Bilateral comparison

EURAMET.M.T-S3

Final Report

Torque wrenches

(10 N·m - 1 kN·m)

1.- COMPARISON PURPOSE

The purpose is the comparison of the measurement capabilities between PTB and CEM for torque wrenches from 10 N·m up to 1000 N·m calibrated according DKD-R 3-7.

2.- GENERAL INFORMATION

2.1 - Participants

The participating laboratories have been PTB and CEM (pilot). The contact details are:

PTB	**CEM**
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2.2- Traveling standards and realization of the comparison

The traveling standards have been:

-1000 N·m standard torque wrench, manufacturer HBM, type TTS, serial number 050840021 (belonging to CEM).

-100 N·m standard torque wrench, manufacturer GTM, type DRS serial number 45926 (belonging to PTB).

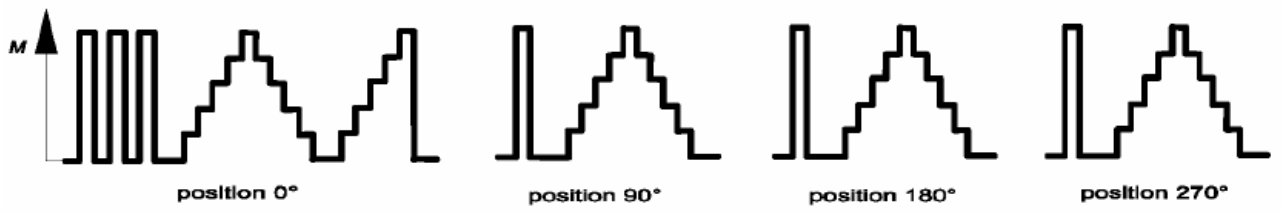
Both standards indications have been recorded by means of a measuring amplifier manufacturer HBM type DMP-40 (belonging to CEM). Square drive adapters were mounted at the torque wrenches and had not been removed during the comparison. The size of the square drive adaptor was 25.4 mm (1'') for the 1000-N·m wrench and 12.7 mm (1/2'') for the 100-N·m wrench. The standards have been mounted in vertical position so that the torque was always applied for the fixed arm length indicated in every wrench (1000 mm for the 1000-N·m wrench, 500 mm for the 100-N·m wrench). The change of the mounting positions (0°, 90°, 180°, and 270°) has been realized by rotating the female square drive adapter of the calibration machine. The standards have been kept in the laboratory for environmental conditioning for at least 48 hours before measuring (21°C ± 1°C, 50% rH ± 5% rH).

The traveling standards have been measured between November and December 2010. The standards have been measured by CEM at the start and the end. PTB has measured between these measurements.

3.- MEASUREMENT TESTS

3.1 – Measurement procedure

The calibration sequence has been the same as the one specified in section D.2 of EURAMET cg-14 [1].



The standards have been calibrated clockwise and anticlockwise.

The measurement range has been from 10% up to 100% of the maximum torque value of the measuring range. The loading steps have been 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100 % of the maximum torque value of the measuring range.

Creep has been determined for 6 min after this measurement sequence at zero removing the load and disconnecting the wrench mechanically by the pilot laboratory.

The required time intervals have been:

- Loading: 50 s for preloading, 30 s for step loading
- Unloading: 50 s for preloading, 30 s for step loading
- Stabilization after the three preloadings: 120 s
- Stabilization before taking the indication value: 10 s
- Creep indication values will be taken every 15 s

3.2-Measurement results

The measurement results for each loading step include:

- Mean value for increasing series (x_r)
- Repeatability (b')
- Reproducibility (b)
- Resolution (r)

The measurement relative uncertainty (k=2) (w) has been determined by each laboratory according to JCGM 100:2008 [2] taking into account repeatability, reproducibility, resolution and standard uncertainty of the laboratory standard machine (w_{tcm}) in the following way:

$$w = 2 \cdot \sqrt{\frac{(b')^2}{2} + \frac{(b)^2}{4} + \frac{(r)^2}{12} + w^2_{tcm}}$$

3.2.1-PTB results

PTB results for the 1000 N·m standard torque wrench have been (clockwise table 1 and anticlockwise table 2):

Table 1: PTB results for the 1000 N·m standard torque wrench (clockwise)

M (N·m)	X_r (mV/V)	b'/X_r (%)	b/X_r (%)	*r*/*M* (%)	*W* (%) (*k*=2)
100	0,162313	0,0012	0,0094	0,0006	0,022
200	0,324475	0,0018	0,0097	0,0003	0,022
300	0,486588	0,0002	0,0094	0,0002	0,022
400	0,648694	0,0011	0,0097	0,0002	0,022
500	0,810805	0,0009	0,0086	0,0001	0,022
600	0,972932	0,0007	0,0094	0,0001	0,022
800	1,297181	0,0001	0,0090	0,0001	0,022
1000	1,621439	0,0008	0,0097	0,0001	0,022

Table 2: PTB results for the 1000 N·m standard torque wrench (anticlockwise)

M (N·m)	X_r (mV/V)	b'/X_r (%)	b/X_r (%)	*r*/*M* (%)	*W* (%) (*k*=2)
-100	-0,162392	0,0043	0,0156	0,0006	0,026
-200	-0,324597	0,0034	0,0084	0,0003	0,022
-300	-0,486763	0,0027	0,0074	0,0002	0,022
-400	-0,648913	0,0011	0,0079	0,0002	0,022
-500	-0,811065	0,0018	0,0085	0,0001	0,022
-600	-0,973221	0,0009	0,0091	0,0001	0,022
-800	-1,297513	0,0012	0,0101	0,0001	0,022
-1000	-1,621763	0,0015	0,0112	0,0001	0,023

PTB results for the 100 N·m standard torque wrench have been (clockwise table 3 and anticlockwise table 4):

Table 3: PTB results for the 100 N·m standard torque wrench (clockwise)

M (N·m)	X_r (mV/V)	b'/X_r (%)	b/X_r (%)	*r*/*M* (%)	*W* (%) (*k*=2)
10	0,208610	0,0048	0,0243	0,0005	0,032
20	0,417237	0,0007	0,0173	0,0002	0,026
30	0,625872	0,0005	0,0142	0,0002	0,025
40	0,834520	0,0001	0,0130	0,0001	0,024
50	1,043184	0,0000	0,0113	0,0001	0,023
60	1,251859	0,0002	0,0105	0,0001	0,023
80	1,669258	0,0001	0,0095	0,0001	0,022
100	2,086726	0,0001	0,0093	0,0000	0,022

Table 4: PTB results for the 100 N·m standard torque wrench (anticlockwise)

M (N·m)	X_r (mV/V)	b'/X_r (%)	b/X_r (%)	*r*/*M* (%)	*W* (%) (*k*=2)
-10	-0,208559	0,0005	0,0270	0,0005	0,034
-20	-0,417132	0,0022	0,0195	0,0002	0,028
-30	-0,625710	0,0018	0,0154	0,0002	0,025
-40	-0,834296	0,0007	0,0150	0,0001	0,025
-50	-1,042900	0,0009	0,0143	0,0001	0,025
-60	-1,251525	0,0006	0,0145	0,0001	0,025
-80	-1,668835	0,0012	0,0153	0,0001	0,025
-100	-2,086245	0,0012	0,0149	0,0000	0,025

The relative standard uncertainty of the PTB standard laboratory machine is w_{tcm} (%) (k=1) = **0,01.**

3.2.2-CEM results

CEM has performed two measurements before PTB measurements and two measurements after PTB measurements (for each standard torque wrench).

In the following tables the mean value for increasing series (X_{ri}) for each measurement i (i = 1, 2 for measurements before PTB measurements and i = 3, 4 for measurements after PTB measurements) is included as well as their mean ($X_{r\ mean}$) and the maximum relative values for repeatability (b'), reproducibility (b), resolution (r) and relative expanded uncertainty (W). The relative standard uncertainty of the CEM standard laboratory machine is w_{tcm} (%) (k=1) = **0,01.**

CEM results for the 1000 N·m standard torque wrench have been (clockwise table 5 and anticlockwise table 6):

Table 5: CEM results for the 1000 N·m standard torque wrench (clockwise)

M (N·m)	X_{r1} (mV/V)	X_{r2} (mV/V)	X_{r3} (mV/V)	X_{r4} (mV/V)	$X_{r\ mean}$ (mV/V)	$b'/X_{r\ mean}$ (%)	$b/X_{r\ mean}$ (%)	r/M (%)	W (%) (k=2)
100	0,162337	0,162329	0,162329	0,162334	0,162332	0,0092	0,0064	0,0006	0,024
200	0,324520	0,324536	0,324522	0,324537	0,324529	0,0071	0,0059	0,0003	0,023
300	0,486690	0,486700	0,486673	0,486695	0,486689	0,0037	0,0051	0,0002	0,021
400	0,648848	0,648863	0,648828	0,648839	0,648844	0,0034	0,0050	0,0002	0,021
500	0,811021	0,811035	0,810984	0,811004	0,811011	0,0028	0,0046	0,0001	0,021
600	0,973199	0,973199	0,973143	0,973167	0,973177	0,0017	0,0044	0,0001	0,021
800	1,297541	1,297534	1,297482	1,297501	1,297514	0,0013	0,0032	0,0001	0,020
1000	1,621852	1,621841	1,621781	1,621790	1,621816	0,0011	0,0033	0,0001	0,020

Table 6: CEM results for the 1000 N·m standard torque wrench (anticlockwise)

M (N·m)	X_{r1} (mV/V)	X_{r2} (mV/V)	X_{r3} (mV/V)	X_{r4} (mV/V)	$X_{r\ mean}$ (mV/V)	$b'/X_{r\ mean}$ (%)	$b/X_{r\ mean}$ (%)	r/M (%)	W (%) (k=2)
-100	-0,162422	-0,162434	-0,162427	-0,162420	-0,162426	0,0080	0,0073	0,0006	0,024
-200	-0,324665	-0,324689	-0,324655	-0,324661	-0,324667	0,0037	0,0070	0,0003	0,022
-300	-0,486874	-0,486907	-0,486846	-0,486863	-0,486873	0,0029	0,0065	0,0002	0,021
-400	-0,649057	-0,649099	-0,649038	-0,649053	-0,649062	0,0031	0,0071	0,0002	0,021
-500	-0,811228	-0,811288	-0,811221	-0,811236	-0,811243	0,0014	0,0066	0,0001	0,021
-600	-0,973409	-0,973484	-0,973415	-0,973416	-0,973431	0,0013	0,0064	0,0001	0,021
-800	-1,297777	-1,297850	-1,297769	-1,297808	-1,297801	0,0012	0,0042	0,0001	0,021
-1000	-1,622054	-1,622136	-1,622068	-1,622118	-1,622094	0,0018	0,0040	0,0001	0,021

The following figures show the relative variation of the measurements with the mean value as a reference for clockwise (figure 1) and anticlockwise (figure 2) measurements versus the relative torque nominal value. It can be seen that all these variations are much less than the measurement uncertainties (W (%) (k=2) ≥ **0,02**), so possible creep is negligible.

For all the measurements the maximum variation of temperature while measurements were performed has been 2 ºC for both laboratories. This fact may be a source of uncertainty, which effect is included in the reproducibility and repeatability test.

Figure 1: Relative variation of the measurements with the mean value as a reference for the 1000 N·m standard torque wrench (clockwise)

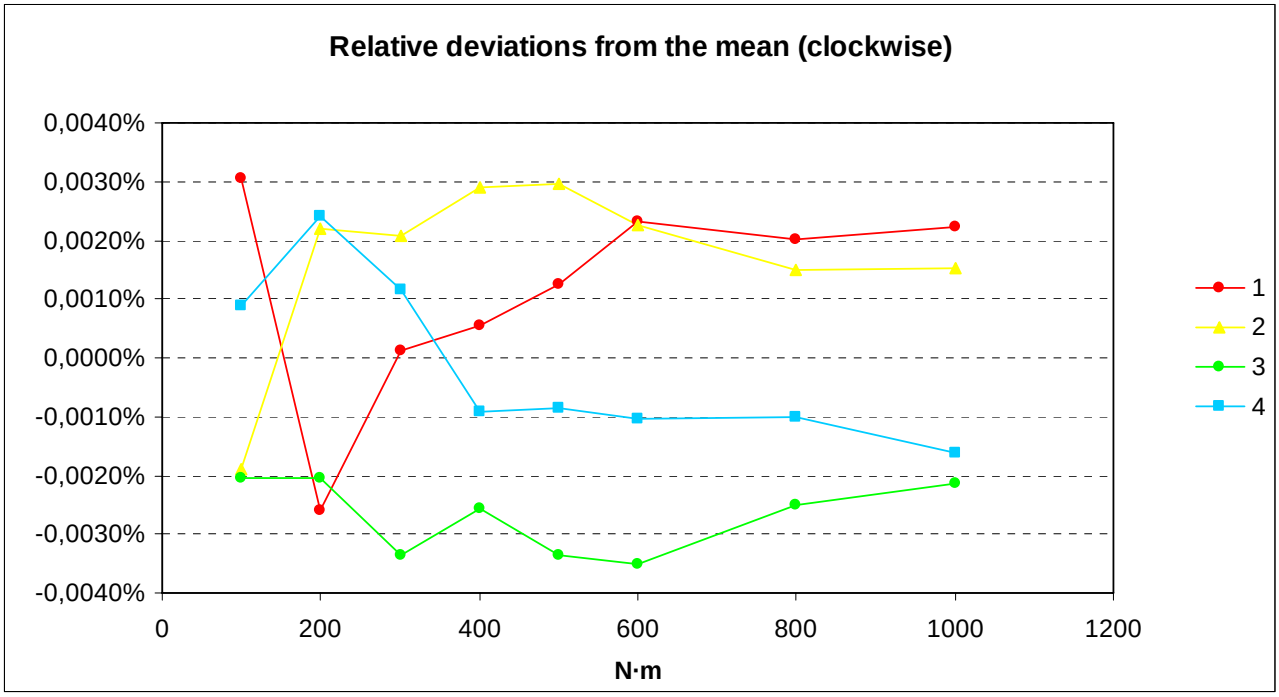
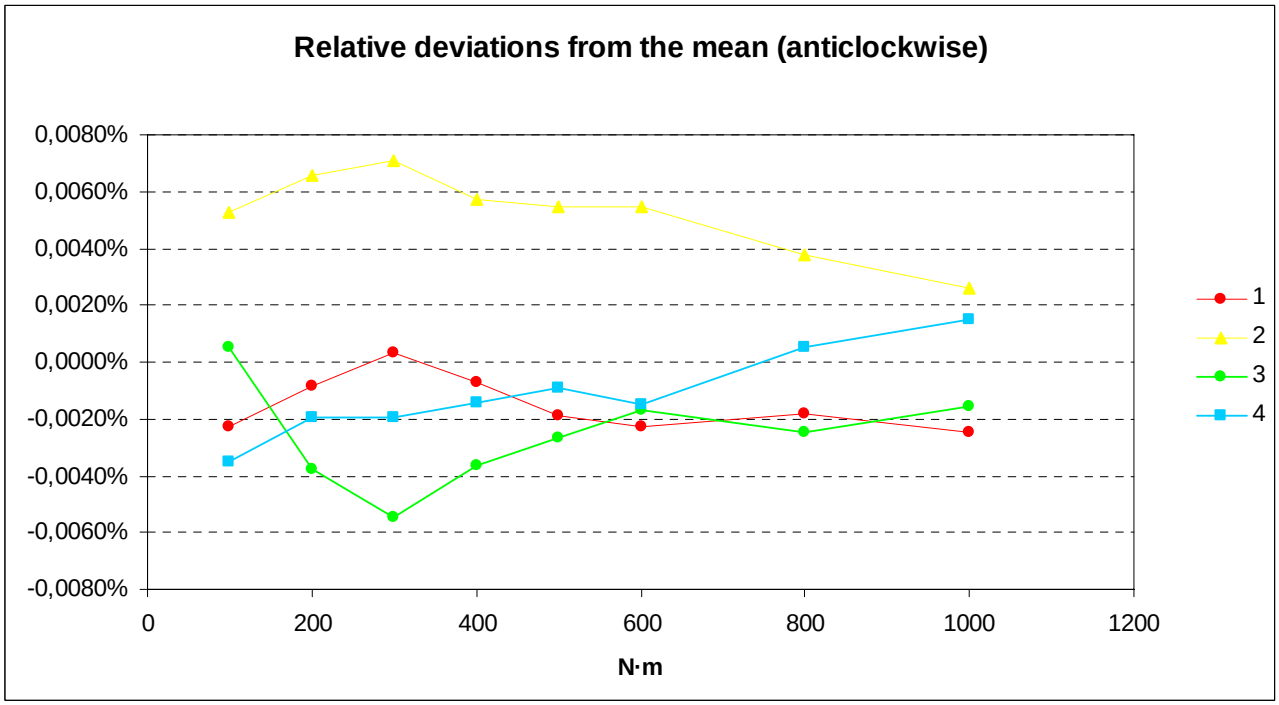


Figure 2: Relative variation of the measurements with the mean value as a reference for the 1000 N·m standard torque wrench (anticlockwise)



CEM results for the 100 N·m standard torque wrench have been (clockwise table 7 and anticlockwise table 8):

Table 7: CEM results for the 100 N·m standard torque wrench (clockwise)

M (N·m)	X_{r1} (mV/V)	X_{r2} (mV/V)	X_{r3} (mV/V)	X_{r4} (mV/V)	$X_{r\ mean}$ (mV/V)	$b'/X_{r\ mean}$ (%)	$b/X_{r\ mean}$ (%)	*r*/*M* (%)	*W* (%) (*k*=2)
10	0,208604	0,208607	0,208603	0,208622	0,208609	0,0058	0,0049	0,0005	0,022
20	0,417220	0,417224	0,417223	0,417240	0,417227	0,0019	0,0053	0,0002	0,021
30	0,625869	0,625860	0,625859	0,625877	0,625866	0,0016	0,0048	0,0002	0,021
40	0,834521	0,834512	0,834521	0,834533	0,834522	0,0008	0,0053	0,0001	0,021
50	1,043186	1,043177	1,043198	1,043196	1,043189	0,0009	0,0050	0,0001	0,021
60	1,251865	1,251869	1,251879	1,251877	1,251872	0,0002	0,0051	0,0001	0,021
80	1,669297	1,669297	1,669305	1,669287	1,669297	0,0005	0,0047	0,0001	0,021
100	2,086788	2,086790	2,086802	2,086769	2,086787	0,0006	0,0044	0,0000	0,021

Table 8: CEM results for the 100 N·m standard torque wrench (anticlockwise)

M (N·m)	X_{r1} (mV/V)	X_{r2} (mV/V)	X_{r3} (mV/V)	X_{r4} (mV/V)	$X_{r\ mean}$ (mV/V)	$b'/X_{r\ mean}$ (%)	$b/X_{r\ mean}$ (%)	*r*/*M* (%)	*W* (%) (*k*=2)
-10	-0,208596	-0,208597	-0,208601	-0,208589	-0,208596	0,0038	0,0046	0,0005	0,021
-20	-0,417203	-0,417198	-0,417209	-0,417194	-0,417201	0,0031	0,0039	0,0002	0,021
-30	-0,625818	-0,625815	-0,625825	-0,625796	-0,625813	0,0010	0,0036	0,0002	0,020
-40	-0,834438	-0,834432	-0,834442	-0,834419	-0,834433	0,0005	0,0031	0,0001	0,020
-50	-1,043082	-1,043069	-1,043062	-1,043061	-1,043069	0,0012	0,0029	0,0001	0,020
-60	-1,251743	-1,251731	-1,251723	-1,251727	-1,251731	0,0005	0,0029	0,0001	0,020
-80	-1,669159	-1,669134	-1,669137	-1,669132	-1,669140	0,0006	0,0026	0,0001	0,020
-100	-2,086637	-2,086631	-2,086604	-2,086596	-2,086617	0,0004	0,0022	0,0000	0,020

The following figures show the relative variation of the measurements with the mean value as a reference for clockwise (figure 4) and anticlockwise (figure 5) measurements versus the relative torque nominal value. It can be seen that all these variations are much less than the measurement uncertainties (***W*** (%) (*k*=2) **≥ 0,02**), so possible creep is negligible.

For all the measurements the maximum variation of temperature while measurements were performed has been 2 ºC for both laboratories. This fact may be a source of uncertainty, which effect is included in the reproducibility and repeatability test.

Figure 3: Relative variation of the measurements with the mean value as a reference for the 100 N·m standard torque wrench (clockwise)

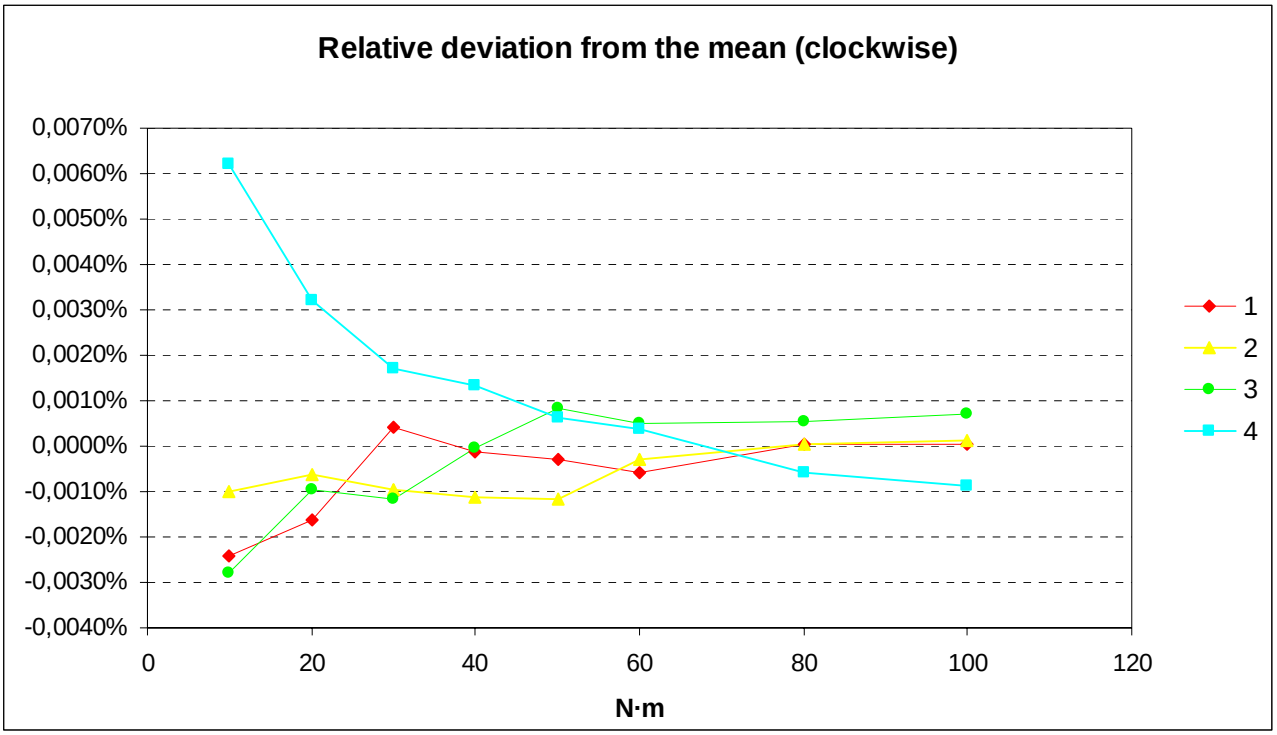
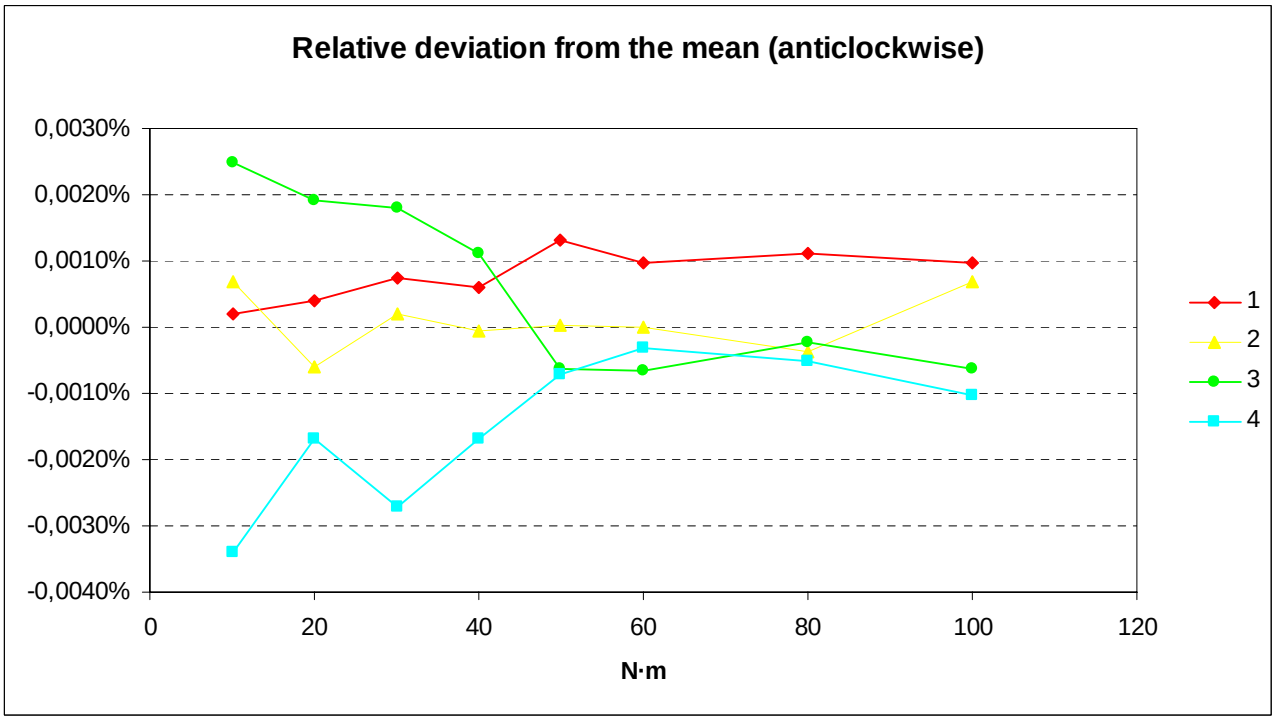


Figure 4: Relative variation of the measurements with the mean value as a reference for the 100 N·m standard torque wrench (anticlockwise)



4.- COMPARISON RESULTS

The analysis of the results has been performed according to Procedure A of [3] that includes a consistency check for the measurements. The measurement values for CEM have been the means among the 4 measurement values ($x_{r\ mean} = x_{CEM}$) and their uncertainties values the maximum uncertainties among the 4 measurement uncertainty values.

4.1- Weighted mean and χ^2 test

The following tables include CEM values (x_{CEM}), PTB values (x_{PTB}) and weighted means ($u_{weighted}$) with their uncertainties (u_{CEM}, u_{PTB}, $u_{weighted}$) for each standard torque wrench and clockwise or anticlockwise cases. It also includes the observed chi squared values χ^2_{obs} as well as the probabilities $\Pr\{\chi^2(\upsilon=1) > \chi^2_{obs}\}$. If these probabilities are more than 0,05 the measurement values are consistent.

Table 9: CEM and PTB values and their weighted mean with their uncertainties (in mV/V) with the consistency evaluation for the 1000 N·m standard torque wrench (clockwise)

M (N·m)	x_{CEM} (mV/V)	u_{CEM} (mV/V)	x_{PTB} (mV/V)	u_{PTB} (mV/V)	$x_{weighted}$ (mV/V)	$u_{weighted}$ (mV/V)	χ^2_{obs}	$\Pr\{\chi^2(\upsilon=1) > \chi^2_{obs}\}$
100	0,162332	$2,0\times10^{-5}$	0,162313	$1,8\times10^{-5}$	0,162322	$1,3\times10^{-5}$	0,6	0,46
200	0,324529	$3,7\times10^{-5}$	0,324475	$3,6\times10^{-5}$	0,324501	$2,6\times10^{-5}$	1,1	0,30
300	0,486689	$5,1\times10^{-5}$	0,486588	$5,4\times10^{-5}$	0,486641	$3,7\times10^{-5}$	1,9	0,17
400	0,648844	$6,8\times10^{-5}$	0,648694	$7,2\times10^{-5}$	0,648774	$4,9\times10^{-5}$	2,3	0,13
500	0,811011	$8,4\times10^{-5}$	0,810805	$8,8\times10^{-5}$	0,810913	$6,1\times10^{-5}$	2,9	0,09
600	0,97318	10×10^{-5}	0,97293	11×10^{-5}	0,973063	$7,3\times10^{-5}$	2,8	0,10
800	1,29751	13×10^{-5}	1,29718	14×10^{-5}	1,297360	$9,7\times10^{-5}$	3,0	0,09
1000	1,62182	16×10^{-5}	1,62144	18×10^{-5}	1,62165	12×10^{-5}	2,4	0,12

Table 10: CEM and PTB values and their weighted mean with their uncertainties (in mV/V) with the consistency evaluation for the 1000 N·m standard torque wrench (anticlockwise)

M (N·m)	x_{CEM} (mV/V)	u_{CEM} (mV/V)	x_{PTB} (mV/V)	u_{PTB} (mV/V)	$x_{weighted}$ (mV/V)	$u_{weighted}$ (mV/V)	χ^2_{obs}	$\Pr\{\chi^2(\upsilon=1) > \chi^2_{obs}\}$
-100	-0,162426	$1,9\times10^{-5}$	-0,162392	$2,1\times10^{-5}$	-0,162410	$1,4\times10^{-5}$	1,4	0,25
-200	-0,324667	$3,5\times10^{-5}$	-0,324597	$3,6\times10^{-5}$	-0,324633	$2,5\times10^{-5}$	2,0	0,16
-300	-0,486873	$5,1\times10^{-5}$	-0,486763	$5,3\times10^{-5}$	-0,486819	$3,7\times10^{-5}$	2,2	0,13
-400	-0,649062	$6,9\times10^{-5}$	-0,648913	$7,0\times10^{-5}$	-0,648988	$4,9\times10^{-5}$	2,3	0,13
-500	-0,811243	$8,5\times10^{-5}$	-0,811065	$8,9\times10^{-5}$	-0,811157	$6,2\times10^{-5}$	2,1	0,15
-600	-0,97343	10×10^{-5}	-0,97322	11×10^{-5}	-0,973331	$7,4\times10^{-5}$	2,0	0,16
-800	-1,29780	13×10^{-5}	-1,29751	15×10^{-5}	-1,297670	$9,8\times10^{-5}$	2,1	0,14
-1000	-1,62209	17×10^{-5}	-1,62176	19×10^{-5}	-1,62195	12×10^{-5}	1,8	0,19

Table 11: CEM and PTB values and their weighted mean with their uncertainties (in mV/V) with the consistency evaluation for the 100 N·m standard torque wrench (clockwise)

M (N·m)	x_{CEM} (mV/V)	u_{CEM} (mV/V)	x_{PTB} (mV/V)	u_{PTB} (mV/V)	$x_{weighted}$ (mV/V)	$u_{weighted}$ (mV/V)	χ^2_{obs}	$\Pr\{\chi^2(\upsilon=1) > \chi^2_{obs}\}$
10	0,208609	$2,3\times10^{-5}$	0,208610	$3,4\times10^{-5}$	0,208609	$1,9\times10^{-5}$	0,0	0,98
20	0,417227	$4,4\times10^{-5}$	0,417237	$5,5\times10^{-5}$	0,417231	$3,4\times10^{-5}$	0,0	0,89
30	0,625866	$6,4\times10^{-5}$	0,625872	$7,7\times10^{-5}$	0,625869	$4,9\times10^{-5}$	0,0	0,95
40	0,834522	$8,6\times10^{-5}$	0,83452	10×10^{-5}	0,834521	$6,5\times10^{-5}$	0,0	0,99
50	1,04319	11×10^{-5}	1,04318	12×10^{-5}	1,043187	$8,0\times10^{-5}$	0,0	0,98
60	1,25187	13×10^{-5}	1,25186	14×10^{-5}	1,25187	10×10^{-5}	0,0	0,94
80	1,66980	17×10^{-5}	1,66926	18×10^{-5}	1,66928	13×10^{-5}	0,0	0,88
100	2,08679	21×10^{-5}	2,08673	23×10^{-5}	2,08676	16×10^{-5}	0,0	0,85

Table 12: CEM and PTB values and their weighted mean with their uncertainties (in mV/V) with the consistency evaluation for the 100 N·m standard torque wrench (anticlockwise)

M (N·m)	X_{CEM} (mV/V)	u_{CEM} (mV/V)	X_{PTB} (mV/V)	u_{PTB} (mV/V)	$X_{weighted}$ (mV/V)	$u_{weighted}$ (mV/V)	χ^2_{obs}	$\Pr\{\chi^2(\upsilon=1)>\chi^2_{obs}\}$
-10	-0,208596	$2{,}2\times10^{-5}$	-0,208559	$3{,}5\times10^{-5}$	-0,208585	$1{,}9\times10^{-5}$	0,8	0,37
-20	-0,417201	$4{,}3\times10^{-5}$	-0,417132	$5{,}9\times10^{-5}$	-0,417176	$3{,}5\times10^{-5}$	0,9	0,34
-30	-0,625813	$6{,}4\times10^{-5}$	-0,625710	$7{,}9\times10^{-5}$	-0,625773	$5{,}0\times10^{-5}$	1,0	0,31
-40	-0,834433	$8{,}4\times10^{-5}$	-0,83430	10×10^{-5}	-0,834379	$6{,}6\times10^{-5}$	1,0	0,31
-50	-1,04307	11×10^{-5}	-1,04290	13×10^{-5}	-1,043001	$8{,}1\times10^{-5}$	1,0	0,31
-60	-1,25173	13×10^{-5}	-1,25153	16×10^{-5}	-1,251648	$9{,}8\times10^{-5}$	1,1	0,30
-80	-1,66914	17×10^{-5}	-1,66884	21×10^{-5}	-1,66902	13×10^{-5}	1,3	0,26
-100	-2,08662	21×10^{-5}	-2,08625	26×10^{-5}	-2,08647	16×10^{-5}	1,2	0,27

From the previous tables it is clear that all the measurements are consistent.

These results can also be expressed in N·m if the comparison reference value (weighted mean) is considered as the nominal torque value in N·m, i.e.:

$$X(\text{N·m}) = \frac{X(\text{mV / V})}{X_{\text{weighted}}(\text{mV / V})} \cdot M(\text{N·m})$$

The following results expressed in N·m are obtained:

Table 13: CEM and PTB values with their uncertainties (in N·m) for the 1000 N·m standard torque wrench

Clockwise					Anticlockwise				
M (N·m)	X_{CEM} (N·m)	u_{CEM} (N·m)	X_{PTB} (N·m)	u_{PTB} (N·m)	M (N·m)	X_{CEM} (N·m)	u_{CEM} (N·m)	X_{PTB} (N·m)	u_{PTB} (N·m)
100	100,007	0,012	99,994	0,011	-100	-100,009	0,012	-99,989	0,013
200	200,017	0,023	199,984	0,022	-200	-200,021	0,022	-199,978	0,022
300	300,030	0,031	299,967	0,033	-300	-300,033	0,032	-299,965	0,032
400	400,043	0,042	399,950	0,045	-400	-400,045	0,043	-399,953	0,043
500	500,060	0,052	499,933	0,054	-500	-500,053	0,053	-499,943	0,055
600	600,070	0,062	599,919	0,066	-600	-600,062	0,063	-599,932	0,066
800	800,095	0,081	799,889	0,088	-800	-800,081	0,082	-799,903	0,090
1000	1000,11	0,10	999,87	0,11	-1000	-1000,09	0,10	-999,89	0,12

Table 14: CEM and PTB values with their uncertainties (in N·m) for the 100 N·m standard torque wrench

Clockwise					Anticlockwise				
M (N·m)	X_{CEM} (N·m)	u_{CEM} (N·m)	X_{PTB} (N·m)	u_{PTB} (N·m)	M (N·m)	X_{CEM} (N·m)	u_{CEM} (N·m)	X_{PTB} (N·m)	u_{PTB} (N·m)
10	10,0000	0,0011	10,0000	0,0016	-10	-10,0005	0,0011	-9,9987	0,0017
20	19,9998	0,0021	20,0003	0,0026	-20	-20,0012	0,0021	-19,9979	0,0028
30	29,9999	0,0031	30,0002	0,0037	-30	-30,0019	0,0031	-29,9970	0,0038
40	40,0000	0,0041	39,9999	0,0048	-40	-40,0026	0,0040	-39,9961	0,0050
50	50,0001	0,0052	49,9999	0,0057	-50	-50,0033	0,0051	-49,9952	0,0061
60	60,0003	0,0062	59,9996	0,0068	-60	-60,0040	0,0061	-59,9941	0,0074
80	80,0009	0,0082	79,9990	0,0089	-80	-80,0057	0,0081	-79,991	0,010
100	100,001	0,010	99,998	0,011	-100	-100,007	0,010	-99,989	0,012

4.2- Degrees of equivalence

The degrees of equivalence are going to be calculated in a relative way in % as follows,

$$d_{CEM} = \frac{X_{CEM} - X_{weighted}}{X_{weighted}} \qquad W(d_{CEM}) = 2 \cdot \frac{\sqrt{u^2_{CEM} - u^2_{weighted}}}{|X_{weighted}|}$$

$$d_{PTB} = \frac{X_{PTB} - X_{weighted}}{X_{weighted}} \qquad W(d_{PTB}) = 2 \cdot \frac{\sqrt{u^2_{PTB} - u^2_{weighted}}}{|X_{weighted}|}$$

but also in N·m as follows,

$$d_{CEM} = X_{CEM} - X_{weighted} \qquad U(d_{CEM}) = 2 \cdot \sqrt{u^2_{CEM} - u^2_{weighted}}$$

$$d_{PTB} = X_{PTB} - X_{weighted} \qquad U(d_{PTB}) = 2 \cdot \sqrt{u^2_{PTB} - u^2_{weighted}}$$

The degree of equivalence between CEM and PTB is also going to be calculated in a relative way in % as follows,

$$d_{CEM-PTB} = \frac{X_{CEM} - X_{PTB}}{X_{weighted}} \qquad W(d_{CEM-PTB}) = 2 \cdot \frac{\sqrt{u^2_{CEM} + u^2_{PTB}}}{|X_{weighted}|}$$

but also in N·m as follows,

$$d_{CEM-PTB} = X_{CEM} - X_{PTB} \qquad U(d_{CEM-PTB}) = 2 \cdot \sqrt{u^2_{CEM} + u^2_{PTB}}$$

The following tables and figures show the results. In all cases $d_i < W(d_i)$ and $d_{ij} < W(d_{ij})$ (or $d_i < U(d_i)$ and $d_{ij} < U(d_{ij})$) so there is no inconsistency in the comparison.

Table 15: Degrees of equivalence for CEM and PTB and between CEM and PTB with their uncertainties for the 1000 N·m standard torque wrench (clockwise). The results are in % and N·m.

M (N·m)	d_{CEM} (%)	$W(d_{CEM})$ (%)	d_{PTB} (%)	$W(d_{PTB})$ (%)	$d_{CEM-PTB}$ (%)	$W(d_{CEM-PTB})$ (%)	d_{CEM} (N·m)	$U(d_{CEM})$ (N·m)	d_{PTB} (N·m)	$U(d_{PTB})$ (N·m)	$d_{CEM-PTB}$ (N·m)	$U(d_{CEM-PTB})$ (N·m)
100	0,007	0,018	-0,006	0,015	0,012	0,033	0,007	0,018	-0,006	0,015	0,012	0,033
200	0,008	0,016	-0,008	0,016	0,017	0,032	0,017	0,033	-0,016	0,031	0,033	0,064
300	0,010	0,014	-0,011	0,016	0,021	0,030	0,030	0,043	-0,033	0,048	0,062	0,091
400	0,011	0,014	-0,012	0,016	0,023	0,030	0,043	0,057	-0,050	0,065	0,093	0,122
500	0,012	0,014	-0,013	0,016	0,025	0,030	0,060	0,071	-0,067	0,08	0,13	0,150
600	0,012	0,014	-0,013	0,016	0,025	0,030	0,070	0,084	-0,081	0,10	0,15	0,181
800	0,012	0,014	-0,014	0,016	0,026	0,030	0,09	0,11	-0,11	0,13	0,21	0,239
1000	0,011	0,014	-0,013	0,016	0,023	0,030	0,11	0,14	-0,13	0,16	0,23	0,301

Figure 5: Degrees of equivalence for CEM and PTB for the 1000 N·m standard torque wrench (clockwise) in %.

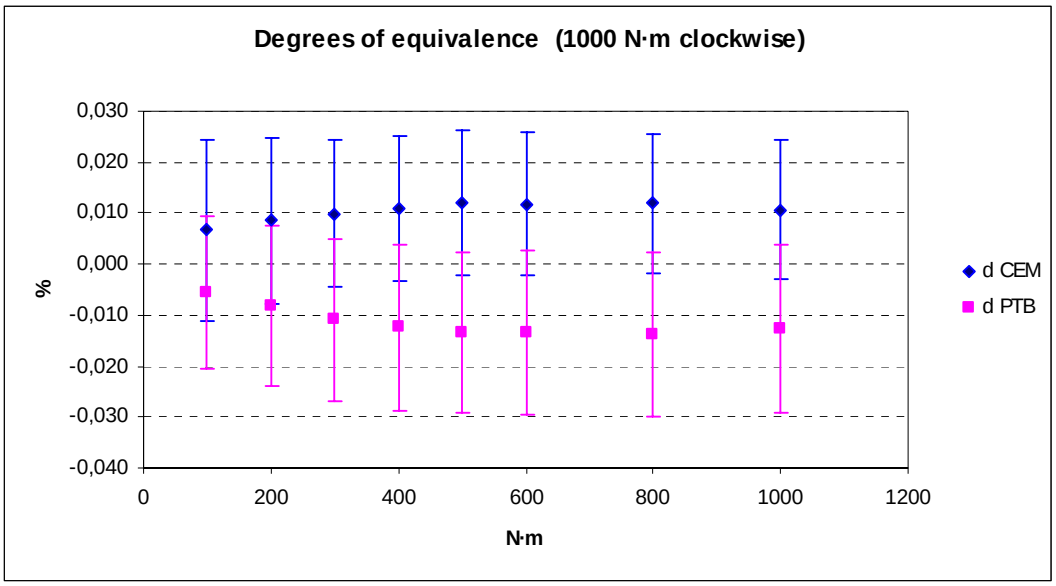


Figure 6: Degrees of equivalence between CEM and PTB for the 1000 N·m standard torque wrench (clockwise) in %.

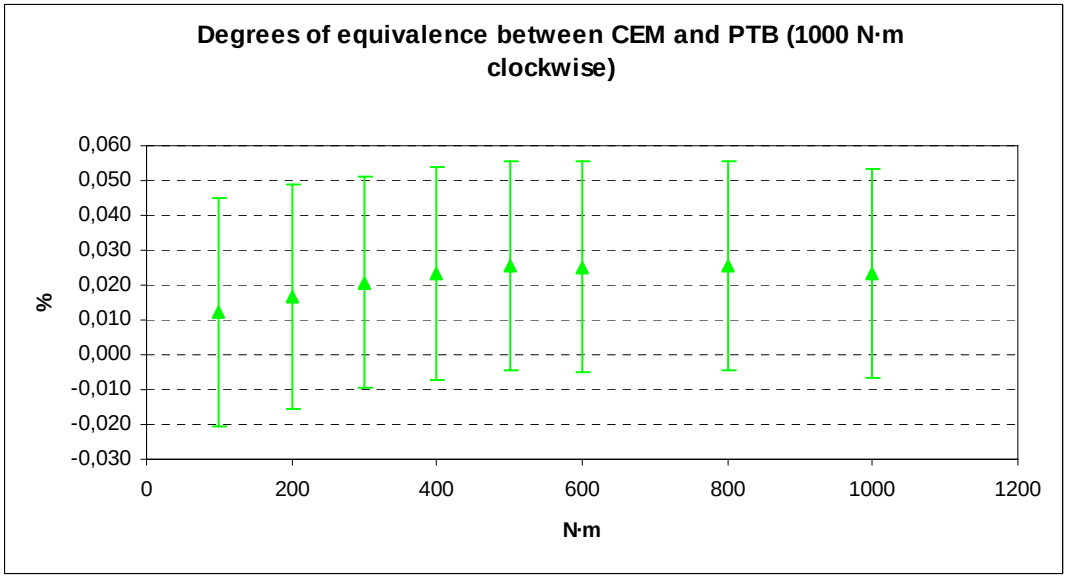


Figure 7: Degrees of equivalence for CEM and PTB for the 1000 N·m standard torque wrench (clockwise) in N·m.

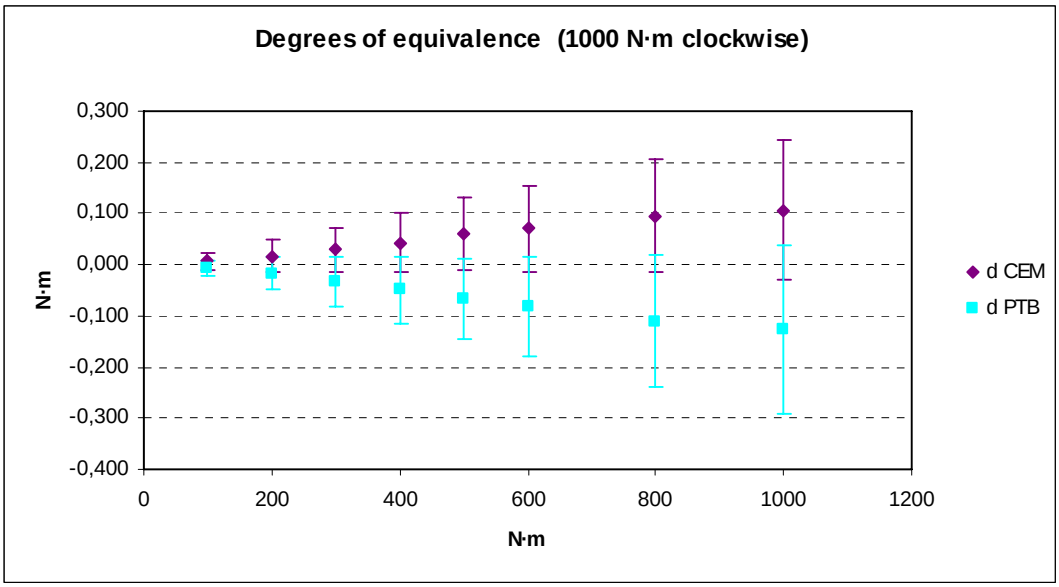


Figure 8: Degrees of equivalence between CEM and PTB for the 1000 N·m standard torque wrench (clockwise) in N·m.

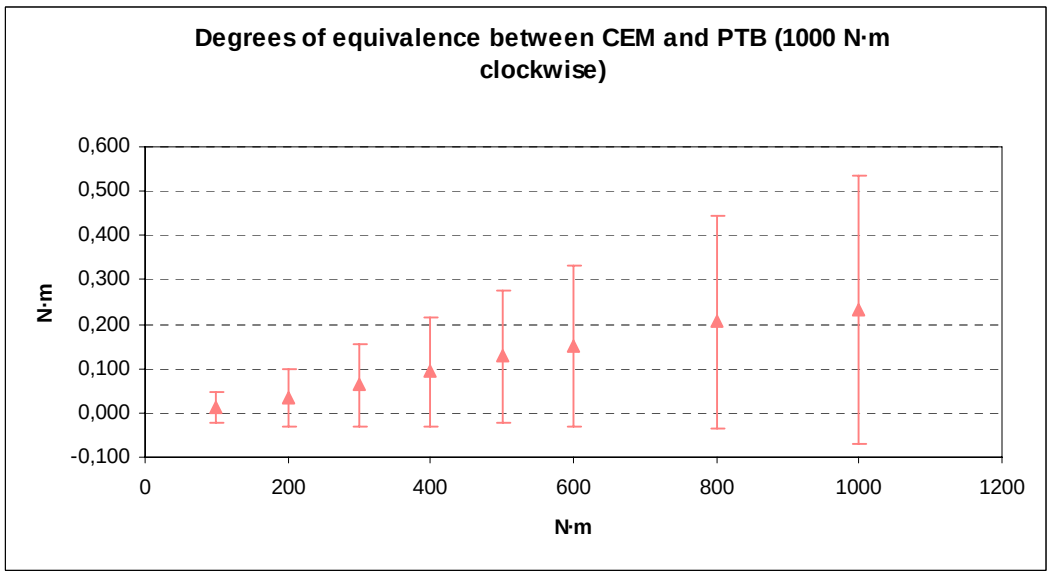


Table 16: Degrees of equivalence for CEM and PTB and between CEM and PTB with their uncertainties for the 1000 N·m standard torque wrench (anticlockwise). The results are in % and N·m.

M (N·m)	d_{CEM} (%)	$W(d_{CEM})$ (%)	d_{PTB} (%)	$W(d_{PTB})$ (%)	$d_{CEM-PTB}$ (%)	$W(d_{CEM-PTB})$ (%)	d_{CEM} (N·m)	$U(d_{CEM})$ (N·m)	d_{PTB} (N·m)	$U(d_{PTB})$ (N·m)	$d_{CEM-PTB}$ (N·m)	$U(d_{CEM-PTB})$ (N·m)
100	0,009	0,016	0,011	0,019	0,021	0,035	-0,009	0,016	0,011	0,019	-0,021	0,035
200	0,011	0,015	0,011	0,016	0,022	0,031	-0,021	0,030	0,022	0,032	-0,043	0,062
300	0,011	0,015	0,012	0,015	0,023	0,030	-0,033	0,044	0,035	0,046	-0,068	0,091
400	0,011	0,015	0,012	0,015	0,023	0,030	-0,045	0,060	0,047	0,061	-0,092	0,121
500	0,011	0,015	0,011	0,016	0,022	0,030	-0,053	0,073	0,057	0,079	-0,11	0,15
600	0,010	0,015	0,011	0,016	0,022	0,030	-0,062	0,087	0,068	0,096	-0,13	0,18
800	0,010	0,014	0,012	0,017	0,022	0,030	-0,08	0,11	0,10	0,13	-0,18	0,24
1000	0,009	0,014	0,011	0,017	0,020	0,031	-0,09	0,14	0,11	0,17	-0,20	0,31

Figure 9: Degrees of equivalence for CEM and PTB for the 1000 N·m standard torque wrench (anticlockwise) in %.

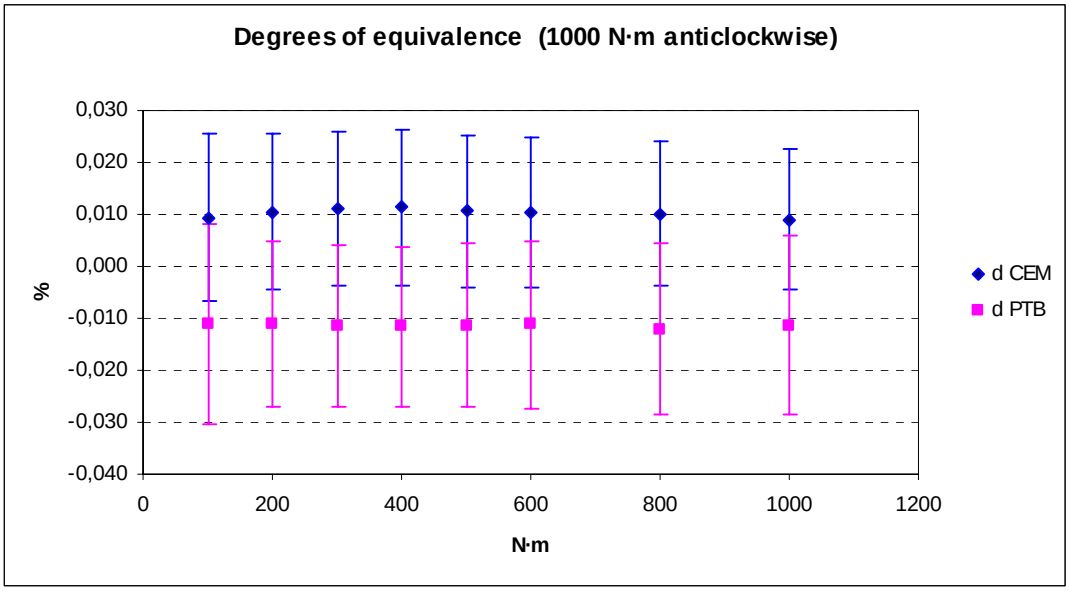


Figure 10: Degrees of equivalence between CEM and PTB for the 1000 N·m standard torque wrench (anticlockwise) in %.

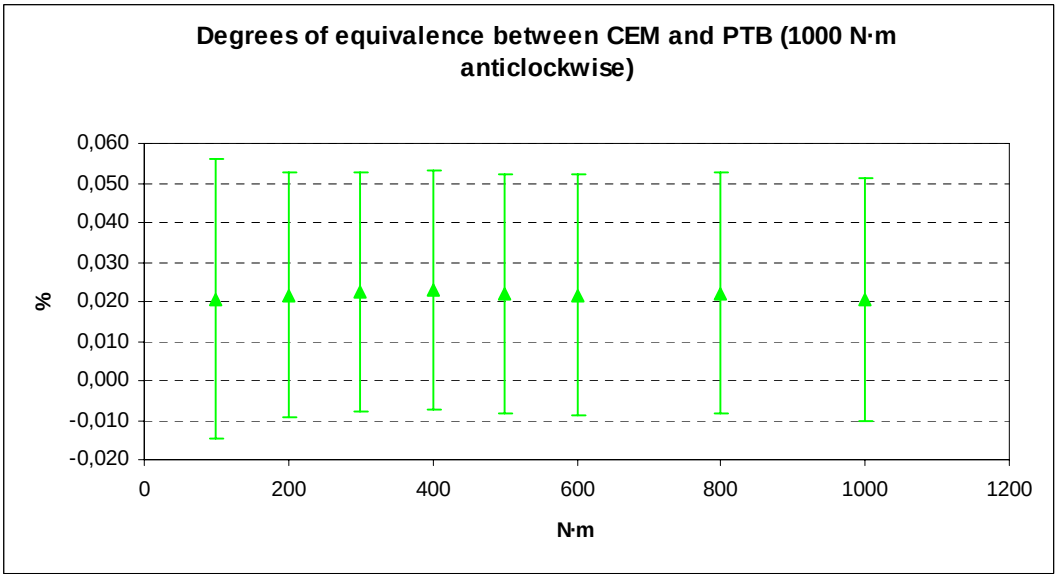


Figure 11: Degrees of equivalence for CEM and PTB for the 1000 N·m standard torque wrench (anticlockwise) in N·m.

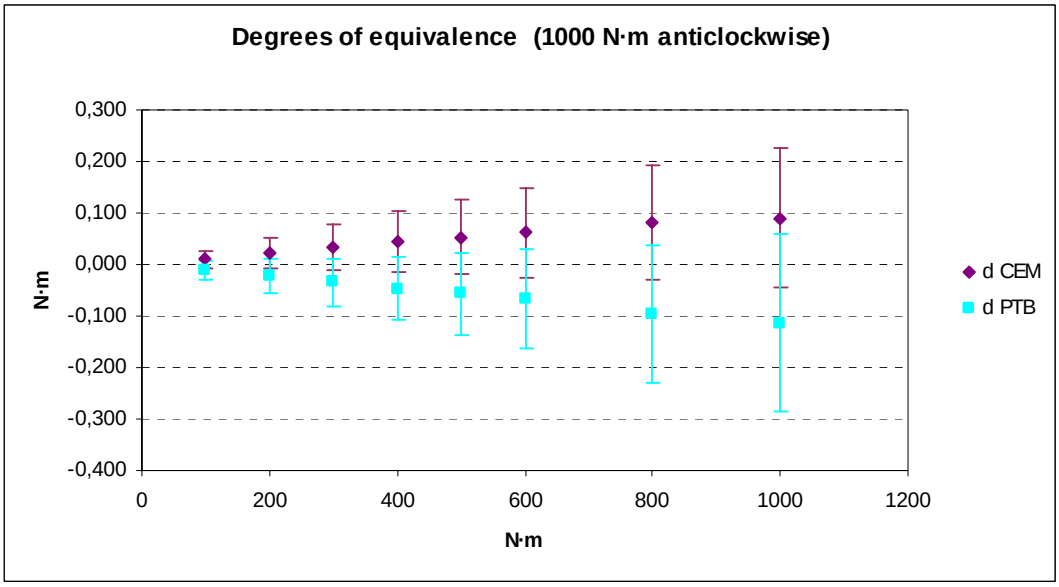


Figure 12: Degrees of equivalence between CEM and PTB for the 1000 N·m standard torque wrench (anticlockwise) in N·m.

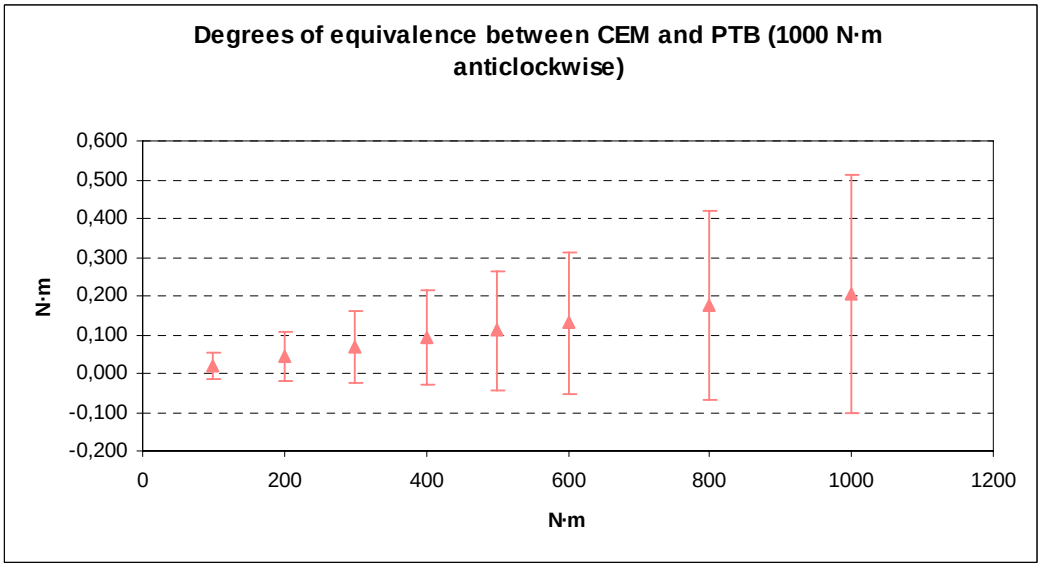


Table 17: Degrees of equivalence for CEM and PTB and between CEM and PTB with their uncertainties for the 100 N·m standard torque wrench (clockwise). The results are in % and N·m.

M (N·m)	d_{CEM} (%)	$W(d_{CEM})$ (%)	d_{PTB} (%)	$W(d_{PTB})$ (%)	$d_{CEM-PTB}$ (%)	$W(d_{CEM-PTB})$ (%)	d_{CEM} (N·m)	$U(d_{CEM})$ (N·m)	d_{PTB} (N·m)	$U(d_{PTB})$ (N·m)	$d_{CEM-PTB}$ (N·m)	$U(d_{CEM-PTB})$ (N·m)
10	0,000	0,012	0,000	0,027	0,000	0,039	0,0000	0,0012	0,0000	0,0027	0,0000	0,0039
20	-0,001	0,013	0,001	0,021	-0,002	0,034	-0,0002	0,0026	0,0003	0,0042	-0,0005	0,0067
30	0,000	0,013	0,001	0,019	-0,001	0,032	-0,0001	0,0040	0,0002	0,0056	0,000	0,010
40	0,000	0,014	0,000	0,018	0,000	0,032	0,0000	0,0054	-0,0001	0,0072	0,000	0,013
50	0,000	0,014	0,000	0,017	0,000	0,031	0,0001	0,0069	-0,0001	0,0085	0,000	0,015
60	0,000	0,014	-0,001	0,017	0,001	0,031	0,0003	0,0084	0,000	0,010	0,001	0,018
80	0,001	0,014	-0,001	0,016	0,002	0,030	0,001	0,011	-0,001	0,013	0,002	0,024
100	0,001	0,014	-0,002	0,016	0,003	0,030	0,001	0,014	-0,002	0,016	0,003	0,030

Figure 13: Degrees of equivalence for CEM and PTB for the 100 N·m standard torque wrench (clockwise) in %.

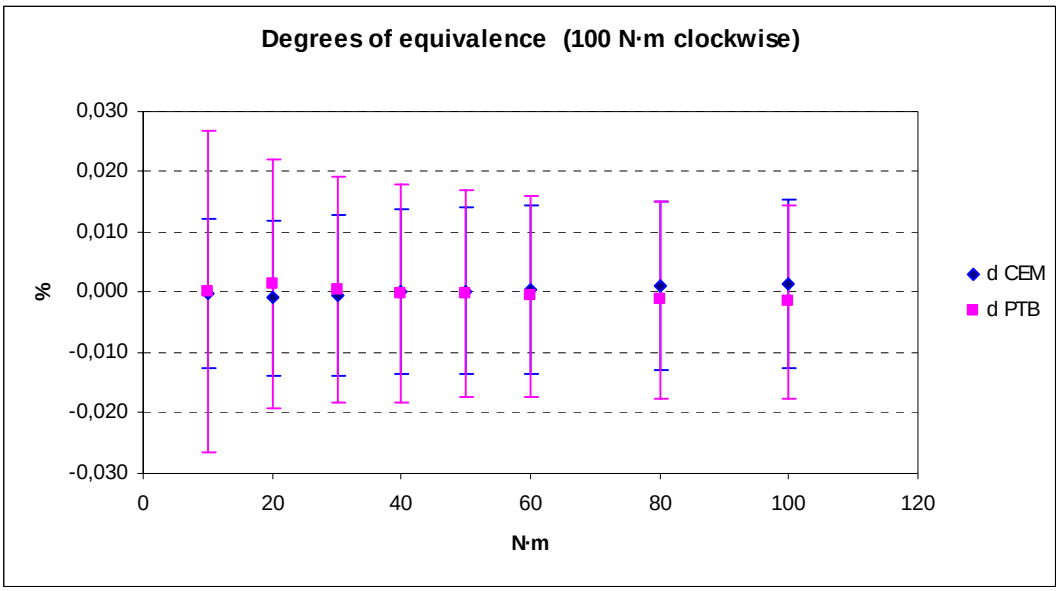


Figure 14: Degrees of equivalence between CEM and PTB for the 100 N·m standard torque wrench (clockwise) in %.

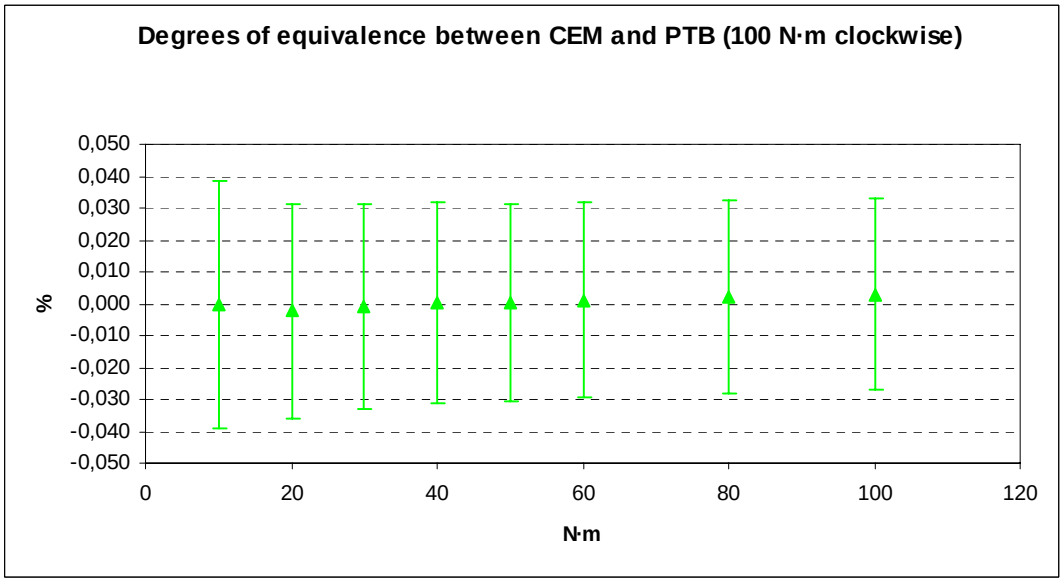


Figure 15: Degrees of equivalence for CEM and PTB for the 100 N·m standard torque wrench (clockwise) in N·m.

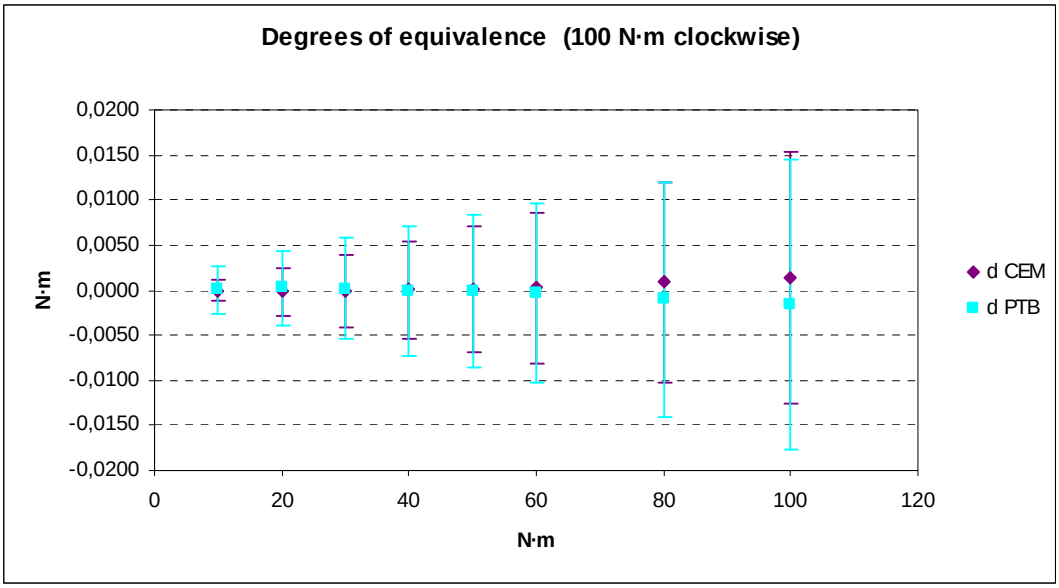


Figure 16: Degrees of equivalence between CEM and PTB for the 100 N·m standard torque wrench (clockwise) in N·m.

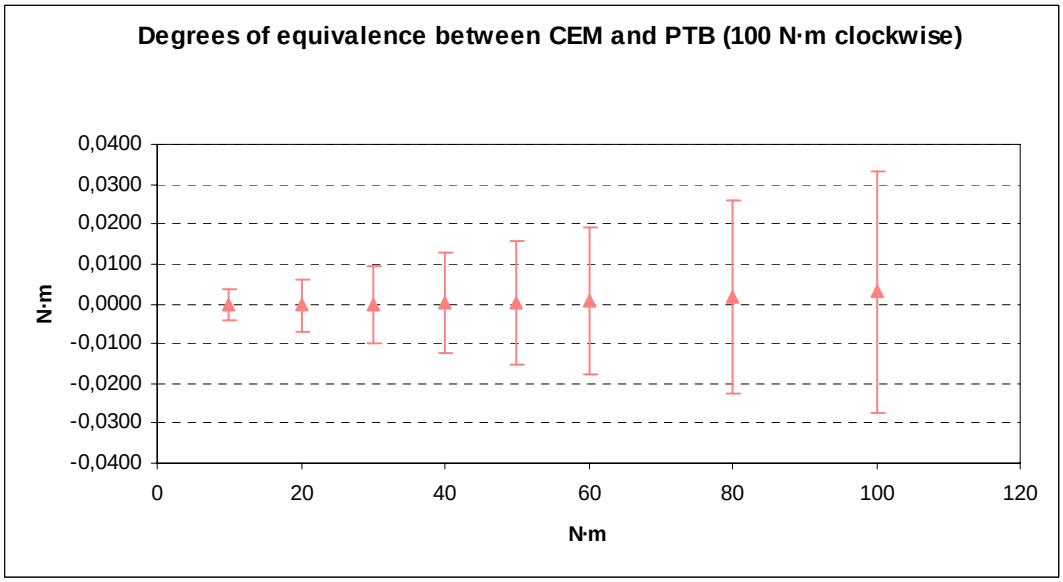


Table 18: Degrees of equivalence for CEM and PTB and between CEM and PTB with their uncertainties for the 1000 N·m standard torque wrench (anticlockwise). The results are in % and N·m.

M (N·m)	d_{CEM} (%)	$W(d_{CEM})$ (%)	d_{PTB} (%)	$W(d_{PTB})$ (%)	$d_{CEM-PTB}$ (%)	$W(d_{CEM-PTB})$ (%)	d_{CEM} (N·m)	$U(d_{CEM})$ (N·m)	d_{PTB} (N·m)	$U(d_{PTB})$ (N·m)	$d_{CEM-PTB}$ (N·m)	$U(d_{CEM-PTB})$ (N·m)
-10	0,005	0,011	-0,013	0,028	0,018	0,040	-0,0005	0,0011	0,0013	0,0028	-0,0018	0,0040
-20	0,006	0,012	-0,011	0,023	0,017	0,035	-0,0012	0,0025	0,0021	0,0045	-0,0033	0,0070
-30	0,006	0,013	-0,010	0,020	0,017	0,033	-0,0019	0,0038	0,0030	0,0059	-0,005	0,010
-40	0,006	0,013	-0,010	0,019	0,016	0,032	-0,0026	0,0051	0,0039	0,0078	-0,007	0,013
-50	0,007	0,013	-0,010	0,019	0,016	0,032	-0,0033	0,0064	0,0048	0,0095	-0,008	0,016
-60	0,007	0,013	-0,010	0,019	0,017	0,032	-0,0040	0,0077	0,006	0,011	-0,010	0,019
-80	0,007	0,013	-0,011	0,020	0,018	0,032	-0,006	0,010	0,009	0,016	-0,015	0,026
-100	0,007	0,013	-0,011	0,019	0,018	0,032	-0,007	0,013	0,011	0,019	-0,018	0,032

Figure 17: Degrees of equivalence for CEM and PTB for the 100 N·m standard torque wrench (anticlockwise) in %.

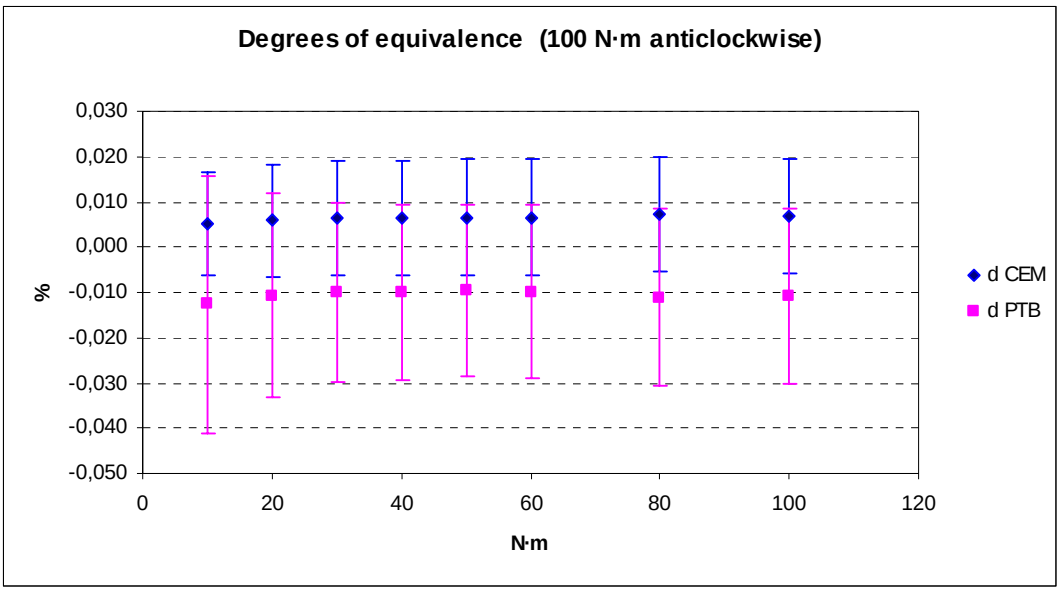


Figure 18: Degrees of equivalence between CEM and PTB for the 100 N·m standard torque wrench (anticlockwise) in %.

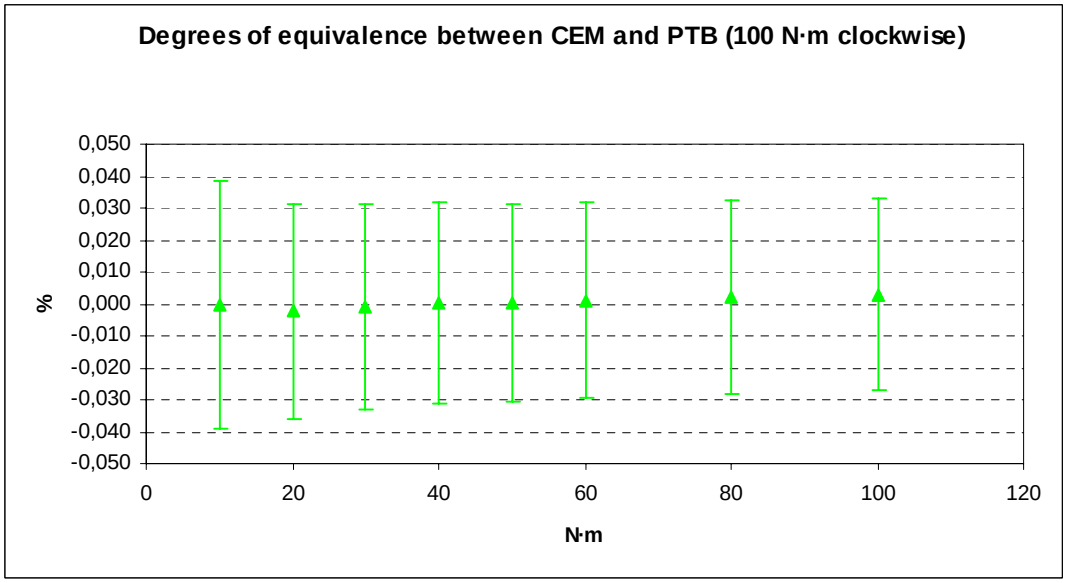


Figure 19: Degrees of equivalence for CEM and PTB for the 100 N·m standard torque wrench (anticlockwise) in N·m.

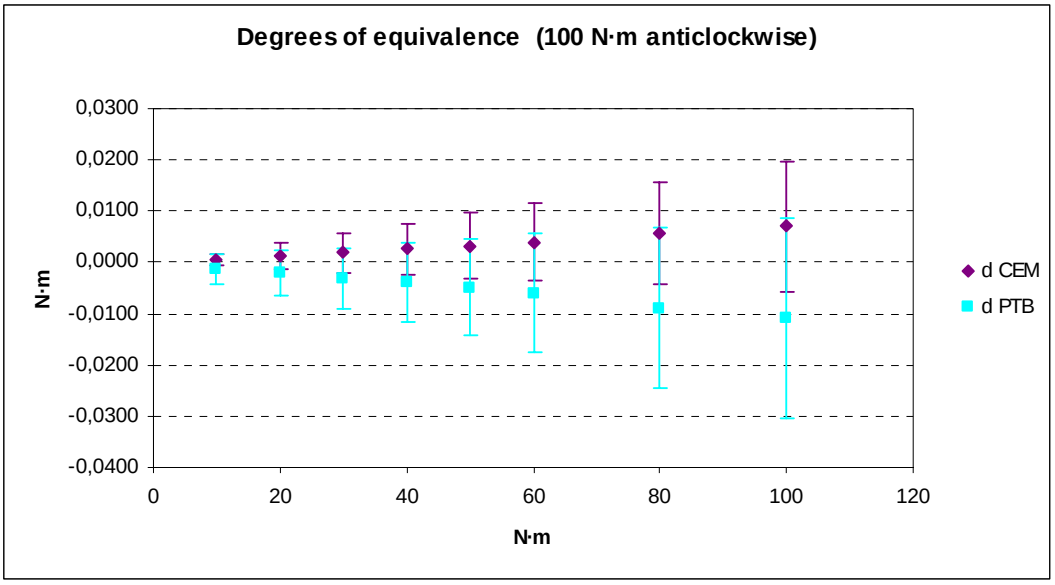
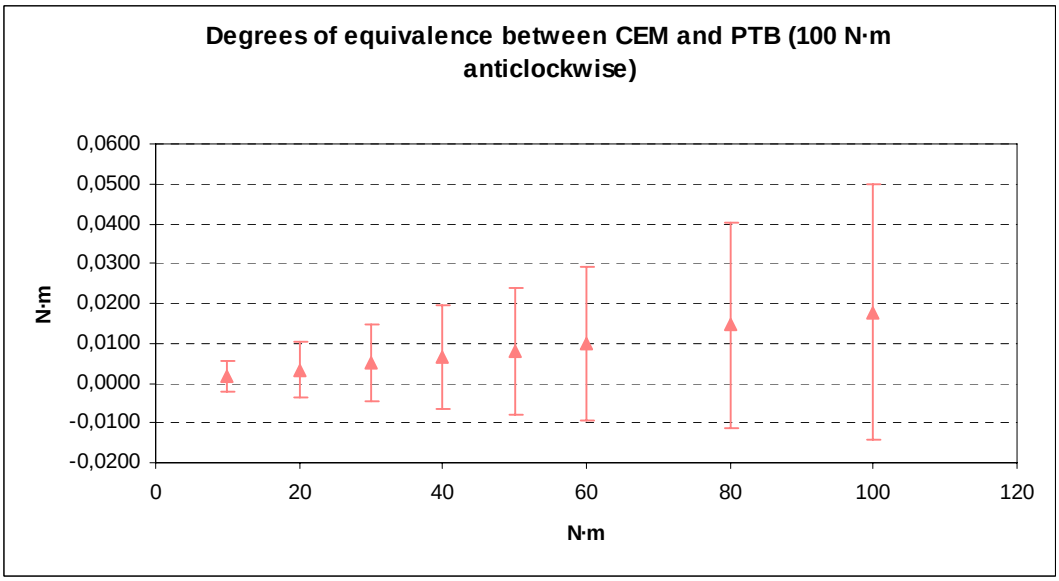


Figure 20: Degrees of equivalence between CEM and PTB for the 100 N·m standard torque wrench (anticlockwise) in N·m.



5.- REFERENCES

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[2] JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement.

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