Results report of the

Bilateral comparison in torque transducer calibration between CENAM, Mexico and CEM, Spain

Measurement target points: 0 N·m, 10 N·m, 20 N·m, 50 N·m

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CONTENT

1. OBJECTIVE

The purpose of this comparison was to determine the results agreement of a torque transducer calibration measurements between the two participating laboratories. The data evaluated in this comparison was the average reading and the uncertainty of the instrument under calibration for each torque target point. Clockwise and counter clockwise values were evaluated separately.

2. SCOPE OF COMPARISON

In this comparison, only the evaluation of the results obtained by each participating laboratory were considered, no other technical characteristics were evaluated. The transducer was evaluated at the measurement target points 0 N·m, 10 N·m, 20 N·m, 50 N·m; considering both directions of operation of the transducer: clockwise and counter clockwise.

3. PARTICIPANTS

Table 1. Bilateral comparison participants.

NMI	Region	Contact
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CEM	EURAMET	**Dra. Maria Nieves Medina Martin** **Dra. Carmen García Izquierdo** **Jorge Luis Robles Verdecia** e-mail: mcgarciaiz@cem.es, jlrobles@cem.es Centro Español de Metrologia C/Alfar, 2. 28760 Tres Cantos, Madrid. SPAIN

3.1 Standard systems used by the laboratories.

Table 2. Standard systems used by the laboratories.

NMI	Standard systems	*u (relative)*	Amplifier	Calibrator
CEM	Dead weights primary system	$1x10^{-5}$ (k =1)	DMP 40 S2, Serial N. 153220007	BN 100 Serial N. 23412
CENAM	Direct comparison system, STPT-2kN·m	$1.0x10^{-4}$	DMP 40, Serial N. 052210002	BN 100 Serial N. 31320

4. TRANSFER STANDARD

The following torque transducer, owned by CENAM, was used:

- Brand: Hottinger Baldwin Messtechnik GmbH, HBM.
- Model: TN.
- Serial number: 1299P03.
- Measurement range: 50 N·m.
- Cable: DB-15 connector, 3 m length.
- Packaging: special transportation suitcase.

The torque transducer used had the temperature and humidity characteristics presented in Table 3, as obtained by CENAM for previous comparisons.

Table 3. Torque transducer temperature and humidity characteristics.

Relative temperature coefficient of sensitivity in 1/K	0.000 003
Relative air humidity coefficient of sensitivity in 1/%	0.000 001
Uncertainty due to temperature influences in mV/V	0.000 004
Uncertainty due to air humidity influences in mV/V	0.000 002

5. COMPARISON PROGRAM

Table 4. Bilateral comparison program.

Torque comparison measurement program. CENAM-CEM-2016.				
No.	**NMI**	**PLACE**	**START**	**FINNISH**
			JAN 2016	
1	CENAM	Queretaro, Mexico.	13	15
2	CEM	Madrid, Spain.	19	21
			MARCH 2016	
3	CENAM	Queretaro, Mexico.	6	10

6. MEASUREMENT PROCESS

Preparations.

The transducer has a DB-15 type connector to be connected directly to the DMP 40 amplifier. Each laboratory has used its own DMP 40 amplifier, which had been calibrated with each's laboratory own BN 100 on channel 1:1, before and after the comparison measurements.

Once the transducer arrived at the laboratory, it was allowed to stabilize at the laboratory's environmental conditions. The established temperature was (20.5 ± 0.5) °C and the relative humidity was (45 ± 10) %. Each participant used their own adapters, ETP hydraulic couplings and accessories, which were necessary for the installation.

The transducer was connected to the DMP 40 on channel 1:1 and switched on the day before measurement. Measurements were made in two days, one day for clockwise (CW) measurements and the other day for counter-clockwise (CCW) measurements.

Amplifier parameters

The DMP 40 amplifier was configured under the following parameters:

- Electrical supply voltage to the bridge, 5 V.
- Measurement range, 2.5 mV/V.
- Filter, 0.22 Hz Bessel.
- Resolution, 0.000 001 mV/V.

DMP 40 was operated on absolute mV/V readings.

Measurement environmental conditions

Measurements performed under stable environmental conditions at a temperature of (20.5 ± 0.5) °C and a relative humidity of (45 ± 10) %. All these data were recorded.

Measurement sequence

All preloads and measurement series were carried out considering the same time interval, that is, the readings were taken 3 minutes after loading the target torque to be measured. Only when the mounting position was changed, the waiting time was 6 minutes.

The measurements sequence is presented in Table 5. In total, in addition to the zero measurement, 3 points were measured in ascending order and in 4 mounting positions (0°, 120°, 240° and 360°). The measurement target torques were 10 N·m, 20 N·m and 50 N·m.

For repeatability evaluation, 3 preloads and 3 measurement series were performed in the first mounting position (0°). Readings were performed in 3 additional mounting positions (120º, 240º and 360º), taking the transducer connector as the reference for the positioning. For reproducibility evaluation, a preload was applied for each change in the mounting position of the transfer standard. Only the transducer was rotated, the hydraulic couplings and mounting accessories did not change their position and were fixed. The transducer measurement sequence was applied in both measurement directions, clockwise and counter-clockwise (CW and CCW).

Table 5. Comparison measurement sequence.

Position	Loads	Measurement target torques
0°	3 initial preloads	-
0°	3 measurement series	0 N·m, 10 N·m, 20 N·m, 50 N·m
120°	1 preload, 1 measurement series	0 N·m, 10 N·m, 20 N·m, 50 N·m
240°	1 preload, 1 measurement series	0 N·m, 10 N·m, 20 N·m, 50 N·m
360°	1 preload, 1 measurement series	0 N·m, 10 N·m, 20 N·m, 50 N·m

7. DATA ANALYSIS

The measured data were evaluated according to the equations given in Table 6. The uncertainty was determined based on the guide for the expression of measurement uncertainty –JCGM 100:2008. Table 7 shows the used symbols, units and designations.

Table 6. Main components of the uncertainty budget.

Uncertainty contribution	Observations	Equation	Standard relative uncertainty
Reproducibility, *b*	Calculated from the values in the 3 different mounting positions	$b=\sqrt{\frac{\sum_{j=1}^{3}(X_j-\overline{X})^2}{2}}$	$w_b=\frac{b}{\sqrt{3}}\bullet\frac{1}{\overline{X}}$
Repeatability, *b'*	Calculated from the values of the first 3 mounting positions.	$b'=\sqrt{\frac{\sum_{i=1}^{3}(X_{0,i}-\overline{X})^2}{2}}$	$w_{b'}=\frac{b'}{\sqrt{3}}\bullet\frac{1}{\overline{X}}$
Uncertainty due to the influence of temperature, *t*	Temperature coefficient uncertainty.	t	$w_t=\frac{t}{\sqrt{12}}\bullet\frac{1}{\overline{X}}$
Uncertainty due to the influence of humidity, *h*	Humidity coefficient uncertainty.	h	$w_h=\frac{h}{\sqrt{12}}\bullet\frac{1}{\overline{X}}$
Resolution of indicator, *r*	Uncertainty of zero and measurement readings influence.	r	$w_r=\frac{r}{\sqrt{12}}\bullet\frac{1}{Tc}$
Applied torque uncertainty, w_{tsm}	Applied torque value uncertainty of the torque standard machine.	-	w_{tsm}
Combined relative standard uncertainty		$w^2\left(\overline{X}\right)=w_{tsm}^2+w_b^2+w_{b'}^2+w_t^2+w_h^2+2\bullet w_r^2$	

Table 7. Symbols, units and designations.

Symbol	Designation	Unit
Tc	Calibration torque applied	N·m
w_{tsm}	Applied torque value uncertainty of the torque standard machine	ppm
$X_{0,i}$	Deviation of series i = 1, 2, 3 for first mounting position (0°)	mV/V
X_j	Deviation of series j = 4, 5, 6 for mounting positions (120°, 240°, 360°)	mV/V
$\overline{X}$	Series average j = 4, 5, 6 for mounting positions (120°, 240°, 360°)	mV/V
b	Reproducibility of j = 4, 5, 6 series of additional mounting positions (120°, 240°, 360°)	mV/V
b'	Repeatability of series i = 1, 2, 3 from first mounting position (0°)	mV/V
t	Temperature influence	mV/V
h	Relative humidity influence	mV/V
r	Indicator resolution considering stability, converted to torque units using transducer sensitivity	N·m

8. MEASUREMENTS

8.1 Amplifier measurements correction

Each laboratory made measurements in its amplifier using its own BN 100 calibrator. A summary of results is presented below. In Table 8 it is included, the readings in each laboratory and the individual zero correction (which is carried out in each series), as well as the difference in readings obtained and the final correction.

Table 8. Amplifier reading data with calibrator and final correction of readings.

CENAM			**CEM**		
BN 100	DMP 40	Reading deviation	BN 100	DMP 40 S2	Reading deviation
mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
+0	-0.000 004		+0	-0.000 027	
0.1	0.099 994	-0.000 002	0.1		
1.0	0.999 992	-0.000 003	1.0	0.999 947	-0.000 026
1.9	1.899 992	-0.000 004	1.9		
2.0	1.999 990	-0.000 006	2.0	1.999 947	-0.000 026
		-0.000 004			-0.000 026
Corrections to the DMP40 readings (for easy of calculations to be made to CEM)			$DMP40_{diff}$ =		**-0.000 022**

8.2 CENAM Measurements

The measurement results corrected by zero measurement, which were carried out by CENAM, are presented in tables 9 and 10 (initial and final calibrations respectively).

Table 9. Measurements made by CENAM, corrected by zero measurement, initial calibration.

Nominal Torque [N·m]	0°/1 [mV/V]	0°/2 [mV/V]	0°/3 [mV/V]	120° [mV/V]	240° [mV/V]	360° [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 608	0.320 608	0.320 601	0.320 645	0.320 634	0.320 657
20.000	0.641 195	0.641 200	0.641 185	0.641 215	0.641 196	0.641 179
50.000	1.603 231	1.603 236	1.603 229	1.603 254	1.603 203	1.603 169
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 419	-0.320 422	-0.320 423	-0.320 423	-0.320 416	-0.320 437
-20.000	-0.640 957	-0.640 949	-0.640 950	-0.640 932	-0.640 960	-0.640 965
-50.000	-1.602 897	-1.602 896	-1.602 908	-1.602 887	-1.602 894	-1.602 961

Table 10. Measurements made by CENAM, corrected by zero measurement, final calibration.

Nominal Torque [N·m]	0°/1 [mV/V]	0°/2 [mV/V]	0°/3 [mV/V]	120° [mV/V]	240° [mV/V]	360° [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 612	0.320 612	0.320 617	0.320 659	0.320 681	0.320 652
20.000	0.641 254	0.641 244	0.641 257	0.641 249	0.641 264	0.641 280
50.000	1.603 170	1.603 182	1.603 170	1.603 211	1.603 208	1.603 215
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 429	-0.320 451	-0.320 470	-0.320 437	-0.320 455	-0.320 428
-20.000	-0.641 036	-0.641 048	-0.641 038	-0.641 035	-0.641 006	-0.641 010
-50.000	-1.602 936	-1.602 919	-1.602 913	-1.602 959	-1.602 921	-1.602 935

Table 11 includes the average values that have been obtained by CENAM during its initial and final calibrations. The case of first mounting position (0°) are designated as $\overline{X}_{0,1}$, $\overline{X}_{0,2}$, and the series of additional mounting positions (120°, 240°, 360°), are presented as $\overline{X}_1$, $\overline{X}_2$.

Table 11. Measurement results average for the initial and final calibrations carried out by CENAM. First mounting position (0°) and additional mounting positions (120°, 240°, 360°).

Nominal Torque [N·m]	$\overline{X}_{0,1}$ 0° [mV/V]	$\overline{X}_1$ 120° [mV/V]	$\overline{X}_2$ 240° [mV/V]	$\overline{X}_{0,2}$ 360° [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 606	0.320 645	0.320 664	0.320 613
20.000	0.641 193	0.641 197	0.641 264	0.641 252
50.000	1.603 232	1.603 209	1.603 212	1.603 174
0.000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 421	-0.320 425	-0.320 440	-0.320 450
-20.000	-0.640 952	-0.640 952	-0.641 017	-0.641 041
-50.000	-1.602 900	-1.602 914	-1.602 938	-1.602 923

The environmental conditions during the measurements for the two calibration performed at CENAM are shown in table 12.

Table 12. Environmental conditions at CENAM.

	Initial	**Final**	**Average**
Temperature, ºC	20.40	20.70	$\overline{temp}_{CENAM} = \mathbf{20.55}$
Humidity, %RH	35	38	$\overline{RH}_{CENAM} = \mathbf{36.5}$

8.3 CEM Measurements

In table 13 are presented the measurements made by CEM, corrected by zero measurement, for the cases of first mounting position (0°) and series of additional mounting positions (120°, 240°, 360°),

Table 13. Measurements made by CEM, corrected by zero measurement.

Nominal Torque [N·m]	0°/1 [mV/V]	0°/2 [mV/V]	0°/3 [mV/V]	$\bar{X}_0$ [mV/V]	120º [mV/V]	240º [mV/V]	360º [mV/V]	$\bar{X}$ [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 509	0.320 528	0.320 515	0.320 517	0.320 504	0.320 510	0.320 502	0.320 505
20.000	0.641 094	0.641 096	0.641 092	0.641 094	0.641 079	0.641 085	0.641 066	0.641 077
50.000	1.603 084	1.603 086	1.603 071	1.603 080	1.603 042	1.603 040	1.603 014	1.603 032
0.000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 509	-0.320 510	-0.320 503	-0.320 507	-0.320 496	-0.320 499	-0.320 502	-0.320 499
-20.000	-0.641 073	-0.641 063	-0.641 058	-0.641 065	-0.641 050	-0.641 054	-0.641 052	-0.641 052
-50.000	-1.602 970	-1.602 950	-1.602 941	-1.602 954	-1.602 930	-1.602 928	-1.602 917	-1.602 925

The environmental conditions during the measurements for the calibration performed at CEM are shown in table 14.

Table 14. Environmental conditions at CEM.

	Initial	Final	Average
Temperature, ºC	20.00	20.24	$\bar{temp}_{CEM} = \mathbf{20.12}$
Humidity, %RH	50	45	$\bar{RH}_{CEM} = \mathbf{47.5}$

For easy of calculations, the correction due to DMP40 deviations, relative humidity and temperature differences between CEM and CENAM are made to the CEM data.

Table 15 includes the average values obtain by CEM for the calibration on the first mounting position case (0°), $\bar{X}_0$. Table 16 presents the average values obtain by CEM for the calibration on the additional mounting positions case (120°, 240°, 360°), $\bar{X}$.

Tables 15 and 16 include, the measurements made by CEM corrected for the DMP40 differences with CENAM, $\bar{X}_{0,DMP40}$, see section 8.1 table 8 (equation 1). Then, these corrected average values are corrected by the different relative humidity between CEM and CENAM, $\bar{X}_{0,DMP40,\%RH}$, and finally corrected for the temperature difference $\bar{X}_{0,DMP40,\%RH,t}$.

The corrections are made by means of equations 1, 2 and 3 with the data on tables 3 and 13.

$$\bar{X}_{0,DMP40} = \bar{X}_0 + DMP40_{diff} \quad (1)$$

$$\bar{X}_{0,DMP40,\%RH} = \bar{X}_{0,DMP40} + h * RH_{diff} * \bar{X}_0 \quad (2)$$

$$\bar{X}_{0,DMP40,\%RH,t} = \bar{X}_{0,DMP40,\%RH} + t * temp_{diff} * \bar{X}_0 \quad (3)$$

Where all symbols are as indicated in tables 6, 7 and 8, and as described in the previous paragraph. Also, from tables 12 and 14:

$$RH_{diff} = \bar{R}H_{CENAM} - \bar{R}H_{CEM} \quad (4)$$

$$temp_{diff} = \bar{t}emp_{CENAM} - \bar{t}emp_{CEM} \quad (5)$$

The temperature difference as well as humidity difference are also included in the uncertainty calculations as part of the main components (see table 6).

Table 15. CEM average measurements including the corrections to deviations between the labs due to DMP40, relative humidity and temperature, first mounting position case, 0°.

Nominal Torque [N·m]	$\bar{X}_0$ [mV/V]	$\bar{X}_{0,DMP40}$ [mV/V]	$\bar{X}_{0,DMP40,\%RH}$ [mV/V]	$\bar{X}_{0,DMP40,\%RH,t}$ [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 517	0.320 539	0.320 543	0.320 542
20.000	0.641 094	0.641 116	0.641 123	0.641 122
50.000	1.603 080	1.603 102	1.603 120	1.603 118
0.000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 507	-0.320 486	-0.320 489	-0.320 489
-20.000	-0.641 065	-0.641 043	-0.641 050	-0.641 049
-50.000	-1.602 954	-1.602 932	-1.602 950	-1.602 948

Table 16. CEM average measurements including the corrections to deviations between the labs due to DMP40, relative humidity and temperature, additional mounting positions case,120°, 240°, 360°.

Nominal Torque [N·m]	$\bar{X}$ [mV/V]	$\bar{X}_{DMP40}$ [mV/V]	$\bar{X}_{DMP40,\%RH}$ [mV/V]	$\bar{X}_{DMP40,\%RH,t}$ [mV/V]
0.000	0.000 000	0.000 000	0.000 000	0.000 000
10.000	0.320 505	0.320 527	0.320 531	0.320 530
20.000	0.641 077	0.641 098	0.641 105	0.641 105
50.000	1.603 032	1.603 054	1.603 071	1.603 069
0.000	0.000 000	0.000 000	0.000 000	0.000 000
-10.000	-0.320 499	-0.320 477	-0.320 481	-0.320 480
-20.000	-0.641 052	-0.641 030	-0.641 037	-0.641 037
-50.000	-1.602 925	-1.602 903	-1.602 921	-1.602 919

9. RESULTS

9.1 CENAM results

CENAM´s results for the initial and final calibrations performed are included in tables 17 and 18, respectively. The symbols used in tables 17 and 18 are the ones described in tables 6 and 7. The symbols w_1 and w_2 refer to the combined relative uncertainty result for the first and second calibrations made by CENAM, respectively.

Table 17. CENAM relative uncertainty components and combined relative uncertainty. Initial calibration.

Tc [N·m]	$\bar{X}_{0,1}$ [mV/V]	$\bar{X}_1$ [mV/V]	w_{tsm} [relative]	$w_{b'}$ [relative]	w_b [relative]	w_t [relative]	w_h [relative]	w_r [relative]	w_1 [relative]
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.320 606	0.320 645	1.00E-04	7.14E-06	2.07E-05	3.60E-06	1.80E-06	1.35E-06	1.02E-04
20	0.641 193	0.641 197	1.00E-04	6.85E-06	1.63E-05	1.80E-06	9.00E-07	6.75E-07	1.02E-04
50	1.603 232	1.603 209	1.00E-04	1.32E-06	1.55E-05	7.20E-07	3.60E-07	2.70E-07	1.01E-04
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-10	-0.320 421	-0.320 425	1.00E-04	-3.85E-06	-1.98E-05	-3.60E-06	-1.80E-06	-1.35E-06	1.02E-04
-20	-0.640 952	-0.640 952	1.00E-04	-4.36E-06	-1.61E-05	-1.80E-06	-9.01E-07	-6.75E-07	1.01E-04
-50	-1.602 900	-1.602 914	1.00E-04	-2.29E-06	-1.46E-05	-7.20E-07	-3.60E-07	-2.70E-07	1.01E-04

Table 18. CENAM relative uncertainty components and combined relative uncertainty. Final calibration.

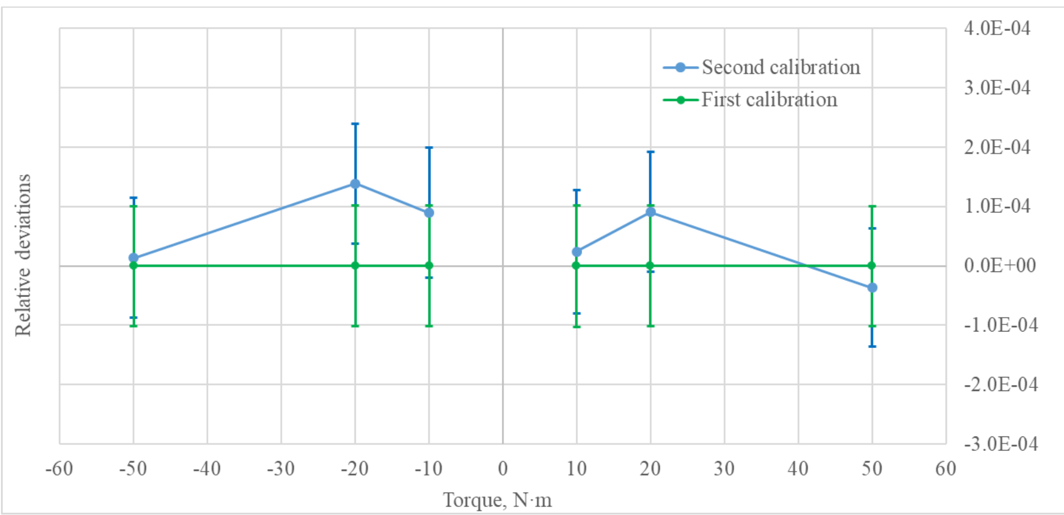
Tc [N·m]	$\bar{X}_{0,2}$ [mV/V]	$\bar{X}_2$ [mV/V]	w_{tsm} [relative]	$w_{b'}$ [relative]	w_b [relative]	w_t [relative]	w_h [relative]	w_r [relative]	w_2 [relative]
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.320 613	0.320 664	1.00E-04	6.06E-06	2.67E-06	3.60E-06	1.80E-06	1.35E-06	1.04E-04
20	0.641 252	0.641 264	1.00E-04	6.42E-06	1.40E-05	1.80E-06	9.00E-07	6.75E-07	1.01E-04
50	1.603 174	1.603 212	1.00E-04	2.51E-06	1.24E-06	7.20E-07	3.60E-07	2.70E-07	1.00E-04
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-10	-0.320 450	-0.320 440	1.00E-04	-3.67E-05	-2.39E-05	-3.60E-06	-1.80E-06	-1.35E-06	1.09E-04
-20	-0.641 041	-0.641 017	1.00E-04	-5.90E-06	-1.44E-05	-1.80E-06	-9.00E-07	-6.75E-07	1.01E-04
-50	-1.602 923	-1.602 938	1.00E-04	-4.34E-06	-7.03E-06	-7.20E-07	-3.60E-07	-2.70E-07	1.00E-04

The difference between the calibrations made by CENAM as well as its associated combined relative uncertainty are presented in table 19 and in graph 1.

The values used by CENAM were the average measurement values of the initial and final calibrations, $\overline{X}_{0CENAM}$. For the uncertainty, the average combined relative uncertainty from the two calibrations made by CENAM was also used $\overline{w}_{CENAM}$. See table 19.

Table 19. CENAM measurement and relative uncertainty average values of the first and second calibrations.

Tc [N·m]	$\overline{X}_{0,1}$ [mV/V]	w_1 [relative]	$\overline{X}_{0,2}$ [mV/V]	w_2 [relative]	$x_{CENAMdiff}$ $\overline{X}_{0,2}-\overline{X}_{0,1}$ [mV/V]	$\overline{X}_{0CENAM}$ [mV/V]	$\overline{w}_{CENAM}$ [relative]
-50	-1.602 900	1.01E-04	-1.602 923	1.00E-04	-0.000 022	-1.602 912	1.01E-04
-20	-0.640 952	1.01E-04	-0.641 041	1.01E-04	-0.000 089	-0.640 996	1.01E-04
-10	-0.320 421	1.02E-04	-0.320 450	1.09E-04	-0.000 029	-0.320 435	1.06E-04
10	0.320 606	1.02E-04	0.320 613	1.04E-04	0.000 008	0.320 610	1.03E-04
20	0.641 193	1.02E-04	0.641 252	1.01E-04	0.000 058	0.641 222	1.01E-04
50	1.603 232	1.01E-04	1.603 174	1.00E-04	-0.000 058	1.603 203	1.01E-04



Graph 1. Differences between the two calibrations made by CENAM, including its relative uncertainties.

From graph 1, it can be seen that there is no constant drift of the transducer. The difference between the two calibrations will be included in the compatibility calculations between the laboratories as an uncertainty component with rectangular distribution.

In table 20, the relative uncertainty due to the difference in measurements between the two calibrations performed by CENAM, $w_{CENAMdiff}$, are presented.

Table 20. CENAM difference between the two calibrations and its relative uncertainty.

Tc [N·m]	$\bar{X}_{0CENAM}$ [mV/V]	$x_{CENAMdiff}$ $\bar{X}_{0,2}-\bar{X}_{0,1}$ [mV/V]	$x_{CENAMdiff}$ [relative]	$w_{CENAMdiff}$ [relative]	$W_{CENAMdiff}$ [relative]
-50	-1.602 912	-0.000 022	0.000 014	0.000 004	7.97E-06
-20	-0.640 996	-0.000 089	0.000 139	0.000 040	8.01E-05
-10	-0.320 435	-0.000 029	0.000 090	0.000 026	5.17E-05
10	0.320 610	0.000 008	0.000 024	0.000 007	1.39E-05
20	0.641 222	0.000 058	0.000 091	0.000 026	5.26E-05
50	1.603 203	-0.000 058	-0.000 036	0.000 011	2.10E-05

9.2 CEM results

The results for the calibration made by CEM are included in table 21. Also, the average torque corrected by the differences on DMP40, temperature and relative humidity, are included for both zero position, $\bar{X}_{0,DMP40,\%RH,t}$, and other positions, $\bar{X}_{DMP40,\%RH,t}$. The uncertainty components and the final combined expanded uncertainty for CEM are shown in the same table.

The symbols used in table 21 are the ones described in tables 6 and 7. The symbol w_{CEM} refers to the CEM combined uncertainty result.

Table 21. CEM results. Uncertainty components and expanded combined uncertainty.

Tc [N·m]	$\bar{X}_{0,DMP40,\%RH,t}$ [mV/V]	$\bar{X}_{DMP40,\%RH,t}$ [mV/V]	w_{tsm} [relative]	$w_{b'}$ [relative]	w_b [relative]	w_t [relative]	w_h [relative]	w_r [relative]	w_{CEM} [relative]
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.320 542	0.320 530	1.00E-05	1.75E-05	7.50E-06	3.60E-06	1.80E-06	1.35E-06	2.20E-05
20	0.641 122	0.641 105	1.00E-05	1.80E-06	8.75E-06	1.80E-06	9.01E-07	6.75E-07	1.36E-05
50	1.603 118	1.603 069	1.00E-05	2.93E-06	5.63E-06	7.20E-07	3.60E-07	2.70E-07	1.19E-05
0	0.000 000	0.000 000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-10	-0.320 489	-0.320 480	1.00E-05	-6.82E-06	-5.41E-06	-3.60E-06	-1.80E-06	-1.35E-06	1.40E-05
-20	-0.641 049	-0.641 037	1.00E-05	-6.88E-06	-1.80E-06	-1.80E-06	-9.01E-07	-6.75E-07	1.25E-05
-50	-1.602 948	-1.602 919	1.00E-05	-5.35E-06	-2.52E-06	-7.20E-07	-3.60E-07	-2.70E-07	1.17E-05

9.3 Results comparison criteria

The criterion used to evaluate the compatibility of results for this comparison is the normalized error equation method (E_n), which can be calculated by means of the following equation, which is in relative units.

$$E_n = \frac{\left(\bar{X}_{0CENAM} - \bar{X}_{0,DMP40,\%RH,t}\right) / \bar{X}_{CEM+CENAM}}{\sqrt{\bar{W}^2_{CENAM} + W^2_{CEM} + W^2_{CENAMdiff}}} \qquad (6)$$

Where:

$\bar{X}_{0,DMP40,\%RH,t}$	corrected measurements obtained by CEM (as presented in section 8.3),
$\bar{X}_{0CENAM}$	measurement results by CENAM (average value of the two calibrations performed by CENAM, as shown in table 19),
$\bar{X}_{CEM+CENAM}$	average of the measurements made by CEM and CENAM,
W_{CEM}	relative expanded uncertainty estimated by CEM (2*w_{CEM}),
$\bar{W}_{CENAM}$	average relative expanded uncertainty from the two calibrations performed by CENAM (2* $\bar{w}_{CENAM}$) and
$W_{CENAMdiff}$	relative expanded uncertainty due to the difference in measurements between the two calibrations performed by CENAM, rectangular distribution for each target torque, as shown in 9.1 Graph 1 (2*$w_{CENAMdiff}$).

According to the normalized error equation model, if $|E_n| < 1$ the results are compatible, if $|E_n| \geq 1$ the results are not compatible.

$$E_n = \frac{\left(\bar{X}_{0,DMP40\%R.H.,t} - \bar{X}_{0,CENAM}\right)}{\sqrt{\left(W_{CENAM} \cdot \bar{X}_{0,CENAM}\right)^2 + \left(W_{CEM} \cdot \bar{X}_{0DMP40\%RH,y}\right)^2 + \left(U_{CENAM-Drift} \cdot\right)^2}}$$

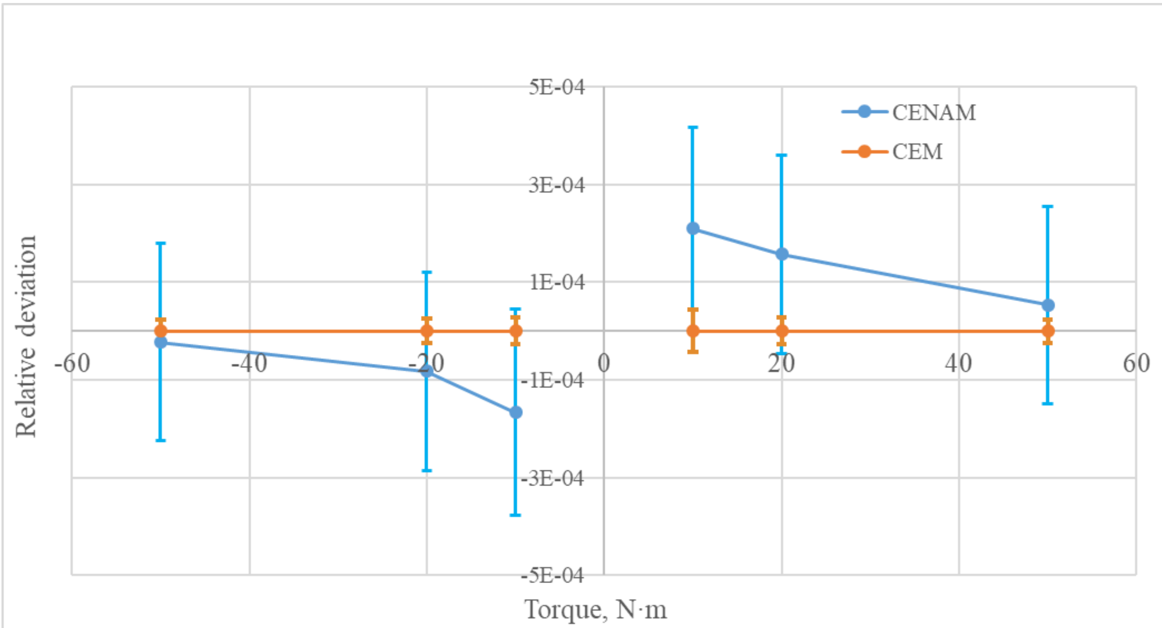
10. FINAL REMARKS AND CONCLUSIONS

Using information from tables 20 and 21 the average of the measurements made by CEM and CENAM at the position of 0 is shown in table 22.

Table 22. Average of the measurements made by CEM and CENAM.

	CENAM		CEM			
Nominal Torque [N·m]	$\bar{X}_{0CENAM}$ [mV/V]	$\bar{W}_{CENAM}$ [relative]	$\bar{X}_{0,DMP40,\%RH,t}$ [mV/V]	W_{CEM} [relative]	Deviation $\bar{X}_{0CENAM}$ - $\bar{X}_{0,DMP40,\%RH,t}$ [mV/V]	Average $\bar{X}_{CEM+CENAM}$ [mV/V]
-50	-1.602 912	2.01E-04	-1.602 948	2.33E-05	3.599E-05	-1.602 930
-20	-0.640 996	2.03E-04	-0.641 049	2.49E-05	5.294E-05	-0.641 023
-10	-0.320 435	2.11E-04	-0.320 489	2.80E-05	5.338E-05	-0.320 462
10	0.320 610	2.06E-04	0.320 542	4.39E-05	6.740E-05	0.320 576
20	0.641 222	2.03E-04	0.641 122	2.72E-05	1.005E-04	0.641 172
50	1.603 203	2.01E-04	1.603 118	2.38E-05	8.546E-05	1.603 160

According to the results presented in previous table 22, the deviations between the two laboratories (taken CEM as reference) are shown in the following graph 2.

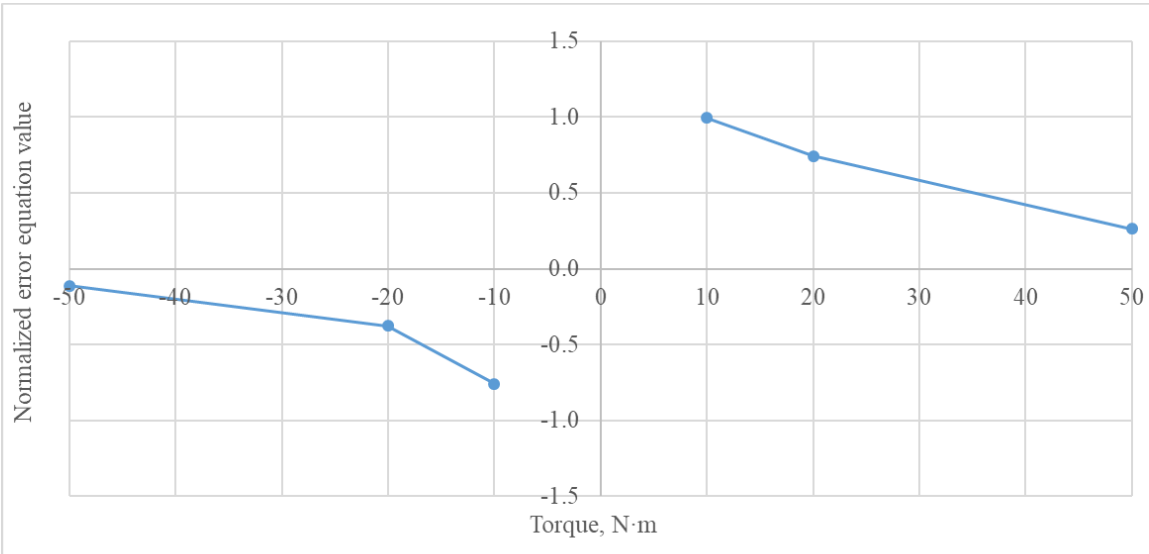


Graph 2. Deviations between the two laboratories, including its uncertainties.

Using the information from tables 20 and 22 and equation 6, the values of the normalized error equation method are presented in table 23 and in the following graph 3.

Table 23. Normalized error equation values for the comparison.

	CENAM		CEM				
Nominal Torque [N·m]	X_{0CENAM} [mV/V]	W_{CENAM} [relative]	$\bar{X}_{0,DMP40,\%RH,t}$ [mV/V]	W_{CEM} [relative]	$W_{CENAMdiff}$ [relative]	$\bar{X}_{CEM+CENAM}$ [mV/V]	***En***
-50	-1.602 912	2.01E-04	-1.602 948	2.33E-05	7.97E-06	-1.602 930	-0.11
-20	-0.640 996	2.03E-04	-0.641 049	2.49E-05	8.01E-05	-0.641 023	-0.38
-10	-0.320 435	2.11E-04	-0.320 489	2.80E-05	5.17E-05	-0.320 462	-0.76
10	0.320 610	2.06E-04	0.320 542	4.39E-05	1.39E-05	0.320 576	0.99
20	0.641 222	2.03E-04	0.641 122	2.72E-05	5.26E-05	0.641 172	0.74
50	1.603 203	2.01E-04	1.603 118	2.38E-05	2.10E-05	1.603 160	0.26



Graph 3. Normalized error equation values between CEM and CENAM.

10.1 Conclusions

As it can be seen in table 23 and graph 3 the values obtained are within the compatibility zone for the normalized error equation method, which was selected as the method to verify compatibility.

The results obtain permit to conclude that compatibility of results between CEM and CENAM for the calibration of torque high accuracy transducers is adequate.