pilot. For determining the temperature sensitivity e_T of each transducer, measurements at a 3 K higher temperature level have been carried out in clockwise direction.

The result reported in [4] could in general be confirmed. 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. The temperatures in the participating laboratories were very close to the nominal value and no correction was necessary. The relative humidity however was in a range from 21% to 54%. Therefore, measurements in the pilot laboratory at higher relative humidity were used to calculate the corresponding sensitivities of the transducers for both torque steps according to the procedure described in [4]. The resultant humidity coefficients as well as the corresponding expanded uncertainties are given in table 5.

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

	10 kN·m	20 kN·m	-10 kN·m	-20 kN·m
	Air humidity coefficient and expanded uncertainty (*k* = 2) in (nV/V)/%			
TB2, S/N #112330004	-3.7 ± 8.5	-4.9 ± 14.9	3.7 ± 8.5	4.9 ± 14.9
TT1, S/N 37365-04	-5.9 ± 5.2	-12.3 ± 10.9	5.9 ± 5.2	12.3 ± 10.9

The figures 3 to 5 show the environmental conditions (temperature and humidity of the ambient air) in the participating labs as recorded by the data logger Hobo. These values were not taken to calculate the corrected results in table 10 but the local values were used instead. The Hobo is not a very accurate temperature and humidity measuring instrument in terms of absolute values. But it is stable enough in order to get comparable values in relative terms and it can be used to record the environmental conditions during transportation and measurement. 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.

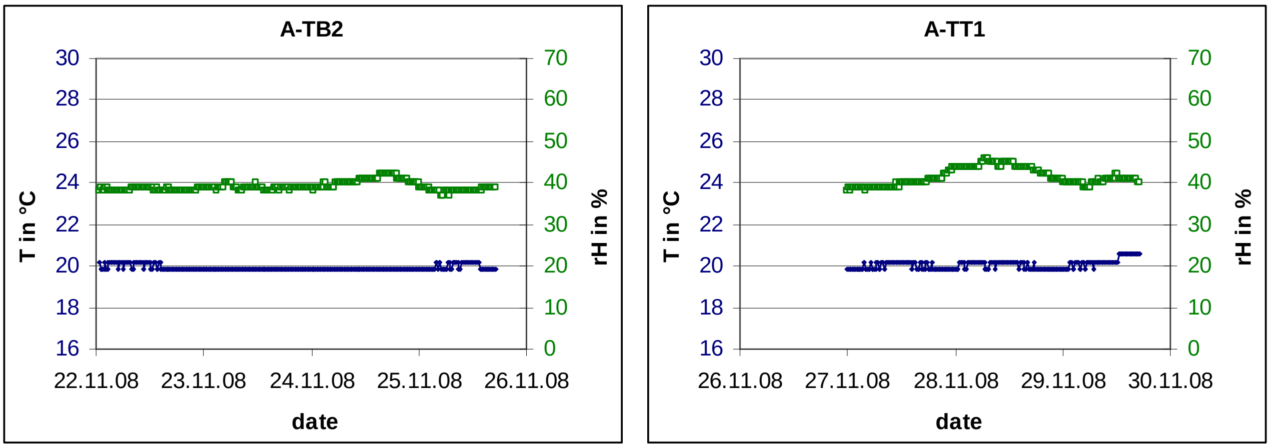

Figure 3 Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant A (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate)

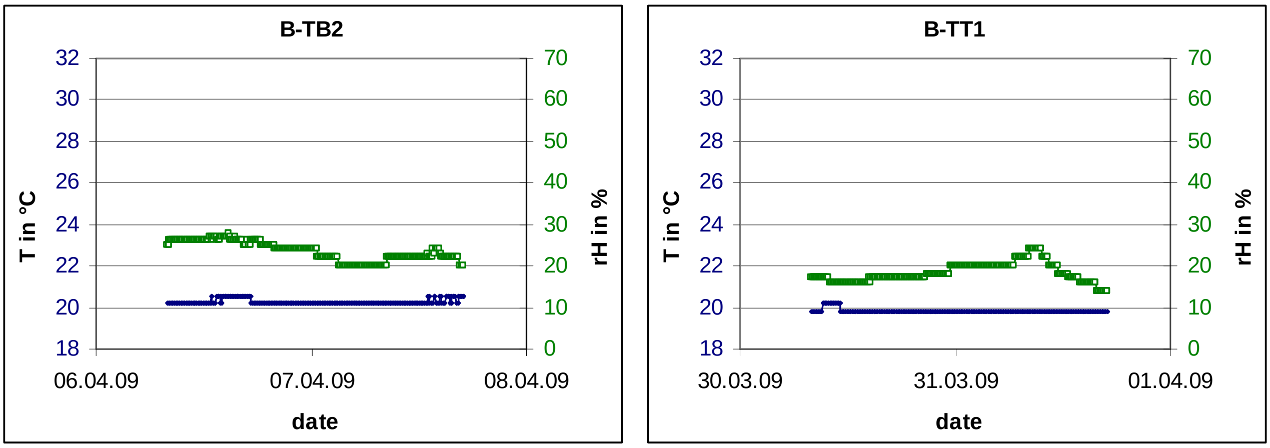

Figure 4 Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant B (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate)

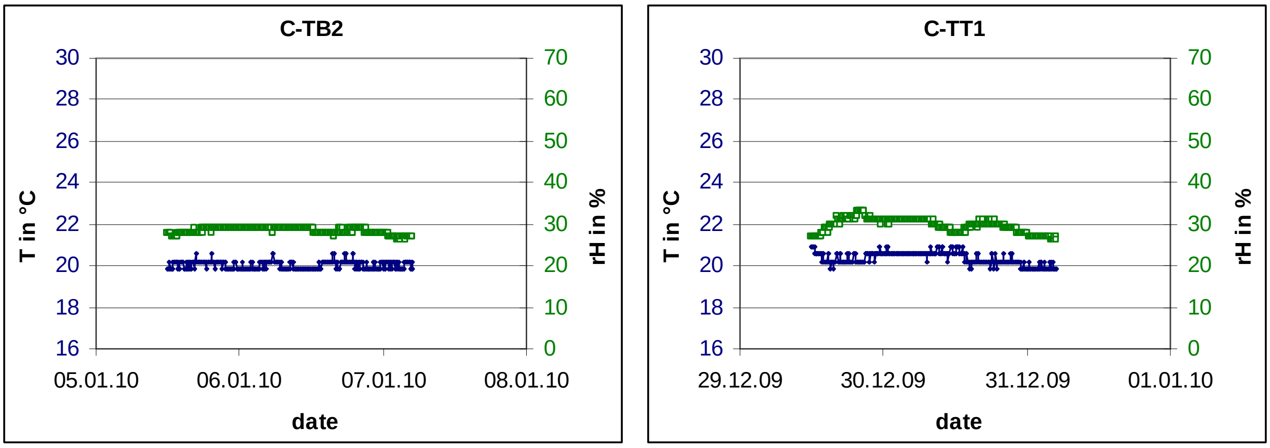

Figure 5 Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant C (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate)

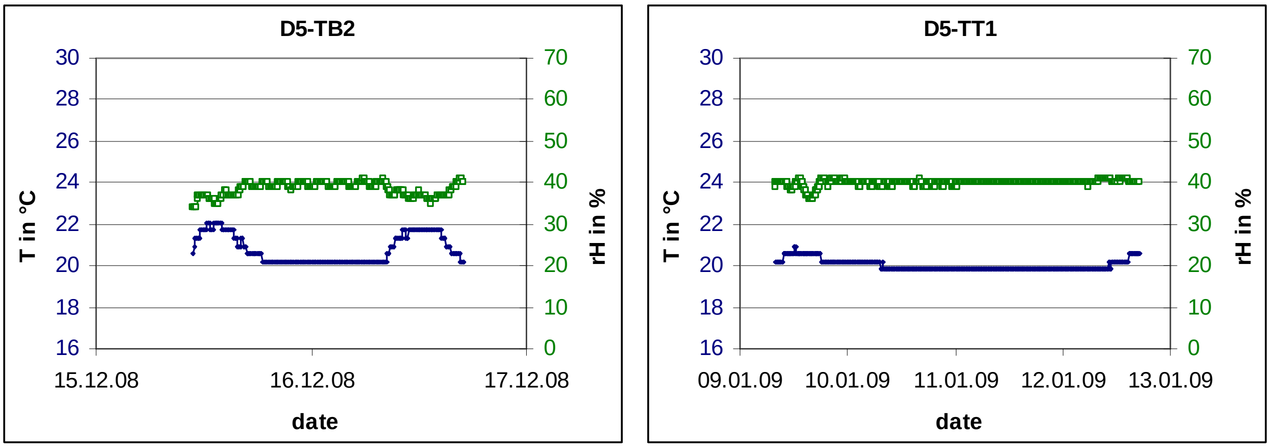

Figure 6 Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant D (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate) for the measuring campaigns D5 to D10 (to be continued)

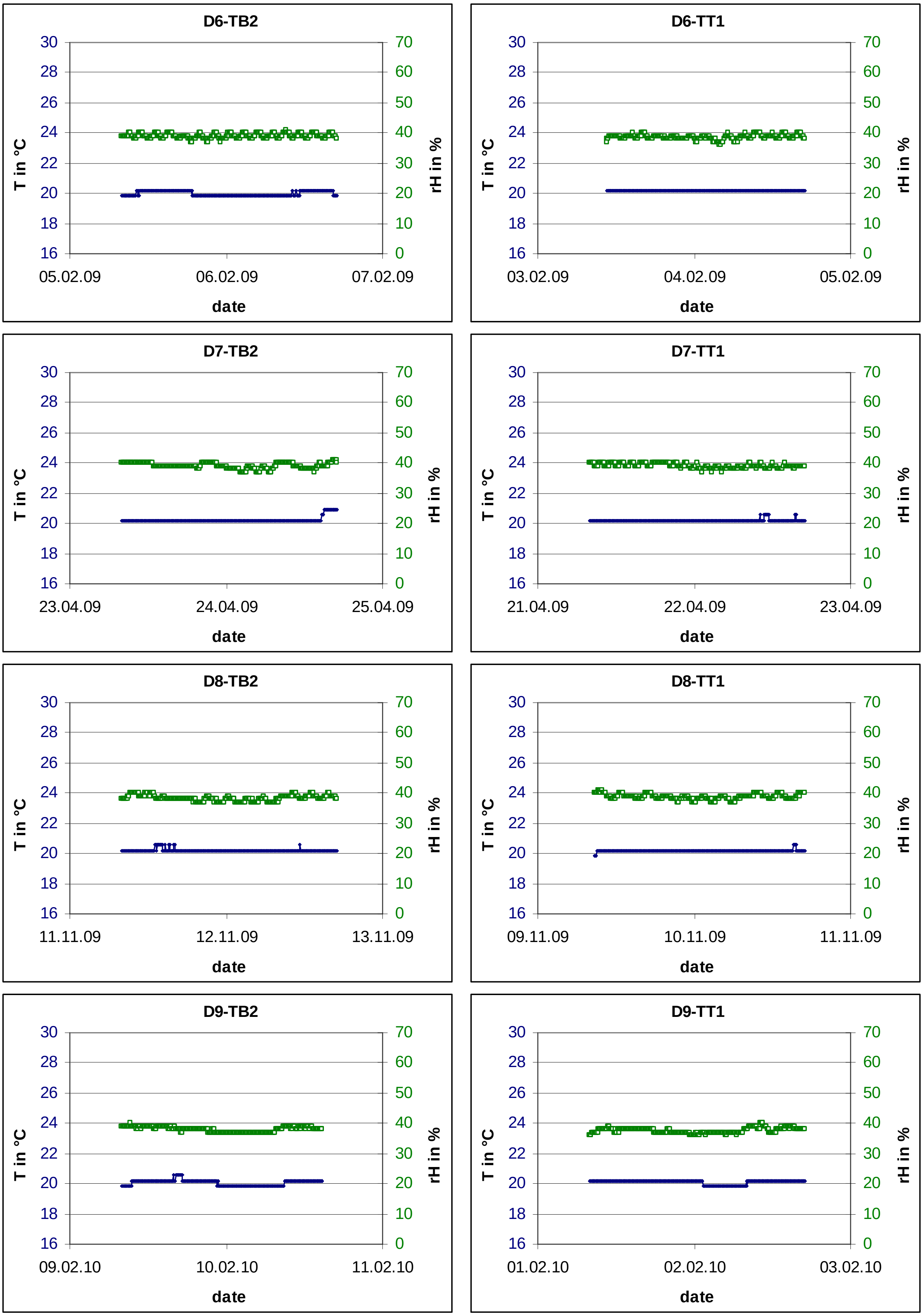

Figure 6 (continued) Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant D (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate) for the measuring campaigns D5 to D10 (to be continued)

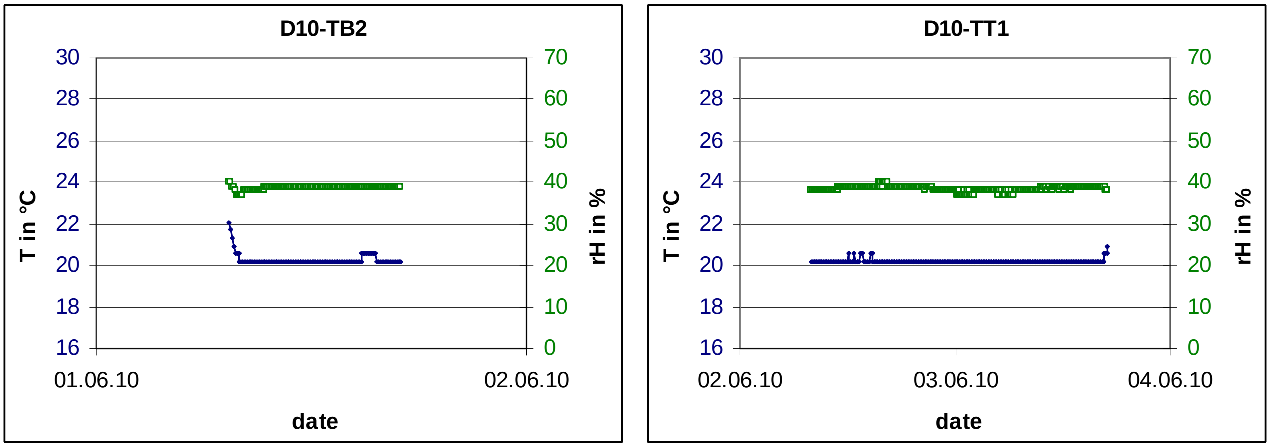

Figure 6 (continued) Environmental conditions during the calibration of the TB2 (left diagram) and the TT1 (right diagram) by participant D (full symbol - temperature on left ordinate, empty symbol - relative humidity on right ordinate) for the measuring campaigns D5 to D10

Using the values e_{rH} given in table 5, for each of the participants the deflections can be corrected taking into account the corresponding deviation ΔrH from the ideal environmental conditions (T = 20°C, rH = 40%) according to (3):

$$Y_i''' = Y_i'' - e_{\mathrm{rH}} \cdot \Delta rH \quad (3)$$

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

<u>Stability of the transfer transducers</u>

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

The chronological order of the calibrations in the pilot and the participating laboratories is given in table 6. 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 7 and 8 show the stability of the transducers over the whole period of the key comparison. It is determined as relative deviations of the resulting deflections for all measurements made by the pilot from their arithmetical mean value. The result of measurement D3 was not used for the further calculations because the humidity deviated from the nominal value by more than 4%. It can be seen that the TT1 transducer has in general higher uncertainty values than the TB2 (it should be taken into account that the scaling in the diagrams is different for both transducers).

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

Measurement	TB2		TT1	
	clockwise	anti-clockwise	clockwise	anti-clockwise
D4	06.10.2008	07.10.2008	08.10.2008	09.10.2008
A	22.11.2008	25.11.2008	27.11.2008	29.11.2008
D5	15.12.2008	16.12.2008	09.01.2009	12.01.2009
D6	05.02.2009	06.02.2009	03.02.2009	04.02.2009
B	06.04.2009	07.04.2009	30.03.2009	31.03.2009
D7	23.04.2009	24.04.2009	21.04.2009	22.04.2009
D8	11.11.2009	12.11.2009	09.11.2009	10.11.2009
C	07.01.2010	06.01.2010	30.12.2009	31.12.2009
D9	09.02.2010	10.02.2010	01.02.2010	02.02.2010
E	15.04.2010	16.04.2010	13.04.2010	14.04.2010
D10	31.05.2010	01.06.2010	02.06.2010	03.06.2010

The results show that the two transducers were not that stable like the two 1 kN·m transducers used in the previous comparison CCM.T-K1. On the other hand, the drift observed did not show a trend, it is probably caused by instabilities due to unknown temperature, humidity or mechanical effects.

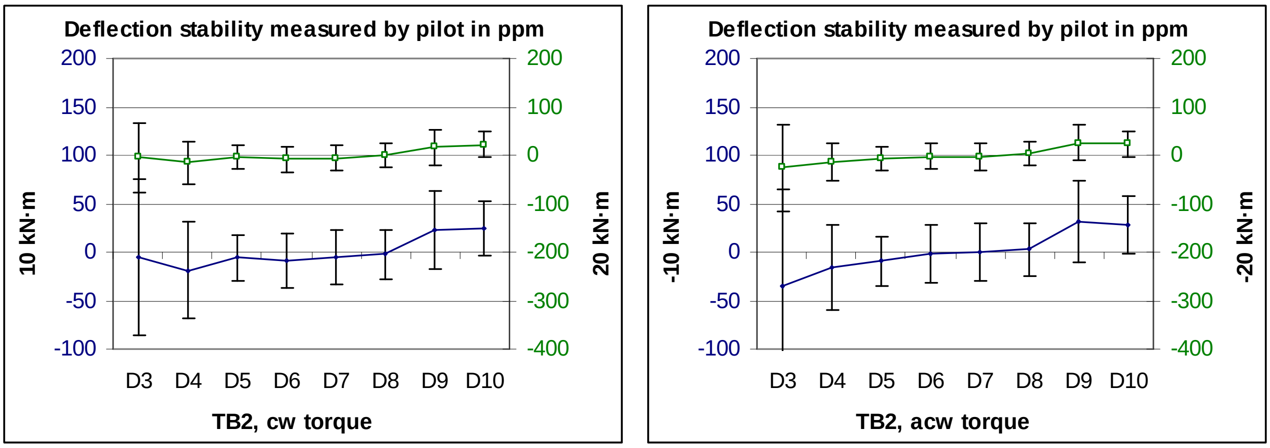

Figure 7 Relative deviations of the deflections for measurements D3 to D10 made by the pilot from their mean values for transducer TB2 with clockwise (left) and anti-clockwise (right) torques and relative expanded (*k* = 2) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity, (full symbol: 10 kN·m on left ordinate, empty symbol: 20 kN·m on right ordinate)

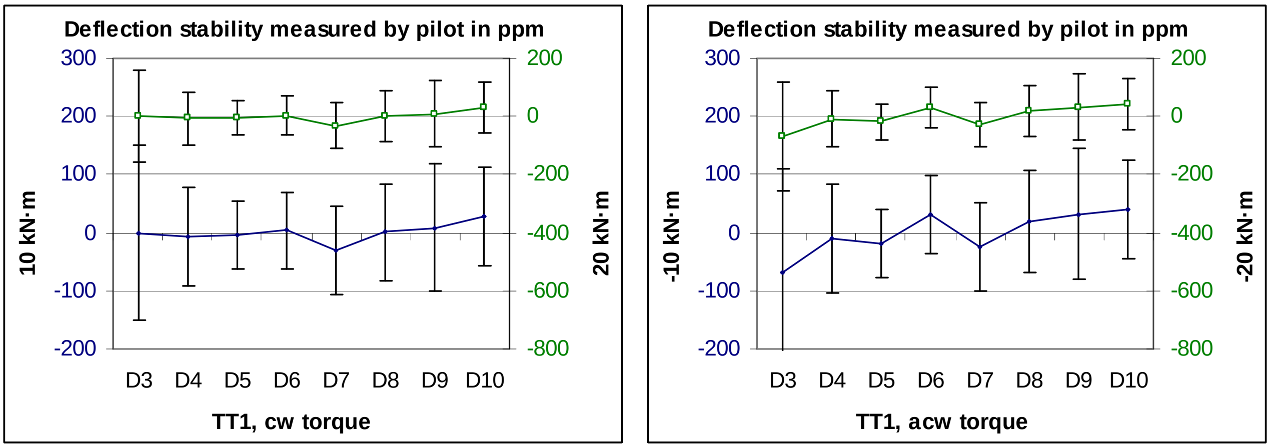

Figure 8 Relative deviations of the deflections for measurements D3 to D10 made by the pilot from their mean values for transducer TT1 with clockwise (left) and anti-clockwise (right) torques and relative expanded (*k* = 2) measurement uncertainties (uncertainty bars), values corrected for the influence of temperature and humidity, (full symbol: 10 kN·m on left ordinate, empty symbol: 20 kN·m on right ordinate)

b) Stability in the loops

The measurements in the pilot laboratory (see figures 7 and 8) demonstrate that the stability of the travelling standards is sufficiently good compared with the measurement uncertainty of the machines to be compared. The deviations from the mean value show a stochastic behaviour. Therefore it was not necessary to use drift corrections for the results from the participants in the different loops. 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 conditions 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 according to 5, equation (1), additionally
- corrections for the creep influence due to different loading regimes in the machines according to 6 (section “Creep effect”), equation (2), and - also in addition -
- corrections for the environmental conditions according to 6 (section “Humidity and temperature influences on the sensitivity”) , equation (3).

The pilot reports the arithmetical mean of the measurements D4 to D10 made in this laboratory and the arithmetical mean of the corresponding corrected values.

The calculation of the weighted means and the key comparison reference values (KCRV) as well as the χ^2 tests are 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:

$Y_{\text{P-Rep}}$ (= Y_i) Deflection reported by participant P (for the pilot: mean of all measurements), in mV/V

$Y_{\text{P-DMP}}$ (= Y_i') Deflection for participant P, corrected for the influence of the DMP40, in mV/V

$Y_{\text{P-Creep}}$ (= Y_i'') Deflection for participant P, additionally corrected for the creep influence, in mV/V

$Y_{\text{P-Envir}}$ (= Y_i''') Deflection for participant P, additionally corrected for the environmental influence, in mV/V

$W_{\text{P-Rep}}$ = Expanded relative uncertainty (k = 2) of $Y_{\text{P-Rep}}$ (for the pilot: mean of all measurements)

$W_{\text{P-DMP}}$ = Expanded relative uncertainty (k = 2) of $Y_{\text{P-DMP}}$

$W_{\text{P-Creep}}$ = Expanded relative uncertainty (k = 2) of $Y_{\text{P-Creep}}$

$W_{\text{P-Envir}}$ = Expanded relative uncertainty (k = 2) of $Y_{\text{P-Envir}}$

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

$$W_{\text{P-Rep}} = 2 \cdot w_{\text{P-Rep}} = 2 \cdot \sqrt{w_{\text{Repeat}}^2 + w_{\text{Reprod}}^2 + 2 \cdot w_{\text{Ind}}^2 + w_{\text{TSM}}^2} \tag{4}$$

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

$$W_{\text{P-Creep}} = 2 \cdot w_{\text{P-Creep}} = 2 \cdot \sqrt{w_{\text{P-DMP}}^2 + w_{\text{Creep}}^2} \tag{6}$$

$$W_{\text{P-Envir}} = 2 \cdot w_{\text{P-Envir}} = 2 \cdot \sqrt{w_{\text{P-Creep}}^2 + w_{\text{Envir}}^2} \tag{7}$$

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 six runs 4 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 creep correction w_{Creep}, calculated applying the GUM procedure to equation (2), and
- the uncertainty contribution of the correction for environmental deviations w_{Envir}, calculated applying the GUM procedure to equation (3).

Table 7: Uncorrected deflections in mV/V and expanded relative uncertainties (k = 2) as reported by the participants

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	10 kN·m		20 kN·m		10 kN·m		20 kN·m	
	$Y_{\text{P-Rep}}$	$W_{\text{P-Rep}}$	$Y_{\text{P-Rep}}$	$W_{\text{P-Rep}}$	$Y_{\text{P-Rep}}$	$W_{\text{P-Rep}}$	$Y_{\text{P-Rep}}$	$W_{\text{P-Rep}}$
A	1.000664	$6.6 \cdot 10^{-5}$	2.001629	$6.6 \cdot 10^{-5}$	0.656912	$6.7 \cdot 10^{-5}$	1.313948	$6.7 \cdot 10^{-5}$
B	1.000691	$5.0 \cdot 10^{-4}$	2.001650	$5.0 \cdot 10^{-4}$	0.656912	$5.0 \cdot 10^{-4}$	1.313923	$5.0 \cdot 10^{-4}$
C	1.000486	$3.3 \cdot 10^{-4}$	2.001127	$3.3 \cdot 10^{-4}$	0.656837	$3.4 \cdot 10^{-4}$	1.313691	$3.4 \cdot 10^{-4}$
D	1.000615	$2.0 \cdot 10^{-5}$	2.001525	$2.0 \cdot 10^{-5}$	0.656859	$2.2 \cdot 10^{-5}$	1.313827	$2.3 \cdot 10^{-5}$
E	0.998515	$1.2 \cdot 10^{-4}$	1.999877	$1.1 \cdot 10^{-4}$	0.655964	$1.3 \cdot 10^{-4}$	1.313593	$1.3 \cdot 10^{-4}$

Table 7 (continued):

Participant	TB2 - anti-clockwise torque				TT1 – anti-clockwise torque			
	-10 kN·m		-20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$Y_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$Y_{P\text{-}Rep}$	$W_{P\text{-}Rep}$	$Y_{P\text{-}Rep}$	$W_{P\text{-}Rep}$
A	-1.000689	$6.6\cdot10^{-5}$	-2.001711	$6.6\cdot10^{-5}$	-0.656897	$6.7\cdot10^{-5}$	-1.313905	$6.7\cdot10^{-5}$
B	-1.000512	$5.1\cdot10^{-4}$	-2.001326	$5.1\cdot10^{-4}$	-0.656897	$5.0\cdot10^{-4}$	-1.313883	$5.0\cdot10^{-4}$
C	-1.000445	$3.4\cdot10^{-4}$	-2.001209	$3.4\cdot10^{-4}$	-0.656818	$3.3\cdot10^{-4}$	-1.313705	$3.3\cdot10^{-4}$
D	-1.000638	$2.0\cdot10^{-5}$	-2.001603	$2.0\cdot10^{-5}$	-0.656854	$2.1\cdot10^{-5}$	-1.313807	$2.2\cdot10^{-5}$
E	-0.999101	$1.4\cdot10^{-4}$	-2.000921	$1.4\cdot10^{-4}$	-0.656134	$1.3\cdot10^{-4}$	-1.313677	$1.3\cdot10^{-4}$

Table 8: Deflections from table 7 in mV/V, corrected for the influence of the DMP40, and corresponding expanded relative uncertainties (k = 2)

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	10 kN·m		20 kN·m		10 kN·m		20 kN·m	
	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
A	1.000664	$6.6\cdot10^{-5}$	2.001633	$6.6\cdot10^{-5}$	0.656909	$6.7\cdot10^{-5}$	1.313937	$6.7\cdot10^{-5}$
B	1.000692	$5.0\cdot10^{-4}$	2.001654	$5.0\cdot10^{-4}$	0.656915	$5.0\cdot10^{-4}$	1.313929	$5.0\cdot10^{-4}$
C	1.000487	$3.3\cdot10^{-4}$	2.001130	$3.3\cdot10^{-4}$	0.656839	$3.4\cdot10^{-4}$	1.313693	$3.4\cdot10^{-4}$
D	1.000609	$2.1\cdot10^{-5}$	2.001517	$2.2\cdot10^{-5}$	0.656855	$2.2\cdot10^{-5}$	1.313826	$2.3\cdot10^{-5}$
E	0.998521	$1.2\cdot10^{-4}$	1.999884	$1.1\cdot10^{-4}$	0.655960	$1.3\cdot10^{-4}$	1.313593	$1.3\cdot10^{-4}$
Participant	TB2 - anti-clockwise torque				TT1 – anti-clockwise torque			
	-10 kN·m		-20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$	$Y_{P\text{-}DMP}$	$W_{P\text{-}DMP}$
A	-1.000690	$6.6\cdot10^{-5}$	-2.001703	$6.6\cdot10^{-5}$	-0.656895	$6.7\cdot10^{-5}$	-1.313896	$6.7\cdot10^{-5}$
B	-1.000512	$5.1\cdot10^{-4}$	-2.001337	$5.1\cdot10^{-4}$	-0.656898	$5.0\cdot10^{-4}$	-1.313886	$5.0\cdot10^{-4}$
C	-1.000450	$3.4\cdot10^{-4}$	-2.001213	$3.4\cdot10^{-4}$	-0.656821	$3.3\cdot10^{-4}$	-1.313708	$3.3\cdot10^{-4}$
D	-1.000635	$2.1\cdot10^{-5}$	-2.001599	$2.2\cdot10^{-5}$	-0.656854	$2.1\cdot10^{-5}$	-1.313807	$2.2\cdot10^{-5}$
E	-0.999057	$1.4\cdot10^{-4}$	-2.000919	$1.4\cdot10^{-4}$	-0.656138	$1.3\cdot10^{-4}$	-1.313685	$1.3\cdot10^{-4}$

Table 9: Deflections from table 8 in mV/V, additionally corrected for the influence of the creep, and corresponding expanded relative uncertainties (k = 2)

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	10 kN·m		20 kN·m		10 kN·m		20 kN·m	
	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$
A	1.000668	$6.7\cdot10^{-5}$	2.001637	$6.7\cdot10^{-5}$	0.656912	$6.7\cdot10^{-5}$	1.313939	$6.7\cdot10^{-5}$
B	1.000692	$5.0\cdot10^{-4}$	2.001654	$5.0\cdot10^{-4}$	0.656915	$5.0\cdot10^{-4}$	1.313929	$5.0\cdot10^{-4}$
C	1.000487	$3.3\cdot10^{-4}$	2.001130	$3.3\cdot10^{-4}$	0.656839	$3.4\cdot10^{-4}$	1.313693	$3.4\cdot10^{-4}$
D	1.000609	$2.1\cdot10^{-5}$	2.001517	$2.2\cdot10^{-5}$	0.656855	$2.2\cdot10^{-5}$	1.313826	$2.3\cdot10^{-5}$
E	0.998521	$1.2\cdot10^{-4}$	1.999884	$1.1\cdot10^{-4}$	0.655960	$1.3\cdot10^{-4}$	1.313593	$1.3\cdot10^{-4}$
Participant	TB2 - anti-clockwise torque				TT1 – anti-clockwise torque			
	-10 kN·m		-20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$	$Y_{P\text{-}Creep}$	$W_{P\text{-}Creep}$
A	-1.000693	$6.7\cdot10^{-5}$	-2.001706	$6.7\cdot10^{-5}$	-0.656897	$6.7\cdot10^{-5}$	-1.313898	$6.7\cdot10^{-5}$
B	-1.000512	$5.1\cdot10^{-4}$	-2.001337	$5.1\cdot10^{-4}$	-0.656898	$5.0\cdot10^{-4}$	-1.313886	$5.0\cdot10^{-4}$
C	-1.000450	$3.4\cdot10^{-4}$	-2.001213	$3.4\cdot10^{-4}$	-0.656821	$3.3\cdot10^{-4}$	-1.313708	$3.3\cdot10^{-4}$
D	-1.000635	$2.1\cdot10^{-5}$	-2.001599	$2.2\cdot10^{-5}$	-0.656854	$2.1\cdot10^{-5}$	-1.313807	$2.2\cdot10^{-5}$
E	-0.999057	$1.4\cdot10^{-4}$	-2.000919	$1.4\cdot10^{-4}$	-0.656138	$1.3\cdot10^{-4}$	-1.313685	$1.3\cdot10^{-4}$

Table 10: Deflections from table 9 in mV/V, additionally corrected for the influence of the environment, and corresponding expanded relative uncertainties (k = 2)

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	10 kN·m		20 kN·m		10 kN·m		20 kN·m	
	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
A	1.000669	$6.8 \cdot 10^{-5}$	2.001639	$6.7 \cdot 10^{-5}$	0.656920	$7.3 \cdot 10^{-5}$	1.313956	$7.3 \cdot 10^{-5}$
B	1.000651	$5.3 \cdot 10^{-4}$	2.001601	$5.3 \cdot 10^{-4}$	0.656814	$5.7 \cdot 10^{-4}$	1.313718	$5.8 \cdot 10^{-4}$
C	1.000459	$3.6 \cdot 10^{-4}$	2.001092	$3.5 \cdot 10^{-4}$	0.656809	$3.4 \cdot 10^{-4}$	1.313631	$3.5 \cdot 10^{-4}$
D	1.000613	$4.1 \cdot 10^{-5}$	2.001522	$3.8 \cdot 10^{-5}$	0.656862	$4.3 \cdot 10^{-5}$	1.313840	$4.6 \cdot 10^{-5}$
E	0.998546	$1.6 \cdot 10^{-4}$	1.999918	$1.5 \cdot 10^{-4}$	0.656042	$2.5 \cdot 10^{-4}$	1.313762	$2.6 \cdot 10^{-4}$
Participant	TB2 - anti-clockwise torque				TT1 – anti-clockwise torque			
	-10 kN·m		-20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$	$Y_{\text{P-Envir}}$	$W_{\text{P-Envir}}$
A	-1.000694	$6.7 \cdot 10^{-5}$	-2.001708	$6.7 \cdot 10^{-5}$	-0.656887	$7.4 \cdot 10^{-5}$	-1.313877	$7.5 \cdot 10^{-5}$
B	-1.000461	$5.6 \cdot 10^{-4}$	-2.001270	$5.5 \cdot 10^{-4}$	-0.657008	$5.8 \cdot 10^{-4}$	-1.314115	$5.9 \cdot 10^{-4}$
C	-1.000421	$3.6 \cdot 10^{-4}$	-2.001175	$3.6 \cdot 10^{-4}$	-0.656857	$3.5 \cdot 10^{-4}$	-1.313784	$3.5 \cdot 10^{-4}$
D	-1.000639	$4.5 \cdot 10^{-5}$	-2.001603	$4.1 \cdot 10^{-5}$	-0.656834	$4.4 \cdot 10^{-5}$	-1.313768	$4.7 \cdot 10^{-5}$
E	-0.999087	$2.0 \cdot 10^{-4}$	-2.000958	$1.9 \cdot 10^{-4}$	-0.656112	$1.5 \cdot 10^{-4}$	-1.313630	$1.5 \cdot 10^{-4}$

8. Summary

The results of the measurements (deflections and uncertainties) reported by the participants of the CIPM key comparison CCM.T-K2 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 calculation of the key 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*, Key comparisons in the field of torque measurement, Presentation and Paper at the 19th International IMEKO TC3 Conference on Force, Mass and Torque, February 19-23, 2005, Cairo/Egypt, on Proceedings-CD file \pdf\36.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

[4] *D. Röske*, Final report on the torque key comparison CCM.T-K1. Measurand torque: 0 N·m, 500 N·m, 1000 N·m, Metrologia: 46 (2009), Tech. Suppl., 07002 [Online only], 32 p.

ANNEX to the Final Report on the Torque Key Comparison CCM.T-K2
Measurand Torque: 0 kN·m, 10 kN·m, 20 kN·m

The results of participant E have not bend used in the following calculations.

A.1 Correlations

For the calculation of the comparison reference value, correlations must be considered between MIKES and PTB because the torque transducer that is used as torque reference transducer in the 20 kN·m of MIKES was calibrated in the 20 kN·m machine of PTB. Both machines were also used for the calibrations within this comparison.

An analysis of the uncertainties (see Table 10) shows, that the uncertainties of the results of MIKES are in all cases more than one order of magnitude higher than the corresponding value of PTB. It was proved that the uncertainty of the weighted mean did not change significantly after the correlation was taken into account. Furthermore, it was proved that the uncertainty of the weighted mean is in all cases not lower than the lowest uncertainty of the applied torques. Therefore, the correlation was neglected in the calculations.

A.2 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].
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.

Table A11: Results of a χ^2 test on the corrected clockwise values from all participants, except participant E (ν = degrees of freedom = number of considered participants - 1)

	TB2 - clockwise torque		TT1 - clockwise torque	
	10 kN·m	20 kN·m	10 kN·m	20 kN·m
χ^2_{obs}	2.93	3.97	3.16	3.99
ν	3	3	3	3
$\chi^2(\nu)$, P = 0,05	7.81	7.81	7.81	7.81
Result	**Test passed**	**Test passed**	**Test passed**	**Test passed**

For all clockwise measurements the values passed the χ^2 test, therefore the corrected values were considered to be consistent and the weighted means were taken as the key comparison reference values for clockwise torque.
For the anti-clockwise torque, the results shown in table A12 were obtained.

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

	TB2 - anti-clockwise torque		TT1 - anti-clockwise torque	
	-10 kN·m	-20 kN·m	-10 kN·m	-20 kN·m
χ^2_{obs}	4.00	3.81	2.49	2.49
ν	3	3	3	3
$\chi^2(\nu)$, P = 0,05	7.81	7.81	7.81	7.81
Result	**Test passed**	**Test passed**	**Test passed**	**Test passed**

For all anti-clockwise measurements the values passed the χ^2 test, therefore the corrected values were considered to be consistent and the weighted means were taken as the key comparison reference values for anti-clockwise torque.
All calculated "mV/V" key comparison reference values ($KCRV_{mV/V}$) x'_{ref} and their corresponding uncertainties $u(x'_{ref})$ are given in table A13.

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

	TB2 clockwise		TB2 anti-clockwise		TT1 clockwise		TT1 anti-clockwise	
	x'_{ref} in mV/V	$u(x'_{ref})$ in nV/V	x'_{ref} in mV/V	$u(x'_{ref})$ in nV/V	x'_{ref} in mV/V	$u(x'_{ref})$ in nV/V	x'_{ref} in mV/V	$u(x'_{ref})$ in nV/V
10 kN·m	1.0006264	17.4	-1.0006524	18.6	0.6568664	18.4	-0.6568706	18.5
20 kN·m	2.0015468	32.8	-2.0016264	35.0	1.3138357	37.8	-1.3138425	37.6

A.3 Relative deviations of the results from the key 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 A13 the round torque values in N·m were taken as the KCRVs x_{ref}. The assigned uncertainties $u(x_{ref})$ were calculated from the relation

$$u(x_{ref}) = \frac{x_{ref}}{x'_{ref}} \cdot u(x'_{ref}) \,. \qquad (8)$$

They are given in N·m in table A14.

Table A14: Key comparison reference values x_{ref} and corresponding standard uncertainties $u(x_{ref})$

	TB2 clockwise		TB2 anti-clockwise		TT1 clockwise		TT1 anti-clockwise	
	x_{ref} in kN·m	$u(x_{ref})$ in N·m	x_{ref} in kN·m	$u(x_{ref})$ in N·m	x_{ref} in kN·m	$u(x_{ref})$ in N·m	x_{ref} in kN·m	$u(x_{ref})$ in N·m
10 kN·m	10.0000	0.2	-10.0000	0.2	10.0000	0.3	-10.0000	0.3
20 kN·m	20.0000	0.3	-20.0000	0.3	20.0000	0.6	-20.0000	0.6

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

$$Y_{\text{P-N·m}} = \frac{x_{ref}}{x'_{ref}} \cdot Y_{\text{P-Envir}} \,. \qquad (9)$$

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

Table A15: Deflections from table 10 converted to torque units in kN·m and corresponding expanded relative uncertainties (k = 2), (* result not used for the KCRV calculation)

Participant	TB2 - clockwise torque				TT1 - clockwise torque			
	10 kN·m		20 kN·m		10 kN·m		20 kN·m	
	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$
A	10.0004	$6.8 \cdot 10^{-5}$	20.0009	$6.7 \cdot 10^{-5}$	10.0004	$7.3 \cdot 10^{-5}$	20.0008	$7.3 \cdot 10^{-5}$
B	10.0003	$5.3 \cdot 10^{-4}$	20.0006	$5.3 \cdot 10^{-4}$	9.9988	$5.7 \cdot 10^{-4}$	19.9971	$5.8 \cdot 10^{-4}$
C	9.9983	$3.6 \cdot 10^{-4}$	19.9955	$3.5 \cdot 10^{-4}$	9.9987	$3.4 \cdot 10^{-4}$	19.9958	$3.5 \cdot 10^{-4}$
D	9.9999	$4.1 \cdot 10^{-5}$	19.9998	$3.8 \cdot 10^{-5}$	9.9995	$4.3 \cdot 10^{-5}$	19.9990	$4.6 \cdot 10^{-5}$
E*	9.9792	$1.6 \cdot 10^{-4}$	19.9837	$1.5 \cdot 10^{-4}$	9.9870	$2.5 \cdot 10^{-4}$	19.9979	$2.6 \cdot 10^{-4}$
Participant	TB2 - anti-clockwise torque				TT1 - anti-clockwise torque			
	-10 kN·m		-20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$
A	-10.0005	$6.7 \cdot 10^{-5}$	-20.0010	$6.7 \cdot 10^{-5}$	-10.0003	$7.4 \cdot 10^{-5}$	-20.0005	$7.5 \cdot 10^{-5}$
B	-9.9993	$5.6 \cdot 10^{-4}$	-19.9980	$5.5 \cdot 10^{-4}$	-10.0021	$5.8 \cdot 10^{-4}$	-20.0042	$5.9 \cdot 10^{-4}$
C	-9.9984	$3.6 \cdot 10^{-4}$	-19.9965	$3.6 \cdot 10^{-4}$	-9.9998	$3.5 \cdot 10^{-4}$	-19.9991	$3.5 \cdot 10^{-4}$
D	-9.9998	$4.5 \cdot 10^{-5}$	-19.9998	$4.1 \cdot 10^{-5}$	-9.9995	$4.4 \cdot 10^{-5}$	-19.9989	$4.7 \cdot 10^{-5}$
E*	-9.9844	$2.0 \cdot 10^{-4}$	-19.9933	$1.9 \cdot 10^{-4}$	-9.9885	$1.5 \cdot 10^{-4}$	-19.9969	$1.5 \cdot 10^{-4}$

At the end, the deflections of the two transducers in kN·m obtained for the same torque were merged together by calculating their weighted mean. The results are given in table A16.

Table A16: Merged deflections in kN·m from table A15 (weighted mean) and corresponding expanded relative uncertainties (k = 2), (* result not used for the KCRV calculation)

Participant	10 kN·m		20 kN·m		-10 kN·m		-20 kN·m	
	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$	$Y_{\text{P-N·m}}$	$W_{\text{P-N·m}}$
A	10.0004	$6.8 \cdot 10^{-5}$	20.0009	$6.8 \cdot 10^{-5}$	-10.0004	$6.8 \cdot 10^{-5}$	-20.0008	$6.8 \cdot 10^{-5}$
B	9.9996	$5.2 \cdot 10^{-4}$	19.9990	$5.2 \cdot 10^{-4}$	-10.0001	$5.3 \cdot 10^{-4}$	-20.0001	$5.3 \cdot 10^{-4}$
C	9.9985	$3.4 \cdot 10^{-4}$	19.9957	$3.4 \cdot 10^{-4}$	-9.9988	$3.4 \cdot 10^{-4}$	-19.9974	$3.4 \cdot 10^{-4}$
D	9.9998	$3.9 \cdot 10^{-5}$	19.9997	$3.6 \cdot 10^{-5}$	-9.9998	$4.2 \cdot 10^{-5}$	-19.9996	$3.9 \cdot 10^{-5}$
E*	9.9816	$1.5 \cdot 10^{-4}$	19.9873	$1.4 \cdot 10^{-4}$	-9.9870	$1.3 \cdot 10^{-4}$	-19.9955	$1.2 \cdot 10^{-4}$

It was proved that the uncertainty of the weighted mean is in all cases not lower than the lowest uncertainty of the applied torques.
The figures A9 to A12 show the resulting deviations from these KCRVs and their uncertainties.

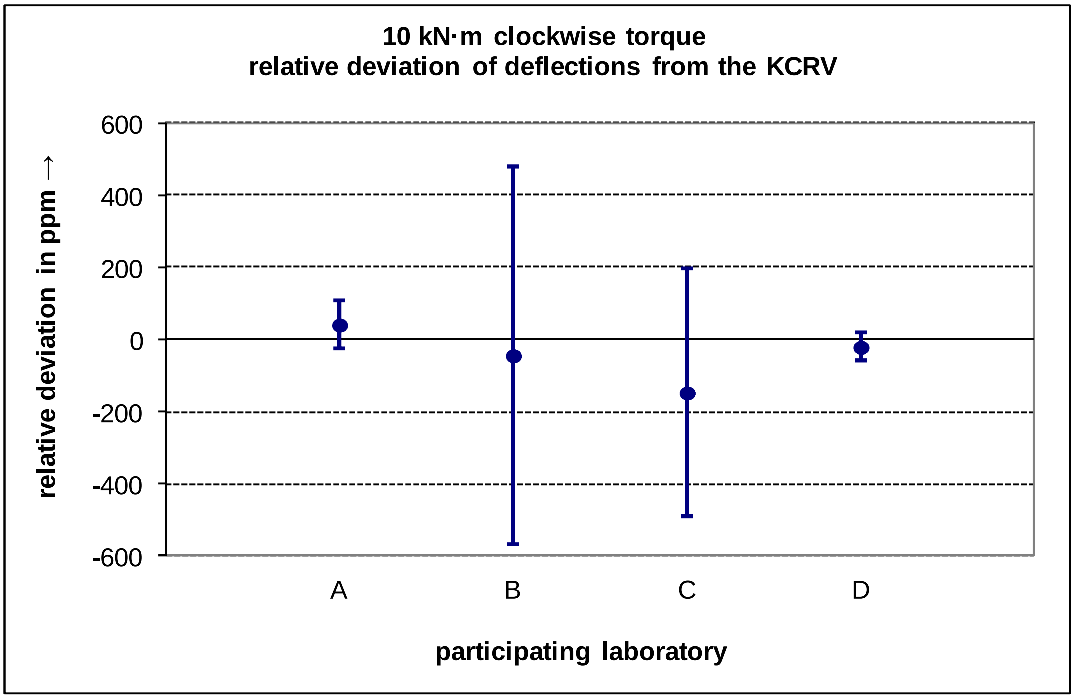

Figure A9 Relative deviations of the corrected and merged deflections for the participating laboratories (except participant E) from the KCRV for 10 kN·m clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

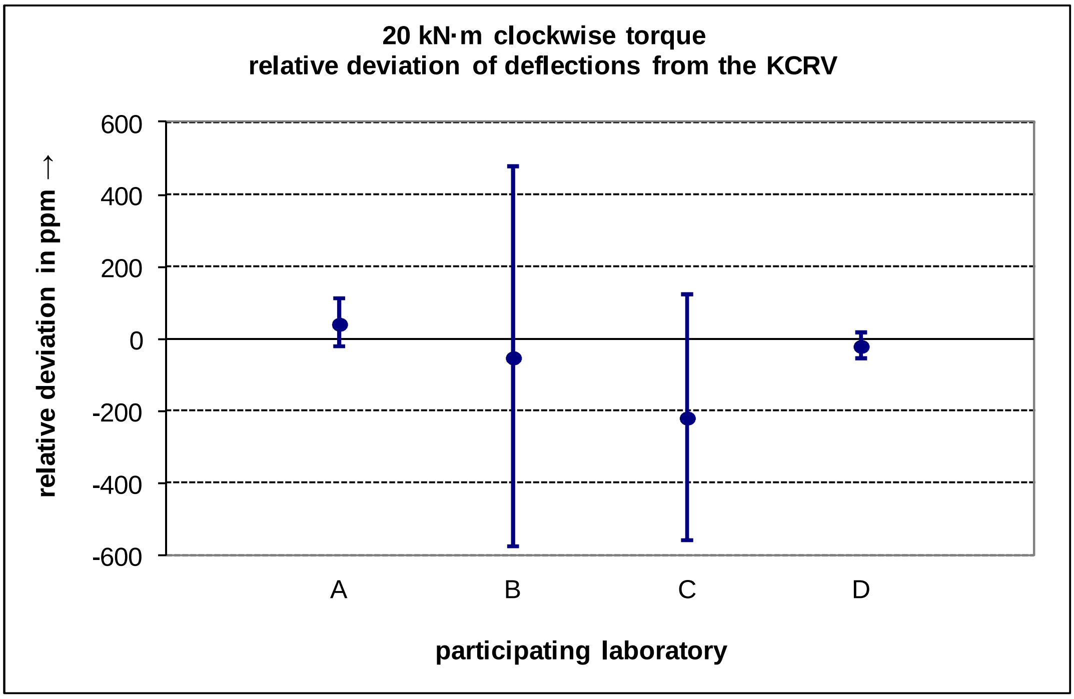

Figure A10 Relative deviations of the corrected and merged deflections for the participating laboratories (except participant E) from the KCRV for 20 kN·m clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

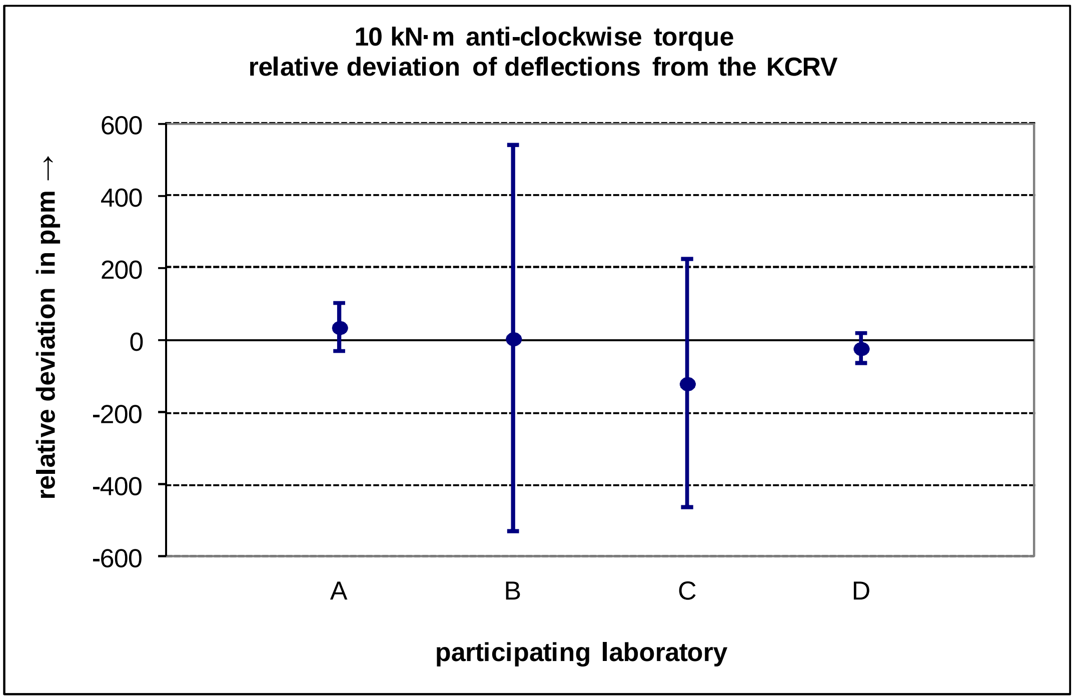

Figure A11 Relative deviations of the corrected and merged deflections for the participating laboratories (except participant E) from the KCRV for 10 kN·m anti-clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

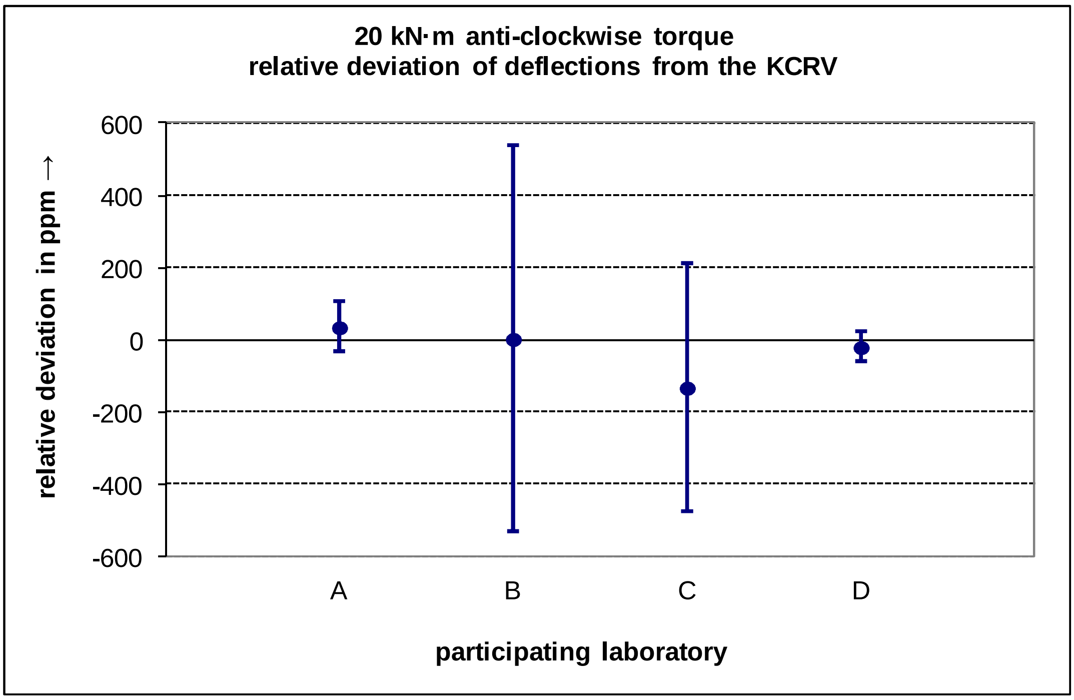

Figure A12 Relative deviations of the corrected and merged deflections for the participating laboratories (except participant E) from the KCRV for 20 kN·m anti-clockwise torque and relative expanded (k = 2) measurement uncertainties (uncertainty bars)

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 A13 to A16 show the results, the values are given in table A17.

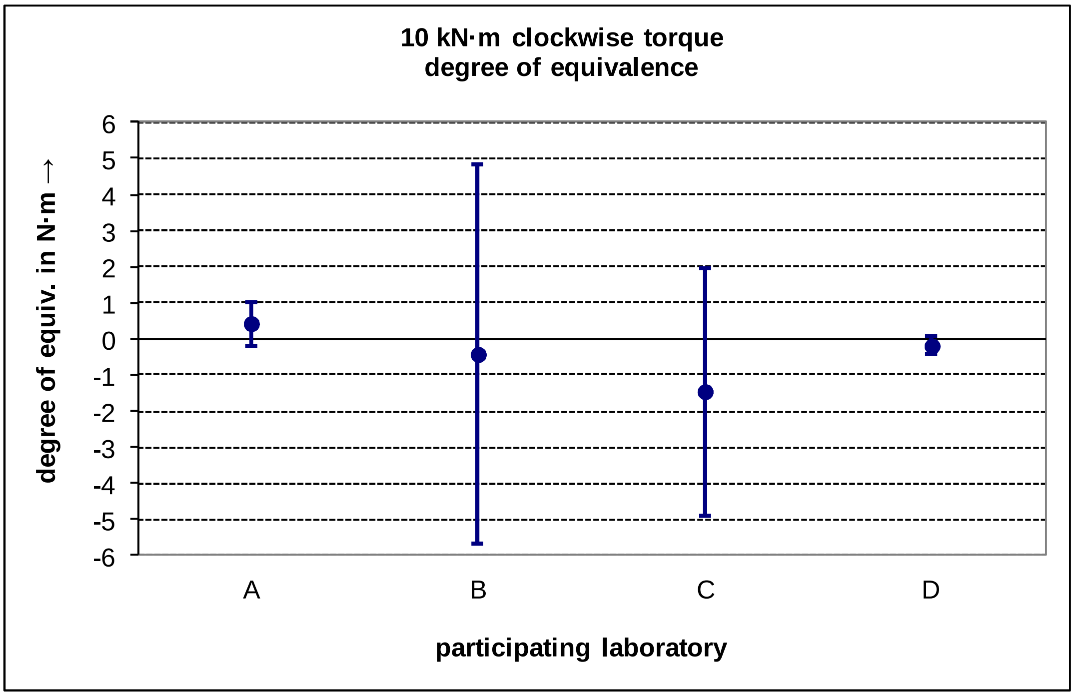

Figure A13 Degrees of equivalence for the participating laboratories (except participant E) at 10 kN·m clockwise torque (dot = D_i, uncertainty bar = $U(D_i) = U_i$)

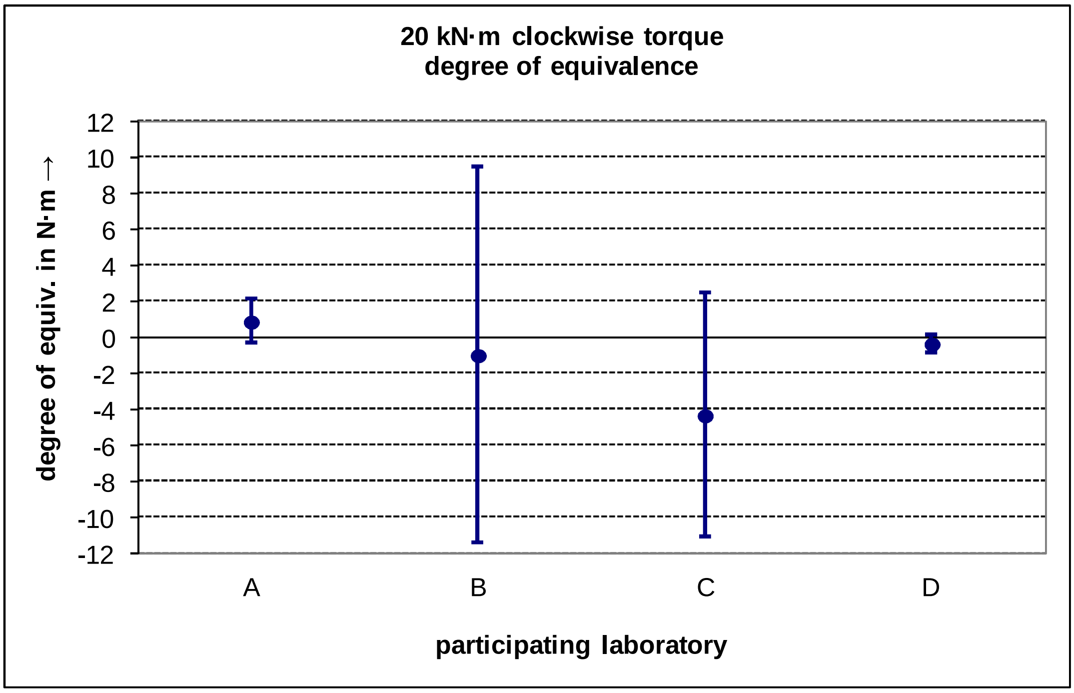

Figure A14 Degrees of equivalence for the participating laboratories (except participant E) at 20 kN·m clockwise torque (dot = D_i, uncertainty bar = $U(D_i) = U_i$)

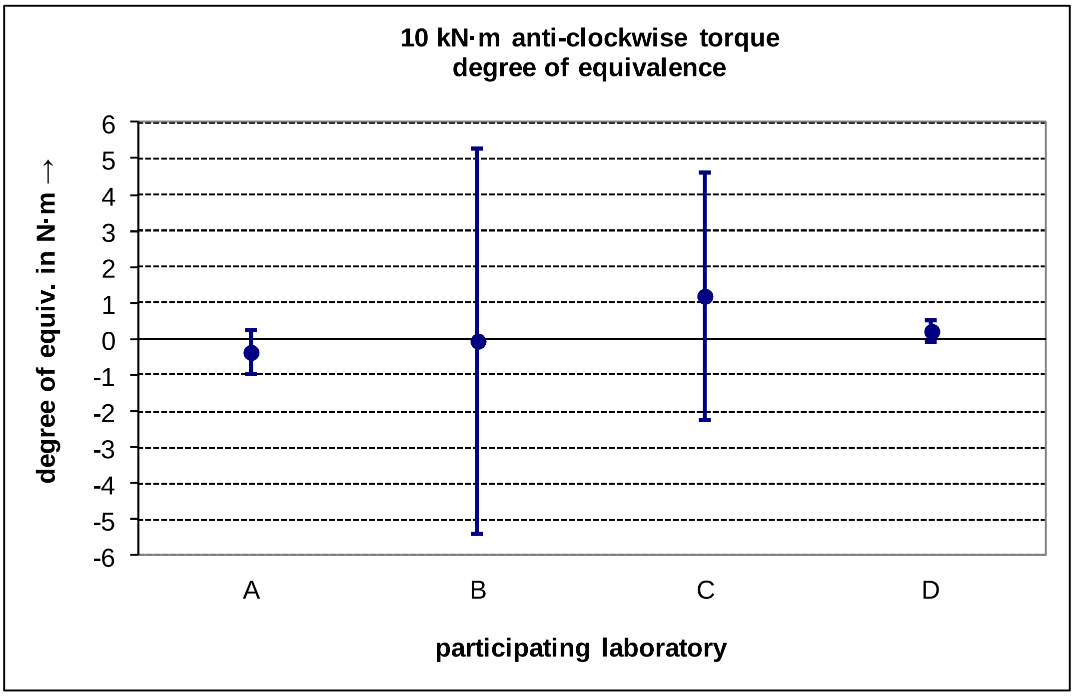

Figure A15 Degrees of equivalence for the participating laboratories (except participant E) at 10 kN·m anti-clockwise torque (dot = D_i, uncertainty bar = $U(D_i) = U_i$)

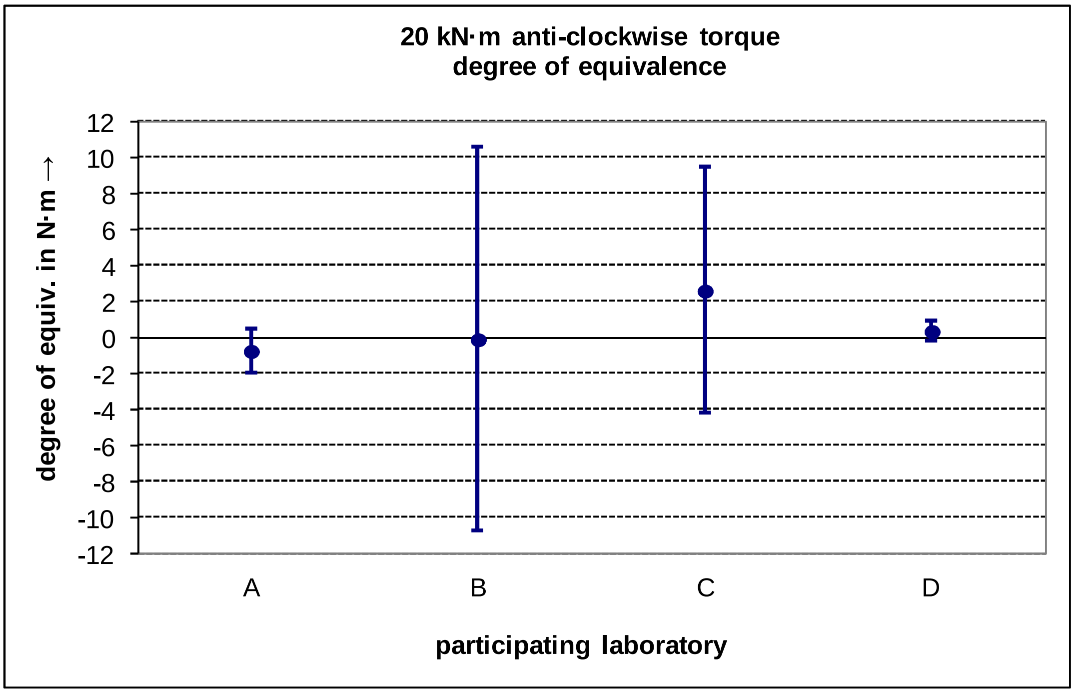

Figure A16 Degrees of equivalence for the participating laboratories (except participant E) at 20 kN·m anti-clockwise torque (dot = D_i, uncertainty bar = $U(D_i) = U_i$)

Table A18 shows the degrees of equivalence ($D_{i,j}$, $U(D_{i,j})$) between the corrected and merged 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 -0.2 nV/V in the second column is the difference result(B) – result(A), 0.2 nV/V in the second row is the difference result(A) – result(B), respectively.

Table A17: Degrees of equivalence (D_i, $U(D_i)$) in N·m between the corrected and merged values from the participants and the corresponding key comparison reference value (* result not used for the KCRV calculation)

(D_i, $U(D_i)$) in N·m	10 kN·m clockwise	20 kN·m clockwise	10 kN·m anti-clockwise	20 kN·m anti-clockwise
A	(0.4; 0.6)	(0.9; 1.2)	(-0.4; 0.6)	(-0.7; 1.2)
B	(-0.4; 5.2)	(-1.0; 10.5)	(-0.1; 5.3)	(-0.1; 10.6)
C	(-1.5; 3.4)	(-4.3; 6.8)	(1.2; 3.4)	(2.6; 6.8)
D	(-0.2; 0.3)	(-0.3; 0.5)	(0.2; 0.3)	(0.4; 0.5)
E*	(-18.4; 1.5)	(-12.7; 2.7)	(13.0; 1.3)	(4.5; 2.4)

Table A18: Degrees of equivalence ($D_{i,j}$, $U(D_{i,j})$) in N·m between the corrected and merged values from the participants (* result not used for the KCRV calculation)

	A	B	C	D	E*
A	10 kN·m 20 kN·m -10 kN·m -20 kN·m	(0.9; 5.3) (1.9; 10.6) (-0.3; 5.4) (-0.6; 10.8)	(1.9; 3.5) (5.2; 7.0) (-1.6; 3.5) (-3.3; 7.0)	(0.6; 0.8) (1.2; 1.5) (-0.6; 0.8) (-1.1; 1.6)	(18.8; 1.6) (13.6; 3.0) (-13.4; 1.5) (-5.3; 2.8)
B	(-0.9; 5.3) (-1.9; 10.6) (0.3; 5.4) (0.6; 10.8)	10 kN·m 20 kN·m -10 kN·m -20 kN·m	(1.0; 6.3) (3.3; 12.5) (-1.2; 6.4) (-2.7; 12.7)	(-0.2; 5.3) (-0.6; 10.5) (-0.3; 5.4) (-0.5; 10.7)	(-18.0; 5.5) (-11.7; 10.8) (13.0; 5.5) (4.6; 11.0)
C	(-1.9; 3.5) (-5.2; 7.0) (1.6; 3.5) (3.3; 7.0)	(-1.0; 6.3) (-3.3; 12.5) (1.2; 6.4) (2.7; 12.7)	10 kN·m 20 kN·m -10 kN·m -20 kN·m	(-1.3; 3.4) (-4.0; 6.9) (1.0; 3.5) (2.3; 6.9)	(17.0; 3.7) (8.4; 7.3) (-11.8; 3.7) (-1.9; 7.3)
D	(-0.6; 0.8) (-1.2; 1.5) (0.6; 0.8) (1.1; 1.6)	(0.2; 5.3) (0.6; 10.5) (0.3; 5.4) (0.5; 10.7)	(1.3; 3.4) (4.0; 6.9) (-1.0; 3.5) (-2.3; 6.9)	10 kN·m 20 kN·m -10 kN·m -20 kN·m	(18.2; 1.5) (12.3; 2.8) (-12.8; 1.4) (-4.2; 2.6)
E*	(-18.8; 1.6) (-13.6; 3.0) (13.4; 1.5) (5.3; 2.8)	(-18.0; 5.5) (-11.7; 10.8) (13.0; 5.5) (4.6; 11.0)	(-17.0; 3.7) (-8.4; 7.3) (11.8; 3.7) (1.9; 7.3)	(-18.2; 1.5) (-12.3; 2.8) (12.8; 1.4) (4.2; 2.6)	10 kN·m 20 kN·m -10 kN·m -20 kN·m