技術報告

Inter-laboratory Comparison of Reference Torque Wrench Calibration between NMIJ and PTB at the Range from 200 N·m to 2 kN·m¶

Koji OGUSHI *, Atsuhiro NISHINO *, Koji MAEDA *, Kazunaga UEDA *,
Andreas BRÜGE ** and Dirk RÖSKE **

Abstract

An inter-laboratory comparison (bilateral comparison) of reference torque wrench calibration was conducted between NMIJ and PTB using a torque transducer in the form of a torque wrench, "TTS/3kNm," as a transfer device. Although the rated capacity of the transducer is 3 kN·m, the calibration range from 200 N·m to 2 kN·m was selected. Each loading time schedule used in daily calibration was also adopted in this comparison. Calibration results obtained by both laboratories coincided with the range of uncertainties, at least for upper steps than 800 N·m.

Keywords: Torque, Torque wrench, Reference torque wrench, Comparison, Square drive.

1. Introduction

A reference torque wrench (RTW[1]) is a key device in the establishment of an SI traceability system in torque metrology[1)]. General hand torque wrenches are usually calibrated or verified using torque wrench testers (TWTs, or torque wrench calibration devices (TWCDs)). Torque wrench testers are calibrated using RTWs. The SI traceability of torque can be completed by calibrating RTWs at accredited calibration laboratories or national metrology institutes (NMIs).

Since 2003, the RTW calibration service for the range from 5 N·m to 1 kN·m has been provided by the National Metrology Institute of Japan (NMIJ) to industry with a calibration and measurement capability (CMC) of 7.0×10^{-5} [2)]. In this service, a deadweight type torque standard machine with a rated capacity of 1 kN·m (1-kN·m-DWTSM) is used. The calibration range was expanded to 5 kN·m using another deadweight type torque standard machine with a rated capacity of 20 kN·m (20-kN·m-DWTSM) with a CMC of 1.0×10^{-4} [3)] in 2009, based on the strong demand from Japanese industry. Such large-capacity torque wrenches are used, for example, in the manufacture of ships, construction machinery, and buildings. Here, hand-loading could be no longer applied at the loading points of the lever of the torque wrench because of extremely large loading. In such a case, a loading apparatus such as a winch is used.

The RTW is defined as a complete set consisting of a torque transducer in the form of a torque wrench, a cable, and an amplifier/indicator. The number of laboratories providing calibration of RTWs remains quite small. The Physikalisch-Technische Bundesanstalt (PTB) has had a great deal of experience in the calibration of RTWs over nearly the last two decades[4),5)]. In the ordinary calibration service of over 1 kN·m range, a comparison type (or reference type) torque calibration machine with a rated

---

¶ Reprinted from Proceedings of XX IMEKO World Congress, TC3, Busan, Republic of Korea, 2012, by courtesy of IMEKO Secretariat.

* National Metrology Institute of Japan, AIST, Tsukuba, Japan.

** Physikalisch-Technische Bundesanstalt, Braunschweig, Germany.

1 In Japan, the term "reference torque wrench" has been stated in the Measurement Law, whereas it has been revised to "Transfer torque wrench" in DKD-R 3-7: 2003 in Germany.

capacity of 5 kN·m (5-kN·m-Dm-KE) was used for the calibration at the PTB. The CMC for all types of calibration has been declared to be less than 2.0×10^{-4} as relative expanded uncertainty ($k=2$) in the range from 100 N·m to 5 kN·m. A deadweight type torque standard machine with a rated capacity of 20 kN·m (20-kN·m-DmNME) also has capability of RTW calibration with appropriate adapters. The machine, however, is not ordinarily used for the RTW calibration service and the CMC for RTW calibration has not been declared by using the 20-kN·m-DmNME (the CMC of torque measuring devices (TMDs) for pure torque has been declared as 2.0×10^{-5}, and the inter-laboratory comparison of the TMD calibration has been conducted with NMIJ in 2004 [6]).

As mentioned above, two NMIs, PTB and NMIJ have provided an RTW calibration service. Unfortunately, however, there exists neither standard documentation nor mutually agreed international guidelines for the method of calibrating RTWs. The authors have compared the calibration results for an RTW obtained by NMIJ and PTB under their respective procedures in order to confirm the equivalence of RTW calibration capability at these institutes in the range from 10 N·m to 100 N·m [2]. In the present paper, the authors report the inter-comparison results of the calibration capability for RTWs between NMIJ and PTB in the expanded range of over 1 kN·m.

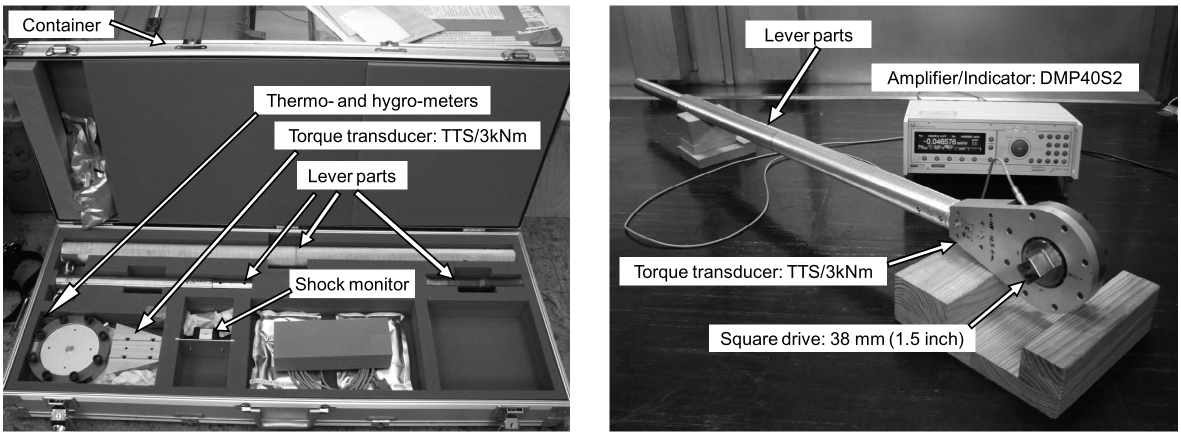
2. Experimental Conditions

2.1. Equipment

A torque transducer with a rated capacity of 3 kN·m (TTS/3kNm, manufactured by HBM GmbH) was transferred by air from NMIJ to PTB, and vice versa. The transducer was packed in a container as shown in Fig. 1(a). The surrounding environment (temperature and humidity) of the transducer during transportation has been recorded by thermo- and hygrometers, and shocks subjected to the container were recorded by a shock monitor. The temperature ranged from 15 ℃ to 28 ℃ and the relative humidity ranged from 38% to 70% during transportation. No large shock to the container was observed.

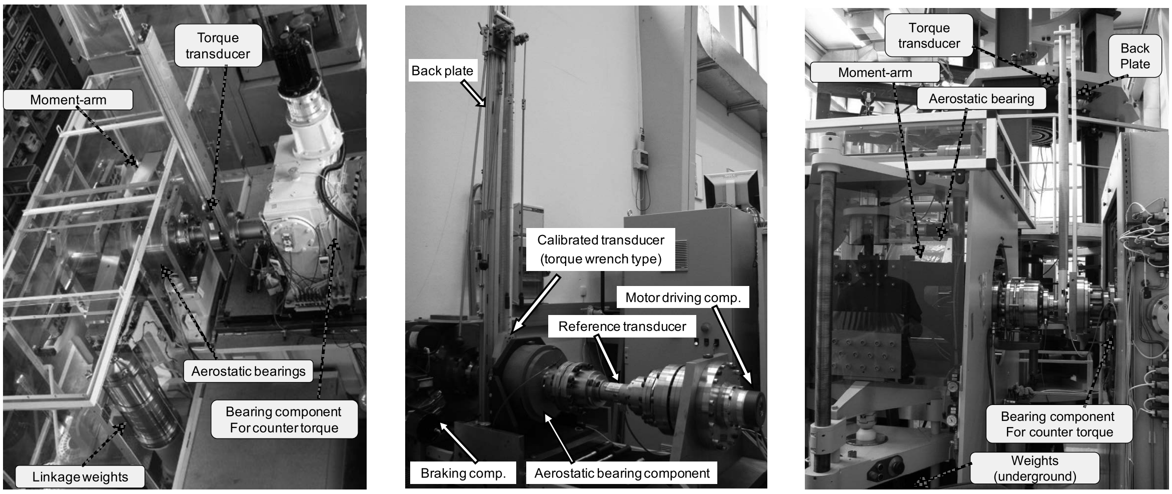
An identical amplifier/indicator (DMP40, manufactured by HBM GmbH) from each laboratory was connected to the TTS/3kNm and used for the measurement during each calibration. Here, a bridge calibrator (BN100A, manufactured by HBM GmbH) which calibrates the AC bridge voltage with an excitation voltage of 5 V and a carrier frequency of 225 Hz, was also transferred from NMIJ to PTB by air transport. Amplifier/indicators were calibrated before and after each torque calibration by the BN100A. Figure 1(b) shows the complete assembly of RTW (TTS/3kNm and DMP40).

A deadweight type torque standard machine with a rated capacity of 20 kN·m (20-kN·m-DWTSM) was used for the calibration at the NMIJ. The calibration and



(a) Transfer devices and container　　(b) Complete assembly of the RTW

Fig. 1.　Reference torque wrench



(a) 20-kN·m-DWTSM at NMIJ (b) 5-kN·m-Dm-KE at PTB (c) 20-kN·m-DmNME at PTB

Fig. 2. Torque calibration equipment at each NMI

measurement capability (CMC) for the RTW calibration has been declared to be less than 1.0×10^{-4} as relative expanded uncertainty ($k = 2$) in the range from 200 N·m to 5 kN·m.

A comparison type (or reference type) torque calibration machine with a rated capacity of 5 kN·m (5-kN·m-Dm-KE) was used for the calibration at the PTB. The CMC for all types of calibration has been declared to be less than 2.0×10^{-4} as relative expanded uncertainty ($k = 2$) in the range from 100 N·m to 5 kN·m.

Another deadweight type torque calibration machine with a rated capacity of 20 kN·m (20-kN·m-DmNME) was also used for the calibration at the PTB. The CMC for pure torque calibration has been declared to be less than 2.0×10^{-5} as relative expanded uncertainty ($k = 2$) in the range of from 100 N·m to 20 kN·m. The CMC for RTW calibration, however, has not been expressed since the 20-kN·m-DmNME is not used for ordinary calibration service of RTWs.

The 20-kN·m-DWTSM, 5-kN·m-Dm-KE and 20-kN·m-DmNME are shown in Figs. 2(a) to 2(c).

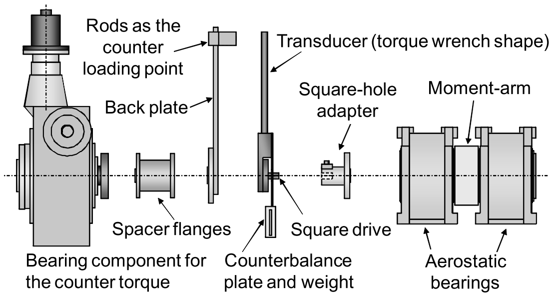


Fig. 3. Mounting method of the transducer of RTW on the 20-kN·m-DWTSM

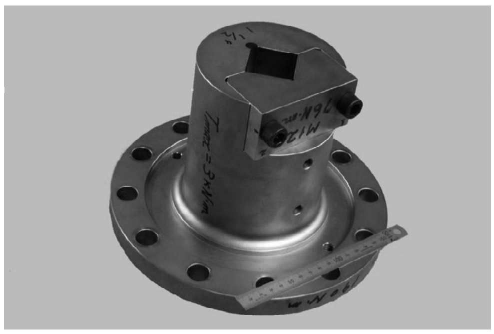


Fig. 4. Square hole adapter flange (nominal size: 38 mm) used in the 20-kN·m-DWTSM

2.2. Calibration procedure

2.2.1. Calibration at NMIJ

In the pre- and post-calibrations at NMIJ, the torque transducer was mounted on the 20-kN·m-DWTSM as shown in Fig. 3. The square drive of the torque transducer on the measuring side was clamped to a special square hole adapter (as shown in Fig. 4). The loading point on the lever of the RTW was supported in the circumferential direction with a back plate fixed to the bearing component for the counter torque of the 20-kN·m-DWTSM. Diaphragm (elastic) couplings were not used for the calibration of the RTW in order to support the torque transducer vertically as much as possible on the measurement axis.

First, two measurement cycles of increasing and decreasing torque were performed after preloading the RTW three times in the rotational mounting position of 0°. Eight torque steps of 10, 20, 30, 40, 50, 60, 80, and 100 % of the maximum torque basically constitute the measurement cycle. One measurement cycle of increasing and decreasing torque was performed after preloading the RTW once after changing the rotational position to 120° and 240°, respectively, as shown in Fig. 5.

In order to attain zero balance, an initial torque of 1 to 2 % of the maximum torque of the RTW was loaded by placing weights on the end of the moment-arm. Moreover, counterbalance plates and weights were attached to the RTW on the opposite side of the lever to generate an additional small constant torque of 1 to 2 % in any mounting position. An example of the mounting method of the transducer on the 20-kN·m-DWTSM is shown in Fig. 6. These techniques are important for the calibration of RTWs when using deadweight type and horizontal measurement axis type torque standard machines [2].

The calibration sequence was performed according to the defined timetable in order to minimize the influence of the creep characteristic of the RTW. Each datum should be recorded once, 30 seconds after each torque step has been achieved.

After measurement at 240°, one measurement cycle of increasing and decreasing torque was performed changing the lever length of the RTW from the average lever length (1,750 mm) to the minimum lever length (1,300 mm) by moving the rods at the counter loading point.

Calibration was conducted separately for the clockwise (CW) and counterclockwise (CCW) directions.

2.2.2. Calibration at PTB

In the calibration at PTB, first, the torque transducer was mounted on the 5-kN·m-Dm-KE, as shown in Fig. 7. Calibration with the 5-kN·m-Dm-KE was essentially similar to the pre- and post-calibrations with the 20-kN·m-DWTSM at NMIJ except for the following conditions:

(1) The square drive of TTS/3kNm was just inserted into the square hole adapter (as shown in Fig. 8) of the 5-kN·m-Dm-KE but not clamped. The inclined posture of

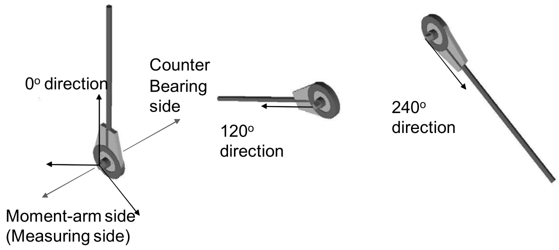


Fig. 5. Rotational mounting position of the transducer at NMIJ

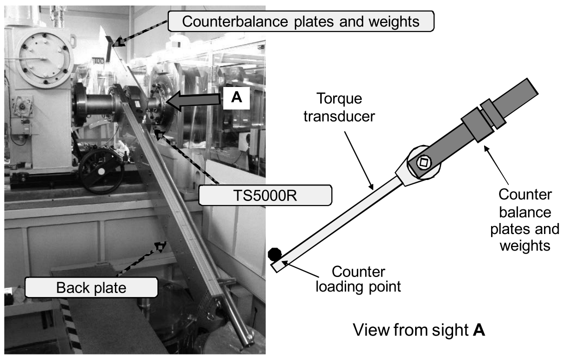


Fig. 6. Example of mounting method by changing the lever direction (in the case of 120°)

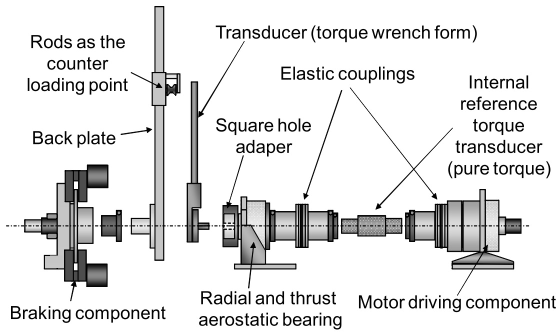


Fig. 7. Mounting method of the transducer of RTW on the 5-kN·m-Dm-KE

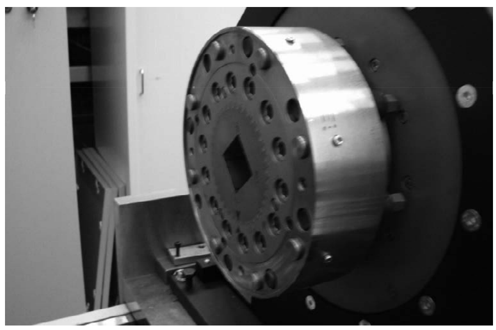


Fig. 8. Square hole adapter flange (nominal size: 38 mm) used in the 5-kN·m-Dm-KE

the lever was automatically adjusted by cone spindles at the loading points of the back plate.

(2) The rotational mounting position was changed by maintaining the lever of the transducer in the vertical direction and changing the direction of the detachable square drive from the body of the transducer by pitches of 0°, 90°, and 180°, as shown in Fig. 9. In this case, counterbalance plates and weights were not required.

Second, the torque transducer was mounted on the 20-kN·m-DmNME, as shown in Fig. 10. Calibration with the 20-kN·m-Dm-NME was also similar to the calibration with the 5-kN·m-Dm-KE except for the following condition:

(1) The square drive of TTS/3kNm was just inserted in the square hole adapter like as the 5-kN·m-Dm-KE, but not clamped. After that, inclined posture of the lever was adjusted by inserting cushions (a kind of expanded polystyrene) between the lever and the back plate.

2.2.3. Environmental conditions

The environmental conditions at both NMIs were as follows:

Room temperature: 21 ℃ ± 0.2 K,

Relative humidity: 47 % ± 5 %.

The temperature coefficient of sensitivity of the TTS/3kNm was approximately −0.005 % /K, as measured at NMIJ. In a very accurate comparison such as the CIPM key comparison, humidity dependence of sensitivity of transducer should be considered[7]. The humidity difference between two NMIs during measurements, however, was so small that the influence of humidity would be negligible in this comparison.

3. Results and discussion

3.1. Voltage ratio span

As a result of bridge calibration of the two DMP40s by the BN100A, the maximum relative short-term drift of approximately one month at NMIJ was less than 1×10^{-6}. The maximum relative difference between PTB and NMIJ was less than 5×10^{-6}. Finally, the maximum relative standard deviation of six measurements (before and after pre- and post-calibration at NMIJ, and before and after the calibration at PTB) at each step was less than 2×10^{-6}. The difference in voltage ratio span of the two DMP40s and the short-term drift of the two DMP40s were sufficiently smaller than the total uncertainty of the RTW calibration, so that their influence was negligible.

3.2. Short-term drift of RTW sensitivity

The short-term drift of the TTS/3kNm (relative deviations of post-calibration results from pre-calibration results for each mean value at NMIJ) is shown in Fig. 11. The relative short-term drift of approximately one month was within 0.022 % for calibration steps of more than 10 % (200-N·m step), but was within 0.018 % for calibration steps of more than 50 % (1000-N·m

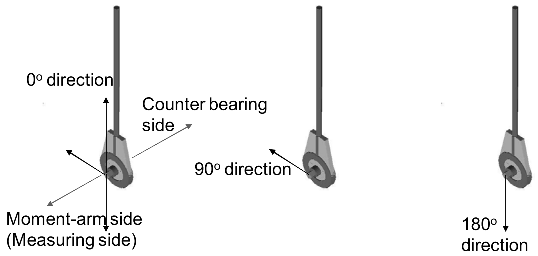


Fig. 9. Rotational mounting position of the transducer at PTB

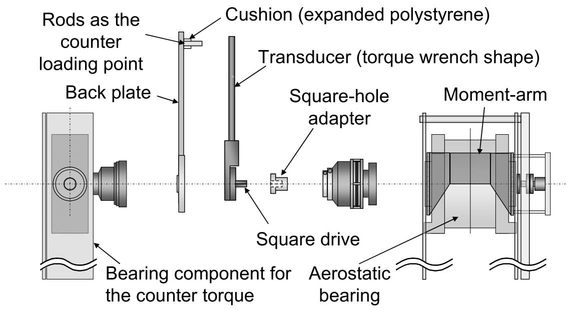


Fig. 10. Mounting method of the transducer of RTW on the 20-kN·m-DmNME

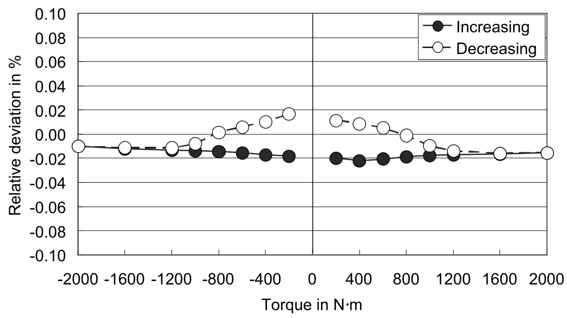


Fig. 11. Short-term drift of the TTS/3kNm (relative deviation between pre- and post-calibrations at NMIJ)

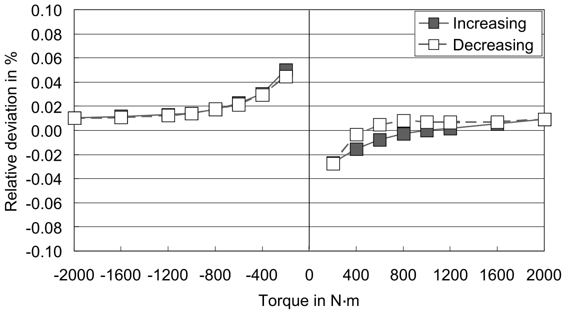


Fig. 12. Comparison result (relative deviation of calibration result obtained by using 5-kN·m-Dm-KE from the average value of pre- and post-calibration results obtained by using 20-kN·m-DWTSM)

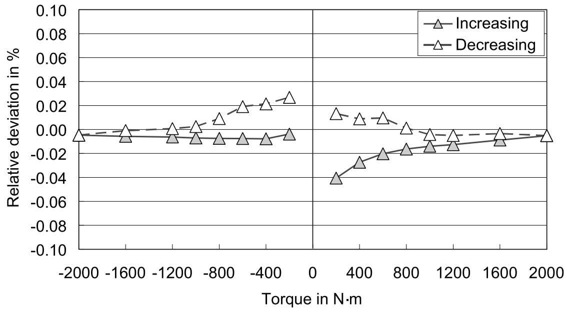


Fig. 13. Comparison result (relative deviation of calibration result obtained by using 20-kN·m-DmNME from the average value of pre- and post-calibration results obtained by using 20-kN·m-DWTSM)

Table 1 Calibration values, relative expanded uncertainties $W^{*)}$, and E_n numbers in the case of using 5-kN·m-Dm-KE at PTB

Clockwise							
Torque		Cal. value at NMIJ	Cal. Value at PTB	Relative deviation	W_{NMIJ}	W_{PTB}	E_n
Inc./Dec.	in N·m	in mV/V	in mV/V	in %	in %	in %	
Inc.	200	0.169244	0.169198	-0.027	0.029	0.088	-0.29
Inc.	400	0.338395	0.338343	-0.015	0.022	0.068	-0.21
Inc.	600	0.507502	0.507464	-0.008	0.020	0.059	-0.12
Inc.	800	0.676584	0.676566	-0.003	0.019	0.053	-0.05
Inc.	1000	0.845650	0.845651	0.000	0.018	0.047	0.00
Inc.	1200	1.014697	1.014715	0.002	0.018	0.046	0.04
Inc.	1600	1.352736	1.352813	0.006	0.017	0.044	0.12
Inc.	2000	1.690712	1.690865	0.009	0.016	0.043	0.20
Dec.	1600	1.352563	1.352662	0.007	0.015	0.040	0.17
Dec.	1200	1.014519	1.014588	0.007	0.014	0.038	0.17
Dec.	1000	0.845481	0.845542	0.007	0.013	0.039	0.18
Dec.	800	0.676413	0.676468	0.008	0.011	0.039	0.20
Dec.	600	0.507329	0.507352	0.005	0.009	0.043	0.11
Dec.	400	0.338229	0.338218	-0.003	0.011	0.050	-0.06
Dec.	200	0.169123	0.169077	-0.027	0.025	0.075	-0.34
Counterclockwise							
Torque		Cal. value at NMIJ	Cal. Value at PTB	Relative deviation	W_{NMIJ}	W_{PTB}	E_n
Inc./Dec.	in N·m	in mV/V	in mV/V	in %	in %	in %	
Inc.	-200	-0.169259	-0.169345	0.050	0.021	0.022	1.64
Inc.	-400	-0.338449	-0.338553	0.031	0.017	0.023	1.07
Inc.	-600	-0.507602	-0.507717	0.023	0.016	0.025	0.77
Inc.	-800	-0.676742	-0.676860	0.017	0.015	0.027	0.57
Inc.	-1000	-0.845868	-0.845990	0.014	0.015	0.029	0.45
Inc.	-1200	-1.014983	-1.015116	0.013	0.015	0.030	0.40
Inc.	-1600	-1.353188	-1.353347	0.012	0.014	0.031	0.34
Inc.	-2000	-1.691367	-1.691540	0.010	0.014	0.031	0.30
Dec.	-1600	-1.352997	-1.353141	0.011	0.013	0.028	0.34
Dec.	-1200	-1.014783	-1.014908	0.012	0.012	0.024	0.45
Dec.	-1000	-0.845685	-0.845805	0.014	0.012	0.024	0.53
Dec.	-800	-0.676566	-0.676686	0.018	0.010	0.024	0.68
Dec.	-600	-0.507414	-0.507523	0.022	0.011	0.025	0.80
Dec.	-400	-0.338266	-0.338366	0.030	0.012	0.023	1.14
Dec.	-200	-0.169127	-0.169203	0.045	0.017	0.025	1.47

*) The relative expanded uncertainty corresponds to a level of confidence of approximately 95 % with a coverage factor k being equal to 2.

Table 2 Calibration values, relative expanded uncertainties $W^{*)}$, and E_n numbers in the case of using 20-kN·m-DmNME at PTB

Clockwise							
Torque		Cal. value at NMIJ	Cal. Value at PTB	Relative deviation	W_{NMIJ}	W_{PTB}	E_n
Inc./Dec.	in N·m	in mV/V	in mV/V	in %	in %	in %	
Inc.	200	0.169244	0.169175	-0.041	0.029	0.020	-1.15
Inc.	400	0.338395	0.338303	-0.027	0.022	0.010	-1.14
Inc.	600	0.507502	0.507400	-0.020	0.020	0.005	-0.99
Inc.	800	0.676584	0.676474	-0.016	0.019	0.004	-0.85
Inc.	1000	0.845650	0.845533	-0.014	0.018	0.004	-0.75
Inc.	1200	1.014697	1.014569	-0.013	0.018	0.004	-0.68
Inc.	1600	1.352736	1.352618	-0.009	0.017	0.003	-0.50
Inc.	2000	1.690712	1.690625	-0.005	0.016	0.004	-0.30
Dec.	1600	1.352563	1.352516	-0.003	0.015	0.003	-0.22
Dec.	1200	1.014519	1.014468	-0.005	0.014	0.003	-0.36
Dec.	1000	0.845481	0.845445	-0.004	0.013	0.004	-0.31
Dec.	800	0.676413	0.676421	0.001	0.011	0.004	0.10
Dec.	600	0.507329	0.507378	0.010	0.009	0.006	0.88
Dec.	400	0.338229	0.338259	0.009	0.011	0.008	0.63
Dec.	200	0.169123	0.169145	0.013	0.025	0.025	0.37
Counterclockwise							
Torque		Cal. value at NMIJ	Cal. Value at PTB	Relative deviation	W_{NMIJ}	W_{PTB}	E_n
Inc./Dec.	in N·m	in mV/V	in mV/V	in %	in %	in %	
Inc.	-200	-0.169259	-0.169253	-0.004	0.021	0.012	-0.15
Inc.	-400	-0.338449	-0.338422	-0.008	0.017	0.012	-0.38
Inc.	-600	-0.507602	-0.507564	-0.008	0.016	0.010	-0.40
Inc.	-800	-0.676742	-0.676692	-0.007	0.015	0.010	-0.40
Inc.	-1000	-0.845868	-0.845808	-0.007	0.015	0.011	-0.39
Inc.	-1200	-1.014983	-1.014919	-0.006	0.015	0.011	-0.34
Inc.	-1600	-1.353188	-1.353111	-0.006	0.014	0.009	-0.33
Inc.	-2000	-1.691367	-1.691288	-0.005	0.014	0.007	-0.31
Dec.	-1600	-1.352997	-1.352983	-0.001	0.013	0.006	-0.07
Dec.	-1200	-1.014783	-1.014790	0.001	0.012	0.005	0.05
Dec.	-1000	-0.845685	-0.845706	0.002	0.012	0.004	0.20
Dec.	-800	-0.676566	-0.676628	0.009	0.010	0.004	0.82
Dec.	-600	-0.507414	-0.507511	0.019	0.011	0.008	1.47
Dec.	-400	-0.338266	-0.338339	0.021	0.012	0.009	1.44
Dec.	-200	-0.169127	-0.169172	0.027	0.017	0.010	1.36

*) The relative expanded uncertainty corresponds to a level of confidence of approximately 95 % with a coverage factor *k* being equal to 2.

step). These variations appear to be larger than the characteristic of the sensitivity drift in the general torque transducer (which would usually be less than 0.01 %). The reproducibility of re-mounting of the transducer might affect the short-term drift of the RTW much more than the sensitivity drift of the transducer itself.

3.3. Comparison of calibration results

The relative deviation of the calibration result obtained by using the 5-kN·m-Dm-KE at PTB, compared with the mean values of pre- and post-calibration at NMIJ, is shown in Fig. 12. The relative deviations were within 0.051 % for calibration steps of more than 10 % (200-N·m step), and was within 0.014 % for calibration steps of more than 50 % (1000-N·m step).

The relative deviation of the calibration result obtained by using the 20-kN·m-DmNME, compared with the mean values of pre- and post-calibration, is also evaluated as shown in Fig. 13. The relative deviations were within 0.041 % for calibration steps of more than 10 % (200-N·m step), and was within 0.018 % for calibration steps of more than 50 % (1000-N·m step).

Calibration values, relative expanded uncertainties ($k = 2$), and E_n numbers are summarized in Table 1 in the case of the 5-kN·m-Dm-KE and Table 2 in the case of the 20-kN·m-DmNME, where the uncertainties were evaluated according to the JMIF016 guideline [8], and the contributions of the hysteresis and zero-error are not included. The equivalence of the calibration for RTWs between the NMIJ and PTB was confirmed for steps of more than 40 % (800 N·m). The reason for comparably large difference at lower steps was unclear. It may be mainly related to the performance of the transducer itself. In addition, the differences of clamping method of the square drive and supporting method at the loading points in each laboratory might affect to the differences of results. In any case, the results of such lower steps are usually not used as comparison data. In order to compare the RTW calibration capabilities between two laboratories much precisely, calibration conditions and procedures should be coincided as much as possible in the next stage.

4. Conclusions

Inter-laboratory comparison (bilateral comparison) of reference torque wrench (RTW) calibration was conducted between NMIJ and PTB using a large RTW (rated capacity of over 1 kN·m). The calibration results of the same RTW (identical TTS/3kNm and each DMP40) obtained by NMIJ (using the 20-kN·m-DWTSM) and PTB (using the 5-kN·m-DmN-KE and the 20-kN·m-DmNME) were compared in the range from 200 N·m to 2 kN·m. The equivalence of the calibration for RTWs between two NMIs was confirmed for calibration steps of more than 40 % (800 N·m).

References

1) P. D. Hohmann, “Advantages of Traceability by using torque transfer standard TTS,” in Proc. of XIII IMEKO World Congress, pp. 253–256, Torino, Italy, Sept. 1994.

2) K. Ohgushi, T. Ota, K. Ueda, D. Peschel and A. Brüge, “Inter-laboratories Comparison of Reference Torque Wrench Calibration between NMIJ and PTB,” in Proc. XVIII IMEKO World Congress, CD-ROM, Rio de Janeiro, Brazil, Sept. 2006.

3) K. Ogushi, A. Nishino, K. Maeda and K. Ueda, “Range Expansion of the Reference Torque Wrench Calibration Service to 5 kN·m at NMIJ,” *MEASUREMENT*, 45–5, pp. 1200–1209, 2012.

4) D. Peschel, “Proposal for the Design of Torque Calibration Machines using the Principle of a Component System,” Proceedings of the 15th TC3 Conference (IMEKO), pp.251–254, Madrid, Spain, October, 1996.

5) A. Brüge, “Influence of Eccentric Mounting on the Calibration of Torque Measuring Device,” Proceedings of the 15th TC3 Conference (IMEKO), pp.255–259, Madrid, Spain, October, 1996.

6) K. Ohgushi, T. Ota, K. Ueda, D. Peschel, D. Röske, H. J. Tambach and D. Mauersberger, “International Comparison of Torque Standards in the Range of 0.5 to 20 kN·m between PTB and NMIJ,” *AIST Bulletin of Metrology*, 6–3, pp. 133–139, 2007.

7) D. Röske, “Final report on the torque key comparison CCM.T-K1.1: Measurand torque: 0 N·m, 500 N·m, 1000 N·m,” Metrologia, 47, Tech. Suppl., 07006, 2010.

8) Torque Traceability Study Group ed., “JMIF016: Guideline for calibration laboratories of reference torque wrenches (in Japanese)”, Japan Measuring Instruments Federation, pp.3–5 - 3–8, 2004.