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INFLUENCE OF CHANGING WAY OF THE ROTATIONAL MOUNTING POSITION ON CALIBRATION RESULTS OF REFERENCE TORQUE WRENCHES

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Abstract: In the calibration of torque measuring devices, measurement is to be repeated by changing the rotational mounting position concerned with the measurement axis as evenly as possible to the direction of rotation because the axi-asymmetric of sensing element and mechanical parts in the transducer contribute to the measurement uncertainty. However, in the calibration of reference torque wrenches, there are some kinds of changing way to change the rotational mounting position. Typical way is to change the angle of detachable square drive parts connected to the front of sensing elements in the transducer of torque wrench form. The other is to change the mounting position of sensing elements themselves. The author investigated to compare the calibration results between two ways for the mounting positions using various transducers. As a result, somewhat large differences of calibration results were occurred between two ways depending on transducers.

Keywords: Torque, Torque wrench, Reference torque wrench, Square drive, Mounting position

1. INTRODUCTION

Recently, reference torque wrenches (RTWs, or torque transfer wrenches) are becoming used for the calibration of torque wrench calibration devices (or torque wrench testers or checkers (TWTs or TWCs)) as important and effective reference standards [1-3]. The authors have developed the largest and the most precise torque transducer, rated capacity of which was 5 kN·m, in the form of torque wrench [4]. We have also demonstrated NMIJ's precise calibration capability for the reference torque wrench by conducting international comparisons [5-6]. Moreover, we have revealed the advantage of using RTWs for the calibration of TWTs compared with conventional weight-bar-systems (WBSs) [7].

In the calibration of RTWs, torque transducer (with torque wrench form) is generally mounted on the measurement axis of torque calibration equipment (such as torque standard machines (TSMs) or torque calibration machines (TCMs)) as shown in the lower side of Fig. 1. For the purpose of the contrast, the mounting way for the pure-torque-transducer is also drawn in the upper side of Fig. 1. A square drive part of the torque-wrench-form-transducer faces to the measuring side of the TSM or the TCM, whereas a lever part of the transducer faces to reaction side, in the case of RTW calibration. In the calibration of torque measuring devices, measurement is generally to be repeated by changing the rotational mounting position concerned with the measurement axis as evenly as possible to the direction of rotation because the axi-asymmetric of sensing element in the transducer contributes to the total measurement uncertainty.

In NMIJ, the rotational mounting position is generally changed by changing the position of sensing element itself, that means the lever direction changes with the sensing element by pitch of 120 degrees as shown in Fig. 2 [5]. This changing way is called as "Lever" way in this paper. The "Lever" way is physically equivalent to the one for the

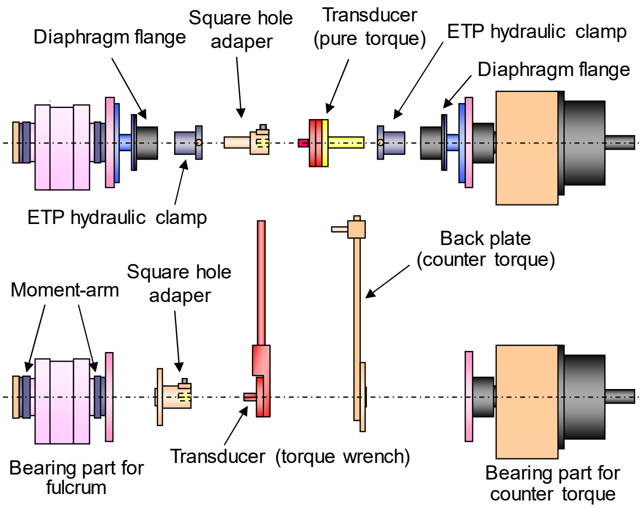

Figure 1. Setup of transducer on the TSM.

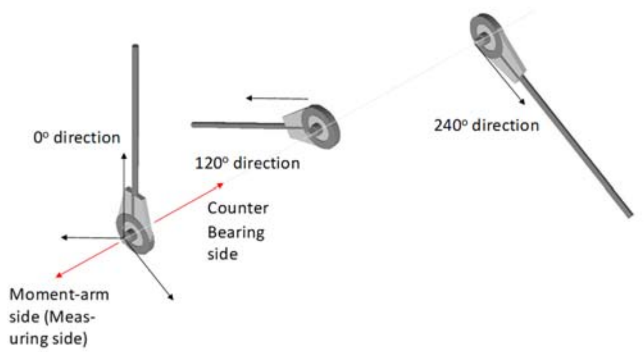

Figure 2. Rotational mounting position change by changing lever direction ("Lever " way).

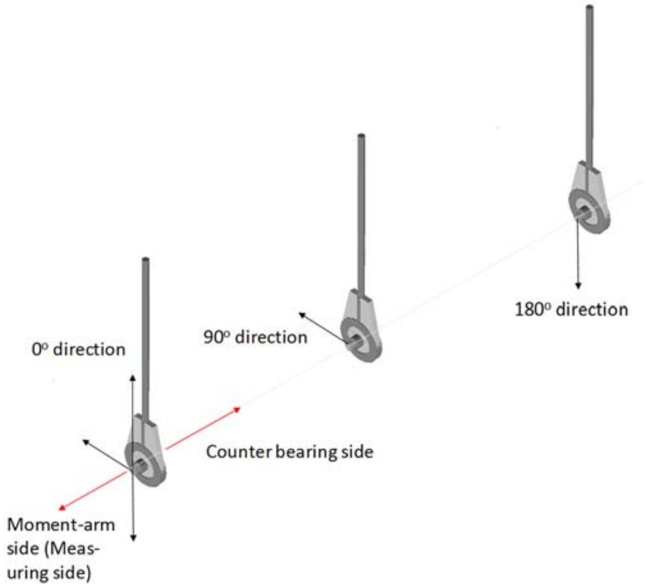

Figure 3. Rotational mounting position change by changing detachable square drive ("Square" way).

calibration of the pure-torque-transducer. Thus, this "Lever" way could be said to be rigorous and precise method. If the shape and dimension (working accuracy) of the torque-wrench-form-transducer are excellent, the uncertainty contribution due to changing mounting position becomes smaller, then, the total uncertainty sometimes becomes similar to the level of uncertainty for pure torque transducers. Actually, the calibration and measurement capability (CMC) of RTWs by NMIJ is 7.0×10^{-5} as relative values in the range from 5 N·m to 1 kN·m in the CMC table of the BIPM website (http://kcdb.bipm.org/appendixC/).

However, the changing way of the mounting position with changing the lever direction takes time and cost because this way needs counter balance weights and to make the balance of the initial small torque in any mounting position. On the other hand, for the convenience, the rotational mounting position is changed by changing the position of detachable square drive at the front of sensing element in the torque-wrench-form-transducer in many RTW calibration laboratories, that means the detachable square drive direction changes without the sensing element by pitch of 90 degrees as shown in Fig. 3. This changing way is called as "Square" way in this paper. Although the "Square" way is simple and easy, it has a risk to result in different calibration values from ones obtained by "Lever" way. Moreover, if the square drive cannot be apart from the sensing body in a certain kind of torque-wrench-form transducer (for any structural reason), the "square" way is not able to be adopted.

The author experimentally investigated to compare the calibration results between two changing ways for the mounting positions using various torque-wrench-form-transducers.

Table 1. Basic specifications of torque-wrench-form-transducers.

Transducer type	TP-50-1210	TS50	TTS/100Nm	TS500
Rated capacity / N m	50	50	100	500
Manufacturer	Showa Ins.	Tohnichi	HBM	Tohnichi
Principle of sensing	Straing gauge			
Rated output / (mV/V)	1.7	1.7	1.9	1.6
Averaged lever length / mm	300	250	500	800
Short lever length / mm	200	200	300	600
Square drive / mm	9.525*1)	9.525*1)	9.525	19.05*1)
Indicator/amprlifier	DMP40	MGCplus (ML38)	DMP40	MGCplus (ML38)
Manufacturer of Ind./amp.	HBM	HBM	HBM	HBM

*1) Tolerance of IT6.

2. EXPERIMENTAL CONDITIONS

2.1 EXPERIMENTAL DEVICES

Table 1 shows basic specification of torque-wrench-form-transducers with indicator/amplifiers. They were connected with each exclusive cable. Here (again), the "reference torque wrench (RTW)" is defined as a complete set of a transducer with the torque wrench form, a cable and an indicator. Power supply was 100 V (AC of 50 Hz). The excitation and frequency of AC amplifier were 5 V and 225 Hz. Digital resolution of indicators were all 20 bits (0.000001 mV/V). Cut off frequency of low-pass filter was 0.1 Hz, then the fluctuation always occurred with three digits at even no loading. Photographs of transducers used in the experiment are shown in Fig. 4 to Fig.6.

A deadweight type torque standard machine with rated capacity of 1 kN·m (so called 1-kN·m-DWTSM) was used for all the RTW calibrations.

2.2 EXPERIMENTAL PROCEDURE

The calibration experiment was carried out by the following procedure. First, the transducers were set on the 1-kN·m-DWTSM as shown in lower side of Fig. 1. Second, pure torque was loaded on the square drive of the transducer but the reaction torque was supported by the loading point at a back plate. The calibration was conducted according to JMIF016 [8], the guideline for calibration laboratories of reference torque wrenches, issued by Japan Measurement Instrumentation Federation. The loading timetable is obvious from Fig. 7, that is, two increasing and decreasing calibration cycles are conducted after three times pre-loadings up to

Figure 4. A photograph of transducer TP-50N-1210.

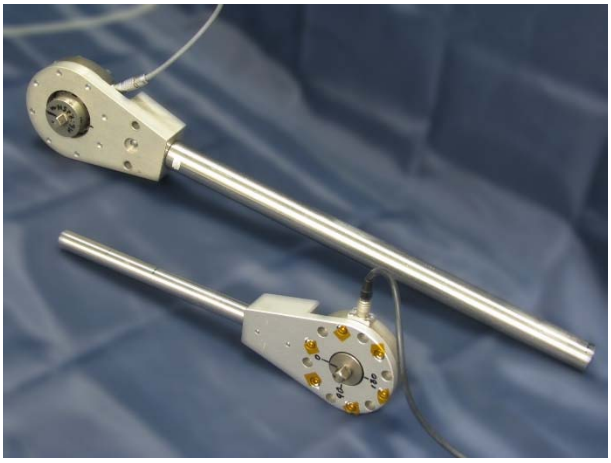

Figure 5. A photograph of transducers TS50 (lower side) and TTS/100Nm (upper side).

Figure 6. A photograph of transducer TS500.

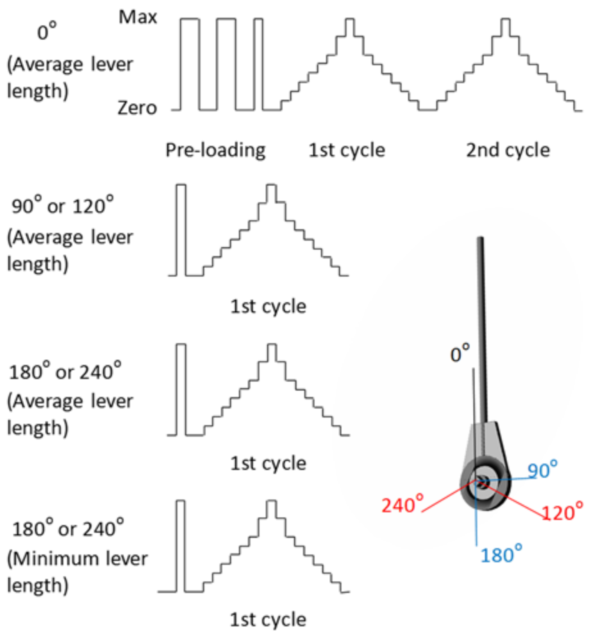

Figure 7. The loading timetable of the calibration for RTW.

100 % of the maximum torque at the 0 degree position. After changing mounting position, one increasing and decreasing calibration cycle was performed after one pre-loading. The calibration series was repeated at the third rotational position. Then, at the same position, the calibration series was repeated changing the lever length (the distance of loading point from the measurement axis) from the average length to the minimum one. The torque steps were all eight steps (10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 80 % and 100 % of the maximum torque). The calibration was carried out in clockwise (CW) and counterclockwise (CCW) directions, separately. The calibration experiments were conducted with "Lever" way and "Square" way, respectively. Figures 8 and 9 show examples of installation of transducers on the 1-kN·m-DWTSM by "Lever" way and "Square" way. Detailed explanation of installation has been described in the reference [5].

3. RESULTS AND DISCUSSION

3.1 CALIBRATION RESULTS

Calibration values were calculated as the means of the measurement values obtained from different mounting positions. The results measured during the second cycles

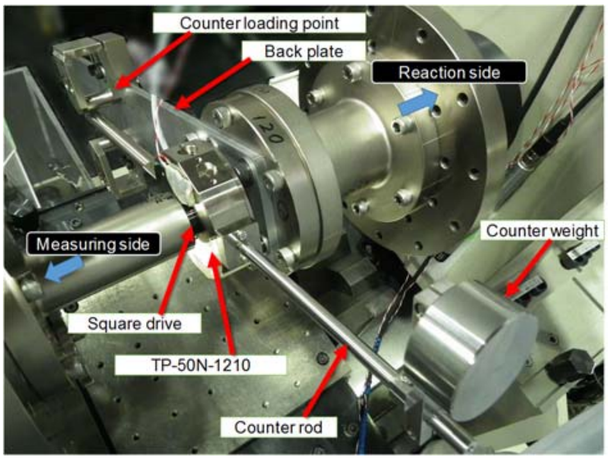

Figure 8. An example of installation of transducer on the 1-kN·m-DWTSM by "Lever" way (TP-50N-1210, at the mounting position of 0 degree for the case of counter-clockwise torque).

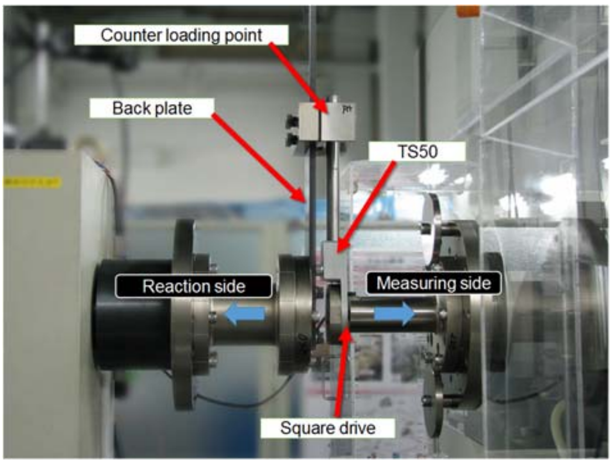

Figure 9. An example of installation of transducer on the 1-kN·m-DWTSM by "Square" way (TS50, at the mounting position of 0 degree for the case of clockwise torque).

were not included in the calculations. Figures 10 to 13 show the calibration results for all four transducers. The vertical axes show the relative values of calibration results with changing detachable square drive (“Square” way), from the ones with changing lever direction (“Lever” way). Blue rectangular shows increasing whereas white rectangular shows decreasing torques. Relative deviations were strongly different depending on the transducer. TP-50N-1210 did not show big differences in two changing ways. The reason could be that TP-50N-1210 was manufactured much precisely. The alignment and asymmetry could be successfully achieved in very high level. Relative deviations were approximately within 0.01 %. Whereas TS50 and TS500 showed approximately 0.1 % deviations. In particular, the signs of deviation were opposite, that means the results obtained by “Square” way was larger than ones by “Lever” way in the calibration of TS50, but smaller than ones by “Lever” way in the calibration of TS500. They could be ascribable to the dimensions and working accuracies of mechanical parts including spring elements, degrees of misalignment and asymmetry, influences of side force depending on the difference of lever length, and so on. If the uncertainty level of more than 0.2 % is acceptable, those results do not affect to the successive calibration of torque wrench calibration devices (torque wrench tester, TWT), which must have the permissible relative expanded uncertainty of less than 1 % according to ISO 6789, the standard documentation of the requirement for the calibration of hand torque tools [9].

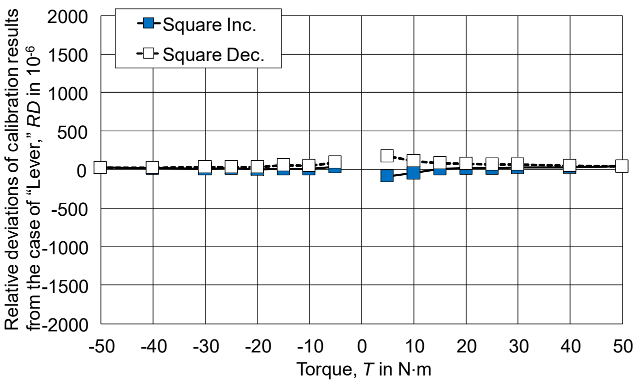

Figure 10. Relative deviations of calibration results from the case of changing lever direction, for TP-50N-1210.

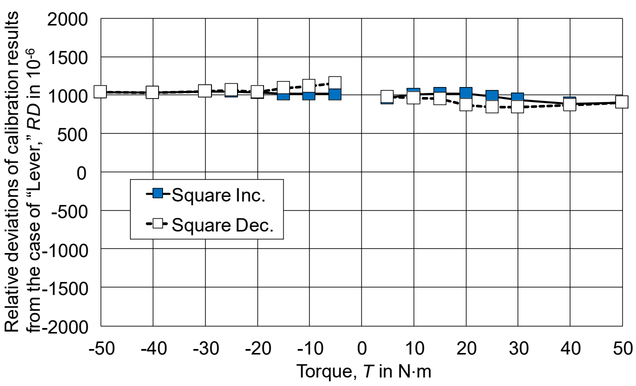

Figure 11. Relative deviations of calibration results from the case of changing lever direction, for TS50.

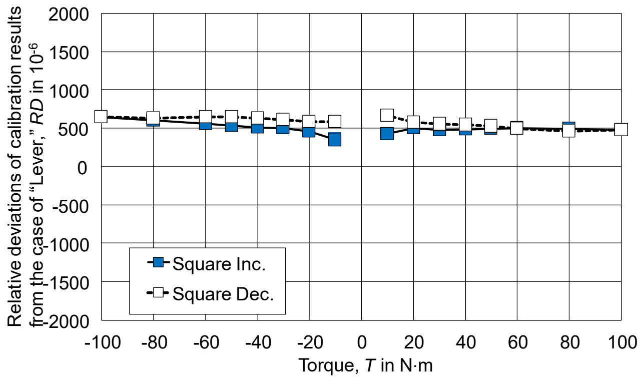

Figure 12. Relative deviations of calibration results from the case of changing lever direction, for TTS/100Nm.

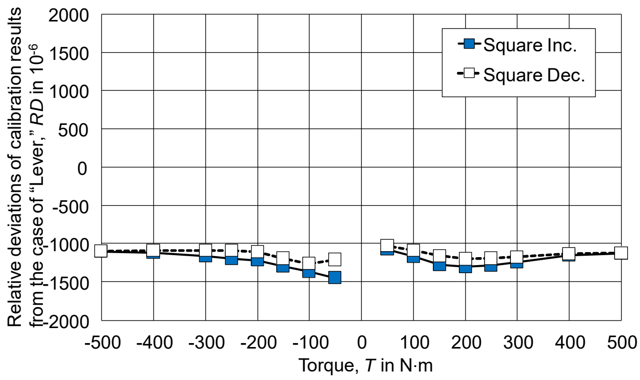

Figure 13. Relative deviations of calibration results from the case of changing lever direction, for TS500.

3.2 UNCERTAINTIES OF CALIBRATION

The uncertainty was evaluated according to JCG209S11 [10], which is a “guideline for the uncertainty evaluation of calibrations for torque meters and reference torque wrenches” issued by the International Accreditation Japan at the National Institute of Testing and Evaluation (IAJapan/NITE: the accreditation body for calibration and testing laboratories in Japan). The guideline was made mainly by NMIJ cooperating with Japanese industry. The uncertainty evaluation method is similar to guidelines in other countries or economies. Detailed explanation of the evaluation method is omitted, but the relative expanded uncertainty W of calibration for the RTW was calculated from the relative combined standard uncertainty w_{tsm} of torque realized by the torque standard machine (TSM) and the relative combined standard uncertainty $w_{\mathrm{c\_tra}}$ ascribable to the measurement of the transducer, according to the following equation:

$$W_{\mathrm{i}} = k \cdot w_{\mathrm{i}} = k \cdot \sqrt{{w_{\mathrm{tsm}}}^2 + {w_{\mathrm{c\_tra}}}^2} \quad , \qquad (1)$$

where the coverage factor k was equal to two and its interval was estimated to have a level of confidence of approximately 95 %. In the case of using torque calibration machine (TCM) at the accredited secondary calibration laboratories, w_{tsm} is replaced by w_{tcm}. The authors also evaluated the effective degree of freedom and confirmed sufficient large number. w_{tsm} has been evaluated as 2.5×10^{-5}. $w_{\mathrm{c\_tra}}$ is calculated as:

$$w_{\mathrm{c\_tra,i}} = \sqrt{w_{\mathrm{rot,i}}^2 + w_{\mathrm{rep,i}}^2 + w_{\mathrm{int,i}}^2 + w_{\mathrm{zer,i}}^2 + w_{\mathrm{rev,i}}^2 + w_{\mathrm{lvr,i}}^2 + w_{\mathrm{res,i}}^2} \, . \tag{2a}$$

In the case of the evaluation of increasing and decreasing torque separately, $w_{\mathrm{c\_tra}}$ is calculated from:

$$w_{\mathrm{c\_tra,i}} = \sqrt{w_{\mathrm{rot,i}}^2 + w_{\mathrm{rep,i}}^2 + w_{\mathrm{int,i}}^2 + w_{\mathrm{zer,i}}^2 + w_{\mathrm{lvr,i}}^2 + w_{\mathrm{res,i}}^2} \, . \tag{2b}$$

Here, i denotes each torque step. w_{rot} is a relative standard uncertainty due to the reproducibility with changing the rotational mounting position, w_{rep} is the one due to repeatability without changing mounting position, w_{int} is the one due to the interpolation, w_{zer} is the one due to zero shift, w_{rev} is the one due to hysteresis, w_{lvr} is the reproducibility with changing lever length and w_{res} is the one due to resolution. Eq. (2b) was used for the calculation in the experiment.

Figures 14 to 17 show the uncertainty evaluation results of calibration for all transducers. The vertical axes show the relative expanded uncertainty (REU) W. Dominant uncertainties were w_{rot} and w_{lvr} in all cases. The uncertainty of the calibration for the torque-wrench-calibration with “Square” way became slightly larger than the one with “Lever” way except the case of TP-50N-1210. The most notable point is that the differences of calibration results in two ways became lager than those uncertainties. Therefore, we need to consider other additional uncertainties or to describe the

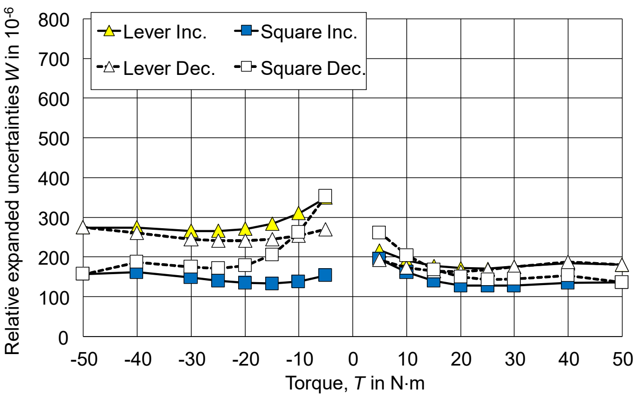

Figure 14. Relative expanded uncertainties of calibration for TP-50N-1210

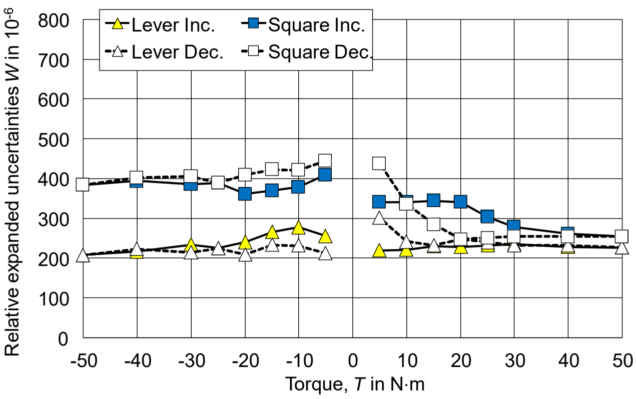

Figure 15. Relative expanded uncertainties of calibration for TS50

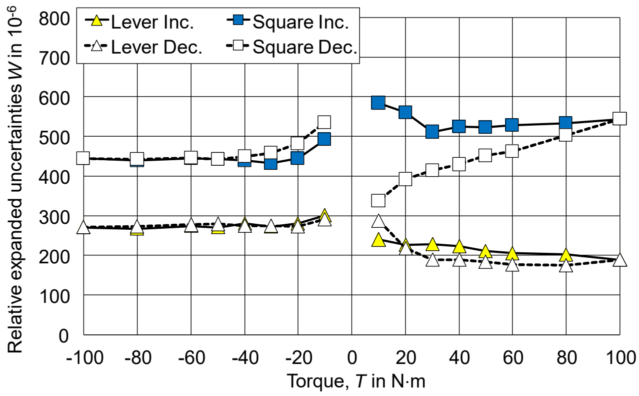

Figure 16. Relative expanded uncertainties of calibration for TTS/100Nm

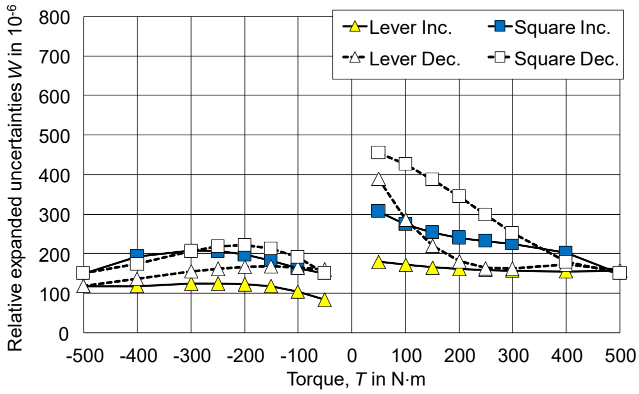

Figure 17. Relative expanded uncertainties of calibration for TS500

changing way as one of the calibration conditions in the calibration certificate as customers can easily use the calibration results for the successive calibration of torque wrench calibration equipment (torque wrench tester, TWT).

4. CONCLUSION

This paper experimentally revealed that the somewhat larger differences occurred in the calibration results between two ways of changing the rotational mounting position in the calibration of reference torque wrenches, changing the position of sensing element itself (lever direction itself) and changing the position of detachable square drive. We need to consider other additional uncertainties or to describe the changing way as one of the calibration condition in the calibration certificate. The permissible relative uncertainty may be within one percent or less for the torque wrench tester or checker according to ISO 6789 [9]. Therefore, the relative value of 0.2 % or less is probably enough for the maximum uncertainty of reference torque wrenches. However, some Japanese manufacturers requested the uncertainty of 0.1 % or less for the reference torque wrenches. They have precise torque wrench testers of uncertainties of 0.3 % or less for the calibration of precise hand torque wrenches having the ability of permissible maximum deviation of less than 1 % from the nominal values (but not 4 % or 6 %).

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