Inter-laboratories Comparison between NMIJ and KRISS for Calibration Capabilities of Torque Measuring Devices in The Range from 50 N·m to 2 kN·m

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ABSTRACT

An inter-laboratories comparison of calibration capability of torque measuring devices (TMDs) was conducted between the National Metrology Institute of Japan (NMIJ) in the National Institute of Advanced Industrial Science and Technology (AIST) and Korea Research Institute of Standards and Science (KRISS). Three high-performance torque transducers, rated capacities of which are 100 N·m, 1 kN·m and 2 kN·m, and one bridge calibration unit (BN100A) were used as transfer devices. Data was acquired for both of two bridges respectively in the transducer of the rated capacity of 100 N·m. The identical indicator/amplifier (DMP40) owned by each laboratory was used. All transducers and BN100A were transferred from the NMIJ to the KRISS. 1 kN·m and 20 kN·m deadweight torque standard machines (TSMs) at the NMIJ and 2 kN·m deadweight torque standard machine at the KRISS were used in the comparison. Especially the capability of 1 kN·m TSM at NMIJ was examined after some improvements. In the calibration range from 50 N·m to 2 kN·m, relative deviations were less than 5.0×10^{-5} for the increasing torques. Sufficient small deviations could be obtained between the calibration results in two laboratories as contrasted with their Calibration and Measurement Capabilities (CMCs: 3.5×10^{-5} for the 1 kN·m TSM in NMIJ, 7.0×10^{-5} for the 20 kN·m TSM in NMIJ and 5.0×10^{-5} for the 2 kN·m TSM in KRISS, as relative expanded uncertainties).

Keywords: Torque Standard Machine, Torque, Comparison, Transfer Standard, Bridge Calibrator

1. INTRODUCTION

Torque Standard Machines (TSMs) in National Metrology Institutes (NMIs) have been being established in many countries in last two decades. Korea Research Institute of Standards and Science (KRISS) has developed two deadweight type TSMs (DWTSMs), rated capacities of which are 100 N·m and 2 kN·m[1)] (abbreviated to 100-N·m-DWTSM(K) and 2-kN·m-DWTSM(K)). A new deadweight type TSM, rated capacity of 20 kN·m, is being developed[2)] (20-kN·m-DWTSM(K)). The National Metrology Institute of Japan (NMIJ) has also developed three DWTSMs, rated capacities of which are 10 N·m[3)] (10-N·m-DWTSM(J)), 1 kN·m[4)] (1-kN·m-DWTSM(J)) and 20 kN·m[5)] (20-kN·m-DWTSM(J)). The first bilateral comparison between NMIJ and KRISS was carried out in the range from 200 N·m to 2 kN·m by using 1-kN·m-DWTSM(J) and 20-kN·m-DWTSM(J) at NMIJ and 2-kN·m-DWTSM(K) at KRISS in 2004[6)]. After that, 1-kN·m-DWTSM(J) was improved reducing the relative expanded uncertainty (REU) of realized torque[7)]. In order to confirm this improvement, and in order to confirm the stability of other TSMs after the first comparison, second bilateral comparison was conducted between NMIJ and KRISS for the range from 50 N·m to 2 kN·m in 2010. Although the evaluation has been paused after the Great East Japan Earthquake at March 11th, 2011, we restarted to investigate the comparison results from 2014. This paper describes the second comparison results. We also investigated the influence of voltage span of indicator/amplifiers using a bridge calibration unit, and temperature and/or humidity coefficients of transducers. Detailed reports, however, will be made in another occasion.

2. TORQUE STANDARD MACHINES

2.1 NMIJ/AIST

Two deadweight machines, 1-kN·m-DWTSM(J) and 20-kN·m-DWTSM(J) were used for the comparison at NMIJ. Figure 1 shows the 1 kN·m-DWTSM which have had a calibration range of from 5 N·m to 1 kN·m. The under limit of the range of which was extended to 0.5 N·m by developing brand new small linkage weights series. The 1-kN·m-DWTSM(J) was also improved reducing the uncertainty of the moment-arm length, by the change of the metal band thickness at the end of the arm from 100 μm to 50 μm, and re-evaluating the sensitivity limit of the furculum (the aerostatic bearing). As a result of these evaluations, REUs (k = 2) of 7.3×10^{-5} and 2.9×10^{-5} could be obtained in the range from 0.5 N·m to 20 N·m and from 5 N·m to 1 kN·m, respectively[7]. After some minor changes like as environmental conditions, 3.4×10^{-5} of REU of the realized torque for the range from 5 N·m to 1 kN·m was obtained. Figure 2 shows the 20 kN·m-DWTSM(J) which has a calibration range from 200 N·m to 20 kN·m. The REU of the torque realized with the TSM was 6.7×10^{-5}[5]. The CMCs, which equal to the REUs (k = 2) of the calibration with almost ideal TMDs, were 3.5×10^{-5} for the 1-kN·m-DWTSM(J) (from 5 N·m to 1 kN·m) and 7.0×10^{-5} for the 20-kN·m-DWTSM(J), respectively.

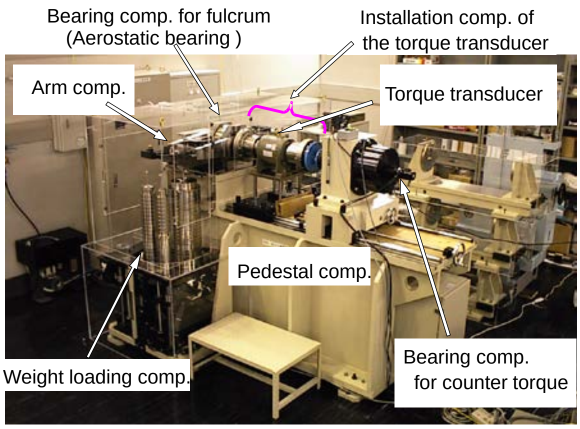

Fig. 1 The 1-kN·m-DWTSM of NMIJ ss

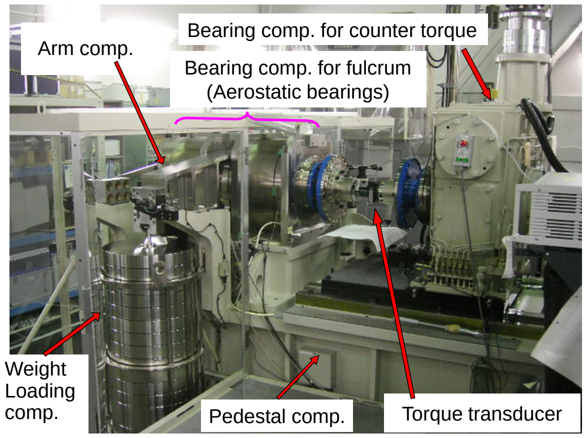

Fig. 2 The 20-kN·m-DWTSM of NMIJsssss

2.2 KRISS

The deadweight machine, 2-kN·m-DWTSM(K) was used for the comparison at KRISS. The CMC with 2-kN·m-DWTSM was evaluated as 5.0×10^{-5}[1]. Figure 3 shows 2-kN·m-DWTSM(K). The characteristics of 2-kN·m-DWTSM can be found in references 1) and 6).

3. TRANSFER DEVICES

3.1 TORQUE TRANSDUCERS

Three torque transducers of different capacity were used as transfer devices for this comparison. Three transducers, the rated capacities of which were 2 kN·m (TN/2kNm), 1 kN·m (TB2/1kNm) and 100 N·m (TN/100Nm), were transferred from the NMIJ to the KRISS by an air transport. Figures 4(a) and 4(b) show the transducers and their special containers. TN/2kNm and TN/100Nm are shaft type transducers, whereas the TB2/1kNm is a disk type transducer. The adapter flanges were kept fastened to both sides of the TB2/1kNm for more than one year before the comparison. The 100 N·m transducer of TN/100Nm has double bridges so that two series of output were available. The output from the bridge 1 is expressed with TN/100Nm(MD1), whereas the bridge 2 with TN/100Nm(MD2). The containers sealed the transducers from the outside environment. Accumulators (20 °C – 25 °C) and desiccants (40 % of relative humidity) were put into the containers to keep as much as possible with the same environment at labs. Thermo/hygrometers and a 3-D accelerometer were placed into the containers to monitor the environmental conditions. The sampling rate of the thermo/hygrometers was 30 minutes. The variation of the temperature and relative humidity during transportation were from 10 °C to 24 °C and from 28 % to 63 %, respectively. The sampling rate of the accelerometer was 0.5 s, and the maximum acceleration was recorded within every one hour. The containers received a maximum shock of 76 m/s^2 (one time) during transportation. However, any serious damages were not found in the transducer after unpacked.

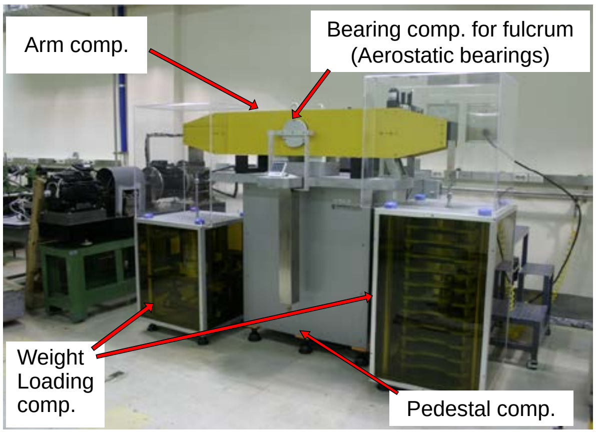

Fig. 3 The 2-kN·m-DWTSM of KRISS

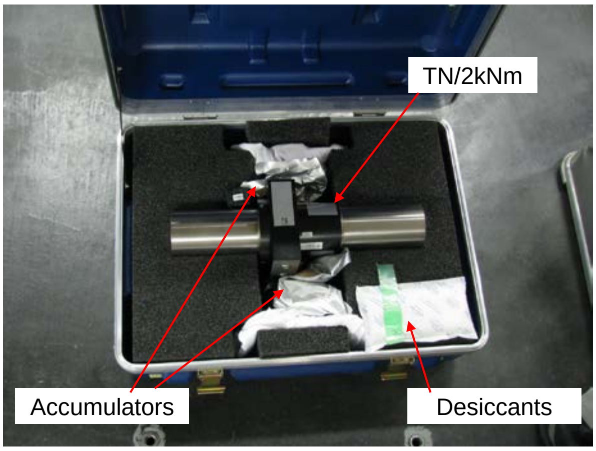

Fig. 4(a) The 2 kN·m transducer and its container

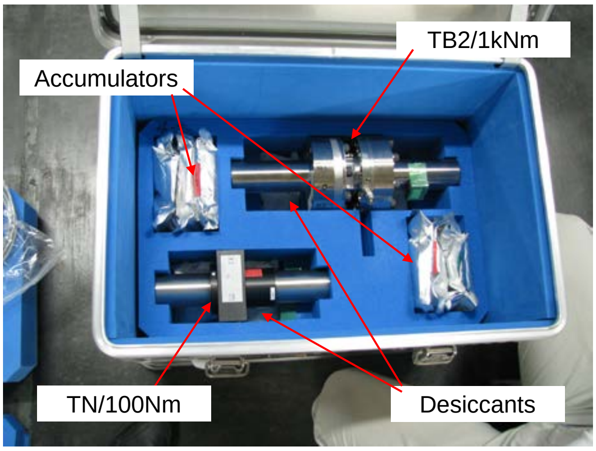

Fig. 4(b) 1 kN·m and 100 N·m transducers and those container

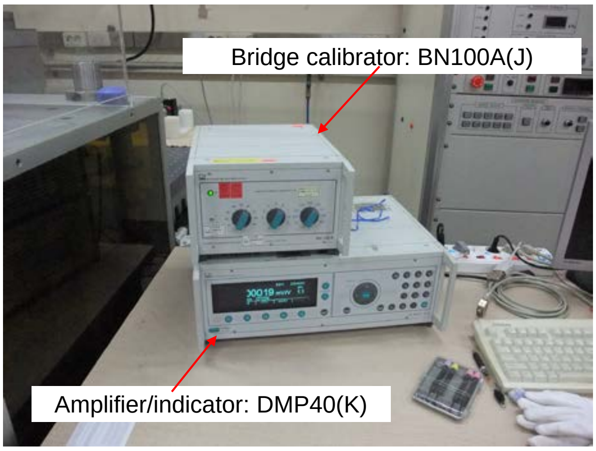

Fig. 6 The bridge calibrator and the amplifier/indicator

Figures 5(a) to 5(d) indicate the long-term stabilities of TN/2kNm, TB2/1kNm and TN/100Nm(MD1 and MD2) before being used for this comparison. The long-term stability was expressed by relative deviations of the calibration results at the rated capacities from the mean values of all calibration results during a certain period. The TN/2kNm and both bridges of TN/100Nm were stable, as the maximum variation over approximately three months was less than 1.0×10^{-5}. The variation of the TB2/1kNm over approximately one and half years was 7.0×10^{-5}. Although the variation was relatively large, the tendency of the variation was approximately linear and the change of the calibration results within three months was less than 2.0×10^{-5}, so that the authors decided that the transducer could be used as a transfer standard.

3.2 AMPLIFIER/INDICATORS AND A BRIDGE CALIBRATOR

A bridge calibrator BN100A, which calibrates the AC bridge voltage with an excitation voltage of 5 V and a carrier frequency of 225 Hz, was also transferred from the NMIJ to the KRISS by the air transport. The amplifier/indicator of each NMI (DMP40S2(J_a) and DMP40S2(J_b) at the NMIJ and DMP40(K) at the KRISS) was connected to the transfer transducers during each torque calibration. Amplifier/indicators were calibrated almost before and after each torque calibration by the BN100A. Figure 6 shows BN100A and DMP40(K).

The reference voltage ratios of bridge calibrators $V_{\mathrm{ref,ir}}$ were measured using the amplifier/indicators, at steps of +0, +0.1, +0.5, +0.7, +0.8, +1.0, +1.4 and +1.6 mV/V, and then -0, -0.1, -0.5, -0.7, -0.8, -1.0, -1.4 and -1.6 mV/V. A small voltage span variation occurred although a detailed explanation of the result is left out. Therefore, the influence of voltage span shift was not included the comparison results here. Detailed analysis of the influence, however, will be described in another report.

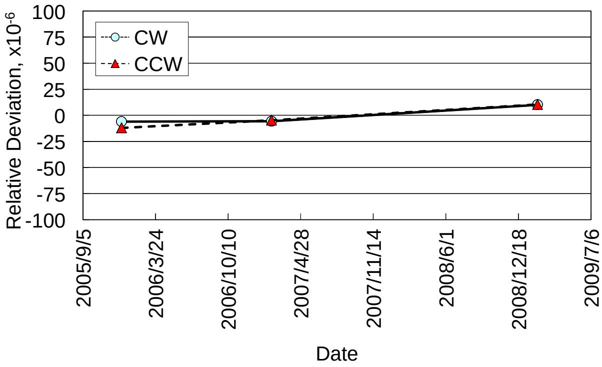

Fig. 5(a) Stability of the TN/2kNm

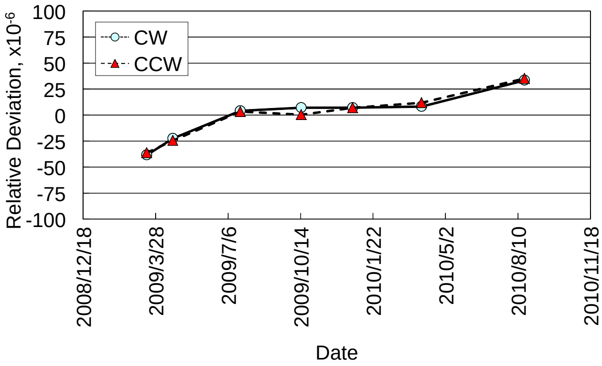

Fig. 5(b) Stability of the TB2/1kNm

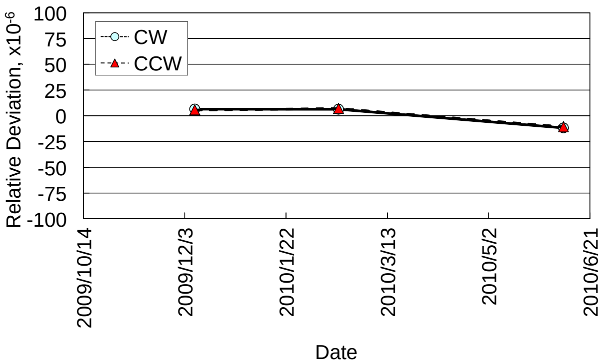

Fig. 5(c) Stability of the TN/100Nm(MD1)

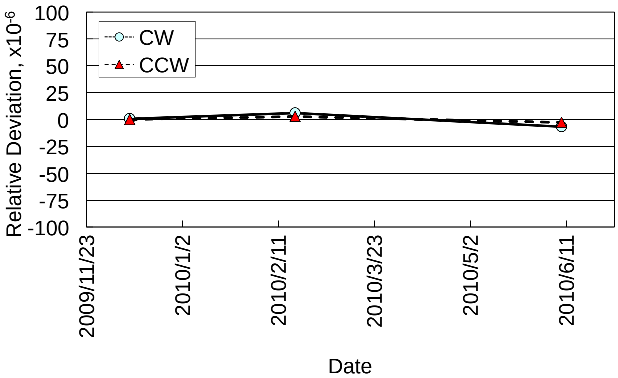

Fig. 5(d) Stability of the TN/100Nm(MD2)

4. CALIBRATION PROCEDURE

Pre- and post-calibrations were conducted at the NMIJ (we call the pre-calibration “J1” and the post-calibration “J2”) using three transducers (four bridges) before and after the calibration at the KRISS (we call the calibration just “K”). Loading timetables for individual calibrations are shown in Fig. 7. The timetable used in the CIPM key comparison of CCM.T-K2[8] was adopted. The torque calibration was conducted separately in both the clockwise (CW) and counterclockwise (CCW) directions. Table 1 shows overall schedule of the comparison.

The rotational mounting position of the transducer was changed to three directions by pitch of every 120° and it was rotated two times. First, after three pre-loading cycles up to the maximum torque (rated capacity of the torque transducer) by two steps of 50 and 100 % of the maximum torque, the combination of one pre-loading and three measurement loading cycles at the direction of 0°. In all cycles, the torque steps were increasing only. The combination of one pre-loading and one measurement loading cycles were performed at the directions of 120°, 240°, 360°, 480°, 600° and 720°. Time intervals were strictly maintained in order to exclude the influence of the creep characteristics of transducers. The interval from the start of loading to data acquisition was six minutes. Interval from the last maximum torque reading at the present mounting position to the first zero reading at the next mounting position was ten minutes.

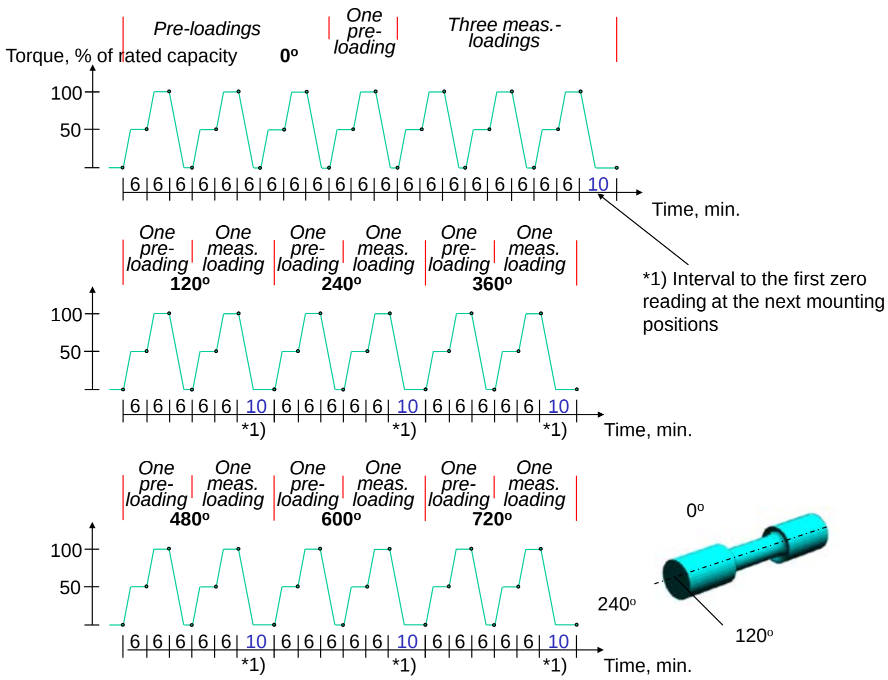

Fig. 7 Loading timetable of calibration for each torque transducer

Table 1 Schedule of measurements and transportations

Pre-calibration at NMIJ (J1)	September 13th – September 24th, 2010
Transportation	September 24th – October 5th, 2010
Calibration at KRISS (K)	October 5, 2010 – October 21th, 2010
Transportation	October 26th – October 29th, 2010
Post-calibration at NMIJ (J2)	November 1st – December 2nd, 2010

5. RESULTS AND DISCUSSION

5.1 CALIBRATION RESULTS OF TORQUE

Calibration results were calculated by the following equations, as the mean values of measured values, which were defined as each indicated value subtracted the zero value at the prior loading cycle, at the measurement loading cycles for all mounting positions except 0° direction:

$$\overline{S'_{\mathrm{i}}} = \frac{1}{n_{\mathrm{rot}}} \sum_{\mathrm{e}=1}^{n_{\mathrm{rot}}} S'_{\mathrm{i1e}}\ , \tag{1}$$

S'_{ije} expresses the measured values at the measurement loading cycles for step i, cycle j (=1) and series e ("series" means successive calibration sequence within the same mounting position). Here, n_{rot} is the number of rotational mounting positions (n_{rot} = 6). The relative deviations of the calibration results obtained at the KRISS from the mean results of the pre- and post-calibration at the NMIJ are shown in Figs. 8(a) to 8(d) for the TN/2kNm, TB2/1kNm, TN/100Nm(MD1) and TN/100Nm(MD2). The short-term drift, which is expressed by eq. (8), was defined as difference of results between pre- and post-calibration at NMIJ. The relative values of short-term drift are also shown in Figs. 8.

At the calibration points of 2 kN·m, 1 kN·m, 500 N·m, 100 N·m and 50 N·m, the relative deviations were from 0.2 × 10^{-5} to 5.0 × 10^{-5}. In some points, very small deviations could be obtained, whereas relatively large deviations occurred in 50 N·m and 100 N·m steps. The tendency of deviation in TN/100Nm(MD1) were similar to that in

TN/100Nm(MD2). The deviation of TN/2kNm in the CW direction became larger than others. Authors thought differences of such deviation levels are ascribed to differences of environment conditions, that is, the temperature and humidity. The principle of measurement in the torque transducers used in this comparison was the strain-gauge. The output of this type of transducer generally depends on the environmental temperature and humidity[9)]. Each environmental condition during each torque calibration was summarized in Table 2. Some of short-term drifts of transducers for approximately two months were also larger than others (0.3×10^{-5} to 3.8×10^{-5}). These large differences, however, were hard to be thought as the influence of environmental conditions because the temperature and relative humidity of J1 and J2 were almost identical. The authors have evaluated the temperature and humidity dependencies of transducers after the comparison. Results of the correction using temperature and humidity coefficients will be reported in other occasion.

5.2 EVALUATION OF E_n NUMBERS

5.2.1 Reproducibility with changing mounting position

Relative reproducibility with changing mounting position *b* was estimated by defining an experimental standard deviation in measured values for the first measurement loading cycles in all of the direction of 120°, 240°, 360°, 480°, 600° and 720°, as follows:

$$b_{\mathrm{i}} = \frac{1}{\left|\overline{S'_{\mathrm{i}}}\right|}\sqrt{\frac{1}{n_{\mathrm{rot}}-1}\sum_{\mathrm{e}=1}^{n_{\mathrm{rot}}}\left(S'_{\mathrm{i1e}}-\overline{S'_{\mathrm{i}}}\right)^{2}}\ . \tag{2}$$

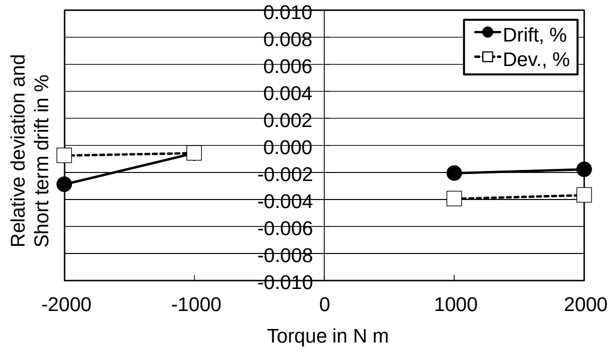

Fig. 8(a) Relative deviation of calibration results and short-term drift (TN/2kNm)

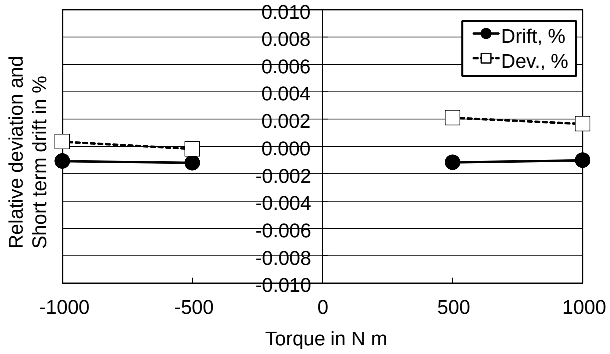

Fig. 8(b) Relative deviation of calibration results and short-term drift (TB2/1kNm)

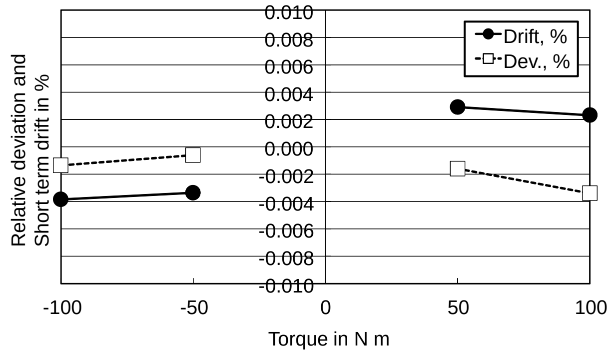

Fig. 8(c) Relative deviation of calibration results and short-term drift (TN/100Nm(MD1))

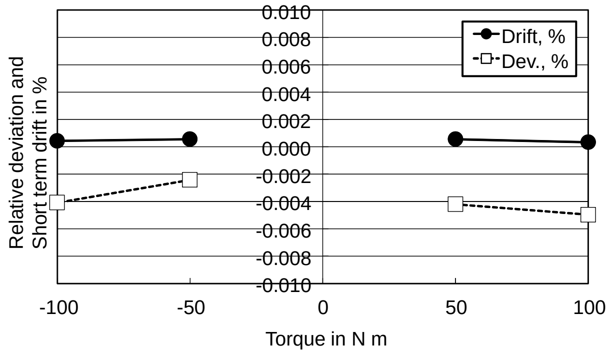

Fig. 8(d) Relative deviation of calibration results and short-term drift (TN/100Nm(MD2))

Table 2 Temperature and humidity condition at each measurement

	J1 Temp./ °C	J1 R. H./ %	K Temp./ °C	K R. H./ %	J2 Temp./ °C	J2 R. H./ %
TN/2kNm						
CW						
Min.	22.9	36	23.1	49	22.8	37
Max.	23.1	37	23.5	53	22.9	39
CCW						
Min.	22.7	37	23.3	36	22.9	37
Max.	22.9	45	23.5	42	23.0	39
TB2/1kNm						
CW						
Min.	23.1	41	23.3	47	22.7	39
Max.	23.3	42	23.6	50	23.0	40
CCW						
Min.	23.2	40	23.4	48	22.8	40
Max.	23.3	40	23.6	51	23.0	44
TN/100Nm(MD1)						
CW						
Min.	23.1	40	22.6	50	22.8	39
Max.	23.2	47	22.9	53	22.9	40
CCW						
Min.	23.0	42	23.0	52	22.8	40
Max.	22.9	39	22.9	51	22.7	40
TN/100Nm(MD2)						
CW						
Min.	23.1	40	22.6	50	22.8	39
Max.	23.2	47	22.9	53	22.9	40
CCW						
Min.	23.0	42	23.0	52	22.8	40
Max.	23.0	42	23.0	52	22.8	40

Relative standard uncertainty u_{rot} is calculated as “an experimental standard deviation of the mean” by the following equation:

$$u_{\mathrm{rot,i}}{}^{2} = \frac{1}{n_{\mathrm{rot}}} b_{\mathrm{i}}{}^{2} . \tag{3}$$

5.2.2 Repeatability with unchanged mounting position

Relative repeatability with unchanged mounting position *b’* was estimated by defining an experimental standard deviation in measured values for three measurement loading cycles in the direction of 0°, as follows:

$$b_{\mathrm{i}}' = \frac{1}{\left|\overline{S'_{\mathrm{i,rep}}}\right|} \sqrt{\frac{1}{n_{\mathrm{rep}}-1} \sum_{\mathrm{j=1}}^{n_{\mathrm{rep}}} \left(S'_{\mathrm{ij0}} - \overline{S'_{\mathrm{i,rep}}}\right)^{2}} , \tag{4}$$

where $\overline{S'_{\mathrm{i,rep}}}$ is the mean value of three measured values at 0° direction (e = 0, n_{rep} = 3).

Relative standard uncertainty u_{rep} is calculated as “an experimental standard deviation of the mean” by the following equation:

$$u_{\mathrm{rep,i}}{}^{2} = \frac{1}{n_{\mathrm{rep}}} b_{\mathrm{i}}'^{2} . \tag{5}$$

5.2.3 Zero point shift

Relative zero point shift f_0 was estimated by defining the deviation between zero signals prior to the increasing torque and after the decreasing torque in the first and second cycle of 0º direction, as follows:

$$f_{0,\mathrm{j0}} = \frac{S''_{0\mathrm{j0}} - S'_{0\mathrm{j0}}}{\left| S'_{\mathrm{nj0}} \right|} , \tag{6}$$

where i = n is the maximum torque step. The zero point shift cannot be calculated at the last measurement loading cycles because zero signals after the decreasing torque were read after changing the mounting positions. Relative standard uncertainty u_{zer} was calculated according to the following equation, considering the mean deviation $f_{0,\mathrm{mean}}$ in two $f_{0,\mathrm{j0}}$ as the half width of the rectangular distribution:

$$u_{\mathrm{zer}}{}^{2} = \frac{1}{3} f_{0,\mathrm{mean}}{}^{2} . \tag{7}$$

5.2.4 Resolution

In the case of a digital scale, resolution r is defined as one increment in the last active number of the amplifier/indicator when the indication does not fluctuate under the no-loading condition. If the indication fluctuates, then r is determined to be half the range of the fluctuation. Here, r should be stated in units of torque [N·m].

The uncertainty due to the resolution should be taken into account twice because each measured value is obtained as a difference between the step-indicated value and the zero-indicated value. The relative standard uncertainty u_{res} was calculated by the following equations for the applied torque T_{i} [N·m] at step i:

1) Considering the resolution r as the whole width of the rectangular distribution when the indication did not fluctuate under the no-loading condition:

$$u_{\mathrm{res,i}}{}^{2} = \frac{2}{3} \left(\frac{r}{2T_{\mathrm{i}}} \right)^{2} . \tag{8a}$$

2) Considering the resolution r as the half width of the rectangular distribution if the indication fluctuated:

$$u_{\mathrm{res,i}}{}^{2} = \frac{2}{3} \left(\frac{r}{T_{\mathrm{i}}} \right)^{2} . \tag{8b}$$

The low pass frequency of the amplifier/indicators was always set to “0.1 Hz Bessel” during this bilateral comparison. In fact, the peak-to-peak fluctuation was only three digits (0.000003 mV/V) at all calibrations.

5.2.5 Short-term drift

The uncertainty due to the short-term drift of the torque transducer during pre- and post-calibration (J1 and J2) was calculated by the following equation for the increasing torque:

$$u_{\mathrm{dft,i}}{}^{2} = \frac{1}{3} \left(\frac{\overline{S'_{\mathrm{post,i}}} - \overline{S'_{\mathrm{pre,i}}}}{2\overline{S'_{\mathrm{J,i}}}} \right)^{2} , \tag{9}$$

where $\overline{S'_{\mathrm{J,i}}}$ is the mean of $\overline{S'_{\mathrm{pre,i}}}$ and $\overline{S'_{\mathrm{post,i}}}$.

5.2.6 Stability of the amplifier/indicators

The relative standard uncertainty due to the stability of the amplifier/indicators was not included in this evaluation.

5.2.7 Realized torque using the TSMs

From the description in Chapter 2, the relative standard uncertainties of realized torque using the TSMs, u_{tsm} are 1.7 × 10^{-5} for the 1-kN·m-DWTSM and 3.4 × 10^{-5} for the 20-kN·m-DWTSM at the NMIJ, and is 2.5 × 10^{-5} for the 2-kN·m-DWTSM at the KRISS, where the coverage factor of k = 2 (equivalent to the confidence level of approximately 95 %).

5.2.8 Evaluation of E_n number

The relative expanded uncertainty of calibration at the NMIJ (which denoted as J1 and J2 calibrations) was calculated by the following equation:

$$U_{\mathrm{J,i}} = k \cdot u_{\mathrm{c\_J,i}} = k \cdot \sqrt{u_{\mathrm{rot,i}}{}^2 + u_{\mathrm{rep,i}}{}^2 + u_{\mathrm{zer,i}}{}^2 + u_{\mathrm{res,i}}{}^2 + u_{\mathrm{dft,i}}{}^2 + u_{\mathrm{tsm}}{}^2} \ . \quad (10)$$

The relative expanded uncertainty of calibration at the KRISS (which denoted as K calibration) was calculated by the following equation:

$$U_{\mathrm{K,i}} = k \cdot u_{\mathrm{c\_K,i}} = k \cdot \sqrt{u_{\mathrm{rot,i}}{}^2 + u_{\mathrm{rep,i}}{}^2 + u_{\mathrm{zer,i}}{}^2 + u_{\mathrm{res,i}}{}^2 + u_{\mathrm{tsm}}{}^2} \ . \quad (11)$$

The E_n number was also evaluated according to the following equation:

$$E_{\mathrm{n,i}} = \frac{\left(\overline{S'_{\mathrm{K,i}}} - \overline{S'_{\mathrm{J,i}}}\right) / \overline{S'_{\mathrm{J,i}}}}{\sqrt{U_{\mathrm{K,i}}{}^2 + U_{\mathrm{J,i}}{}^2}} \ , \quad (12)$$

where $\overline{S'_{\mathrm{K,i}}}$ denotes the result of the calibration at KRISS.

Table 3 summarizes the results of the E_n number evaluation. The E_n numbers were all less than unity in the calibration range from 50 N·m to 2 kN·m. Therefore, the equivalence of the torque standards between the NMIJ and the KRISS were confirmed. Linking the results at 500 N·m and 1000 N·m points to the CCM.T-K1[9)] would be the next subject in the future.

Table 3(a) E_n evaluation results using the transducer of TN/2kNm

Torque N·m	Cal. J mV/V	Cal. K mV/V	Rel. Dev. %	S. T. Drift %	U_J %	U_K %	E_n
CW							
1000	0.751270	0.751240	-0.0040	-0.0021	0.0070	0.0051	-0.45
2000	1.502647	1.502592	-0.0037	-0.0018	0.0070	0.0051	-0.43
CCW							
-1000	-0.751246	-0.751242	-0.0006	-0.0006	0.0069	0.0051	-0.07
-2000	-1.502527	-1.502516	-0.0008	-0.0029	0.0071	0.0051	-0.09

Table 3(b) E_n evaluation results using the transducer of TB2/1kNm

Torque N·m	Cal. J mV/V	Cal. K mV/V	Rel. Dev. %	S. T. Drift %	U_J %	U_K %	E_n
CW							
500	0.500185	0.500196	0.0021	-0.0012	0.0036	0.0051	0.34
1000	1.000439	1.000456	0.0017	-0.0010	0.0035	0.0050	0.27
CCW							
-500	-0.500193	-0.500192	-0.0002	-0.0012	0.0036	0.0051	-0.03
-1000	-1.000468	-1.000471	0.0003	-0.0011	0.0035	0.0051	0.06

Table 3(c) E_n evaluation results using the transducer of TN/100Nm(MD1)

Torque N·m	Cal. J mV/V	Cal. K mV/V	Rel. Dev. %	S. T. Drift %	U_J %	U_K %	E_n
CW							
50	0.757801	0.757789	-0.0016	0.0029	0.0039	0.0052	-0.25
100	1.515684	1.515632	-0.0034	0.0023	0.0037	0.0050	-0.54
CCW							
-50	-0.757804	-0.757799	-0.0006	-0.0034	0.0040	0.0052	-0.09
-100	-1.515701	-1.515681	-0.0014	-0.0038	0.0041	0.0051	-0.21

Table 3(d) E_n evaluation results using the transducer of TN/100Nm(MD2)

Torque N·m	Cal. J mV/V	Cal. K mV/V	Rel. Dev. %	S. T. Drift %	U_J %	U_K %	E_n
CW							
50	0.755866	0.755834	-0.0042	0.0006	0.0035	0.0055	-0.65
100	1.511798	1.511723	-0.0050	0.0003	0.0035	0.0050	-0.81
CCW							
-50	-0.755879	-0.755861	-0.0024	0.0006	0.0035	0.0055	-0.37
-100	-1.511847	-1.511786	-0.0041	0.0004	0.0035	0.0052	-0.65

6. CONCLUSION

Bilateral comparison of calibration for torque measuring devices was conducted between the NMIJ/AIST and the KRISS, in the range from 50 N·m to 2 kN·m. Both NMIs have well-established deadweight type TSMs. In the calibration range from 50 N·m to 2 kN·m, the relative deviations were from 0.2×10^{-5} to 5.0×10^{-5}. Sufficiently small deviations could be obtained between the calibration results of the two laboratories as contrasted with their Calibration and Measurement Capabilities, so that the equivalence of the torque standards between the NMIJ and the KRISS were confirmed again. The influence of stability of amplifier/indicator and temperature and humidity dependency of the transducer output will be described in other report.

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	J1 Temp./ °C	J1 R. H./ %	K Temp./ °C	K R. H./ %	J2 Temp./ °C	J2 R. H./ %
TN/2kNm						
CW						
Min.	22.9	36	23.1	49	22.8	37
Max.	23.1	37	23.5	53	22.9	39
CCW						
Min.	22.7	37	23.3	36	22.9	37
Max.	22.9	45	23.5	42	23.0	39
TB2/1kNm						
CW						
Min.	23.1	41	23.3	47	22.7	39
Max.	23.3	42	23.6	50	23.0	40
CCW						
Min.	23.2	40	23.4	48	22.8	40
Max.	23.3	40	23.6	51	23.0	44

	J1 Temp./ °C	J1 R. H./ %	K Temp./ °C	K R. H./ %	J2 Temp./ °C	J2 R. H./ %
TN/100Nm(MD1)						
CW						
Min.	23.1	40	22.6	50	22.8	39
Max.	23.2	47	22.9	53	22.9	40
CCW						
Min.	23.0	42	23.0	52	22.8	40
Max.	22.9	39	22.9	51	22.7	40
TN/100Nm(MD2)						
CW						
Min.	23.1	40	22.6	50	22.8	39
Max.	23.2	47	22.9	53	22.9	40
CCW						
Min.	23.0	42	23.0	52	22.8	40
Max.	23.0	42	23.0	52	22.8	40