

SIMULTANEOUS DETERMINATION OF TEMPERATURE AND HUMIDITY SENSITIVITY COEFFICIENTS OF TORQUE TRANSFER STANDARDS IN AMBIENT CONDITIONS

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Abstract: Temperature and humidity sensitivity coefficients of torque transfer standards used for key comparison should be determined to improve the degree of equivalence among participants. This report presents a simple method to determine them using a natural and seasonal change of ambient conditions in a laboratory.

Keywords: torque, temperature, humidity, sensitivity coefficient.

1. INTRODUCTION

It is well known that the sensitivity (that is, an electrical output at a rated torque) of the torque transducer of strain gauge type used as the travelling standards has dependences on ambient conditions, especially temperature and humidity of the air [1-2]. These dependences must be accounted for in order to improve the resolution of key comparison since it is inevitable that ambient conditions of the air during the measurements vary with places (laboratories of the participants and the pilot) and time, even though temperature and humidity with their allowable limits are specified in the protocol.

To date, the sensitivity coefficients of temperature and humidity of the torque travelling standards have been measured by using a special environmental controlled chamber [1] or intentionally changing ambient conditions of a laboratory [2]. The use of the special environmental controlled chamber that is capable of controlling temperature and humidity of the air independently and precisely that surrounds a transducer would be the most accurate method, but its application is limited in some cases; for example, when measuring the temperature sensitivity coefficient, the chamber should have an enough volume to accommodate not only the transducer but also the whole torque standard machine in order to set the temperature of the transducer and the machine itself equal. Otherwise, it is difficult to control the transducer's temperature because the spring element of the transducer is thermally connected to the torque machine that has a large heat capacity via two cylindrical adapters. The other method that intentionally changes the ambient conditions of the laboratory could circumvent such a thermal flow problem, but it also costs time and money to control both of temperature and humidity of the air of the whole laboratory independently that has a huge volume.

Now in our investigation an attempt is made to determine both of sensitivity coefficients of the temperature and humidity of the torque transducer at the same time. We have used a natural change of the ambient conditions of the air in the laboratory caused by a seasonal climate change. The climate of Korea has huge seasonal temperature and humidity ranges. Summer is very hot and humid mixed with rain, whereas winter is cold and dry. In spring and fall, the climate conditions tend to be steadily distributed in the middle of these ranges. Although the air in our laboratory always should be conditioned and seems to be maintained constant from a short-term perspective, the actual ambient conditions have varied gradually and steadily with such a huge seasonal climate change. During our 11 months observation, the temperature and the relative humidity of our laboratory had varied between 20.0 °C and 25.0 °C and between 35 % rH and 78 % rH, respectively, as shown in Figure 1. These variations in ambient conditions of the laboratory are large enough to determine the sensitivity coefficients of the temperature and humidity of the torque transducers accurately.

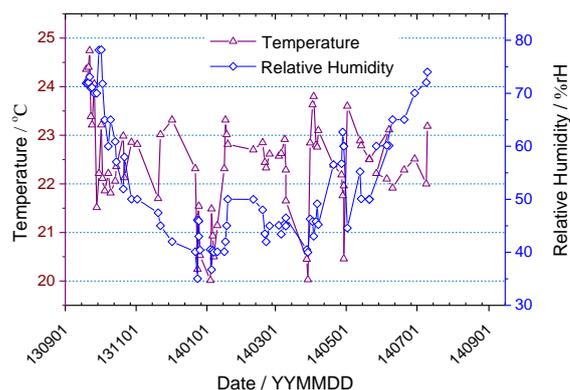


Figure. 1 Variations of the climatic conditions at KRISS laboratory over the measurement period

This paper describes a simple method that possibly reduces our efforts and costs for determination of the sensitivity coefficients of the temperature and the humidity of torque transducers by using the calibration data of the torque transducer acquired at various ambient conditions over seasons as a part of regular tasks in a laboratory.

2. EXPERIEMENTS

The sensitivities of the torque transducers at their rated torques had been measured by using the KRIS 2 kN-m deadweight torque standard machine (DTSM) [3]. We selected two torque transfer standards (TTS) with different shapes and rated capacities. The first (coded TTS1, model DmTN, accuracy class VN, Gassmann Testing and Metrology GmbH, Germany) and second (coded TTS2, model TN accuracy class TOP, Hottinger Baldwin Messtechnik GmbH, Germany) ones are torque transfer standards of 1000 N-m capacity with cylindrical adapters on their both sides.

A high-precision bridge amplifier (DMP 40, Hottinger Baldwin Messtechnik GmbH, Germany) was used with settings: an excitation voltage of 5 V, a measuring range of 2.5 mV/V, a filter setting of 0.1Hz Bessel and a resolution of 0.000001 mV/V. A temperature and humidity logger (Testo, 435.2) was used to measure the temperature and the humidity of the air close to the transducer under test. We also used another digital thermometer (GREISINGER, GMH 3230) to measure the machine temperature and the ambient temperature of the laboratory at the same time.

We created a measurement protocol based on the one used in CCM.T-K1 in order to determine the comparable and valid sensitivity coefficients of the temperature and the humidity while carefully addressing the effects of other influential factors, which includes creep and creep recovery effects, torque arm length change with the temperature, rotation effect of the torque transducers, amplifier characteristics and drift of sensitivity over time.

The torque transducers were stored and installed for at least 24 hours in ambient conditions of the KRIS laboratory before the test to ensure the equilibrium or saturated state. According to the reported time behaviour of the torque transducers for step changes of the humidity, a day is sufficient time for the relaxation. Compared to the measurement schedule used in CCM.T-K1 KC, the sensitivity of the torque transducers had been measured at the fixed mounting position (0°) throughout the whole measurement period to exclude the effect of the orientation of torque transducers from the sensitivity measurements. In addition, only clockwise (CW) torques had been used to determine the sensitivity coefficients since they are assumed almost same for CW and CCW torques [2].

The measurement schedule in our experiments consists of three cycles of pre-loadings after installation and successive 7 cycles of trials of measurements. The last 7 deflections were averaged to produce a representative sensitivity of the torque transducer at specific ambient conditions. At every measurement, the ambient conditions of the air, the temperature of the DTSM, and the temperature of the transducer had been recorded. Each cycle includes the loading and unloading sequences and the time slot for each cycle was allocated to 12 min (6 min for each loading and unloading) to reduce the creep effect, which will be discussed later in Section 2.3. A same bridge amplifier was used throughout the whole measurement to reduce the effect from the amplifier characteristics. Before starting a series of measurements, its output was calibrated using a self-

calibration function. The measurement campaign had continued for approximately 11 months, though we were able to determine the required sensitivities within a shorter period with reasonable uncertainties.

3. MEASUREMENT RESULTS

We modeled our measurement with a linear equation for the simultaneous determination of the sensitivity coefficients of temperature T and humidity rH , as shown in equation (1).

$$\Delta D = c_T \Delta T + c_{rH} \Delta rH \quad (1)$$

,where ΔD , c_T and c_{rH} are, the relative change in sensitivity, sensitivity coefficients of temperature and humidity effects, respectively. The relative changes from the averages were chosen to simplify computations of the required sensitivity coefficients and associated standard uncertainties. By the method of least squares, in terms of the experimental standard deviations and estimated correlation coefficients of these relative input variables, c_T and c_{rH} are given by

$$c_T = \frac{s_{\Delta D}}{s_{\Delta T}} \left(\frac{r_{\Delta D \Delta T} - r_{\Delta D \Delta rH} r_{\Delta T \Delta rH}}{1 - r_{\Delta T \Delta rH}^2} \right) \quad (2)$$

$$c_{rH} = \frac{s_{\Delta D}}{s_{\Delta rH}} \left(\frac{r_{\Delta D \Delta rH} - r_{\Delta D \Delta T} r_{\Delta T \Delta rH}}{1 - r_{\Delta T \Delta rH}^2} \right) \quad (3)$$

The experimental variance S^2 , which is a measure of the overall uncertainty of the fit given by [4]:

$$S^2 = \frac{\sum_{k=1}^{k=n} [\Delta D_k - \Delta D(T_k)]^2}{n - 2} \quad (4)$$

,where ΔD_k and $\Delta D(T_k)$ are the measured net deflection change ΔD_k at the temperature T_k and the net deflection change predicted by (1), respectively.

The experimental variances of the sensitivity coefficients $s^2(c_T)$, $s^2(c_{rH})$ and their correlation coefficient $r(c_T, c_{rH})$ are given by:

$$s^2(c_T) = \frac{S^2}{\sum_{k=1}^n \Delta T_k^2 (1 - r_{\Delta T \Delta rH}^2)} \quad (5)$$

$$s^2(c_{rH}) = \frac{S^2}{\sum_{k=1}^n \Delta rH_k^2 (1 - r_{\Delta T \Delta rH}^2)} \quad (6)$$

$$r(c_T, c_{rH}) = - \frac{\sum_{k=1}^n \Delta T_k \Delta rH_k}{\sqrt{\sum_{k=1}^n \Delta T_k^2 \sum_{k=1}^n \Delta rH_k^2}} \quad (7)$$

The above equations presented in their respective forms enabled to determine the sensitivity coefficients and the

associated uncertainties due to the applied regression in regular calibration or measurements analysis spread sheets. Then it is easy to combine with other sources of uncertainties such as sensitivities, temperature and relative humidity measurements. Determination of the coefficient of sensitivities with their associated uncertainties originating from all the major sources will help to do sufficient comparison with their specified values by the manufacturer or values obtained by any other laboratory.

The values and uncertainties of c_T and c_{rH} obtained for two transfer standards are given in Table 1.

Table 1. Temperature and humidity sensitivity coefficients of torque transfer standards.

Transducers	Influencing factor	Sensitivity Coefficients	Expanded Uncertainty
TTS1/GTM	temperature	$7.9 \times 10^{-5} / ^\circ\text{C}$	$5.2 \times 10^{-6} / ^\circ\text{C}$
1000	humidity	$4.2 \times 10^{-7} / \%\text{rH}$	$3.6 \times 10^{-7} / \%\text{rH}$
TTS2/HBM	temperature	$9.4 \times 10^{-6} / ^\circ\text{C}$	$1.5 \times 10^{-6} / ^\circ\text{C}$
1000	humidity	$-1.0 \times 10^{-6} / \%\text{rH}$	$1.8 \times 10^{-7} / \%\text{rH}$

Combined errors of both temperature and humidity effects may be big like the case of TTS1. For TTS1 the maximum net deflection variation from the average was 398 nV/V, and when it is corrected with the determined uncertainty, it will improved by about 9 times. So besides to the complement of uncertainty budgets of torque calibrations, c_T and c_{rH} values can be used to take corrections depending on the amount and important of the corresponding systematic errors. For TTS2, the maximum net deflection variation was 40 nV/V and after correction was improved by 4 times. To observe the significance of these deviations in our dissemination of traceability using these two particular transducers as an example, the observed error was equal to the combined uncertainty of the DWTS for TTS2, and eight times this combined uncertainty for the case of TTS2. These big differences in between the transducers magnified their high difference in performance quality of the transducers by different manufacturers though manufactured for the same purpose.

The uncertainties given in table 1 were originating from the applied regression plane, the temperature and humidity measurement, and the repeatability of the net deflection measurement. The standard uncertainties due to the applied regression are determined from the covariance matrix of the sensitivity coefficients given in equation (2) and (3), and Monte Carlo simulation [5], was used to include the uncertainty of the sensitivity coefficients due to the individual input quantities. Half of the maximum statistical range of the temperature $0.20 \text{ }^\circ\text{C}$ and relative humidity 2.0% variations are considered to be half width of rectangular distributions. The maximum standard deviations of the sensitivity measurements with the assumed t-distribution were used to determine the uncertainty due to the sensitivity measurements. Then the expanded uncertainties resulted after Monte Carlo simulations based on each set of data producing the associated sensitivity

coefficients with their standard uncertainty and measurement of the input quantities.

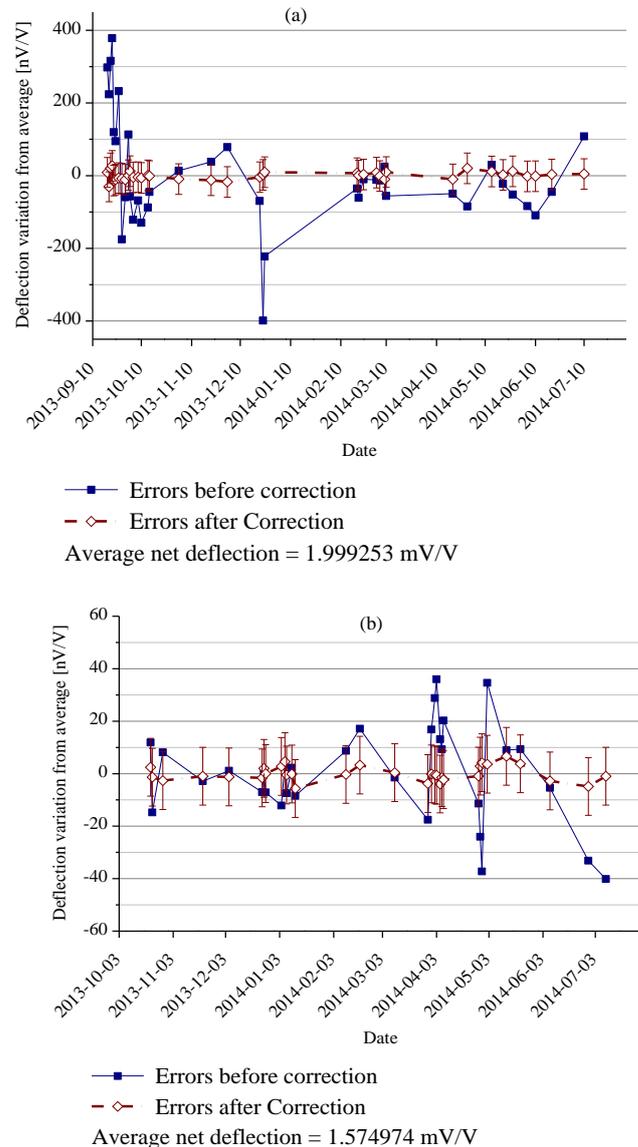


Fig. 2 Measurement results before and after correction for temperature and relative humidity effects for torque transfer standard 1 (a) and 2 (b). This result shows significance of the influences and corrections applied in actual laboratory climatic conditions. The error bar represents the uncertainty of the correction.

4. CONCLUSION

We intended to use unavoidable variations of temperature and relative humidity within the range they are effectively controlled, to determine the coefficients of their influences on torque transfer standards simultaneously. Besides enhancing estimation of uncertainties in traceability dissemination, determination of these coefficients enabled us to correct systematic errors depending on significances in amount and importance. For example, with this work we experienced an error of 398 nV/V, which was eight times

the combined uncertainty of DWTS machine. If we can correct these effects for the torque transfer standards, they can be used to determine sensitivity coefficients of other torque transducers using reference torque calibration facility. The temperature sensitivity coefficient of one of the transducers was also found not to meet the manufacturer declared specification. For all these immediate applications, our approach provides a sort of practical evidence to be implemented by calibration and metrology laboratories.

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