IMEKO 2010 TC3, TC5 and TC22 Conferences
Metrology in Modern Context
November 22–25, 2010, Pattaya, Chonburi, Thailand

EVALUATION OF ACTUAL SENSITIVITY LIMIT IN A 10 N·m DEAD WEIGHT TORQUE STANDARD MACHINE AND STABILITY OF A NEW 1 N·m TORQUE TRANSDUCER

Atsuhiro Nishino, *Koji Ogushi and Kazunaga Ueda*

National Metrology Institute of Japan, AIST, Tsukuba, Ibaraki, Japan, a.nishino@aist.go.jp

Abstract – A 10 N·m dead weight torque standard machine (10-N·m-DWTSM) has been under development at NMIJ/AIST since 2006 to expand the range of the torque standard. Estimation of the sensitivity limit of the fulcrum is one of the most important issues to realize a precise reference torque of small capacity by using a dead weight torque standard machine. In this study, a torque transducer was installed on the 10-N·m-DWTSM in order to keep the moment-arm on the horizontal line (balancing). The sensitivity limit of the fulcrum under real calibration conditions was estimated by reading the change in the output from the torque measuring device (TMD: the torque transducer with a cable and an indicating device) when small weights were loaded or unloaded. The small weights used in the experiment were 0.5 mg, 1 mg, 10 mg, and 100 mg. Equivalent radial loads from 0.1 N·m to 10 N·m were imposed on the fulcrum during the sensitivity measurement. As a result, the sensitivity limit of the fulcrum was confirmed to be sufficient to load at least 0.5 mg. A relative sensitivity limit of the fulcrum of less than 2.5×10^{-5} and relative reproducibility of the sensitivity limit of the fulcrum of less than 1.7×10^{-6} could be obtained within the calibration range from 0.1 N·m to 10 N·m.

It is also important to develop small-rated-capacity torque transducers that can be used as a transfer standard. Therefore, a transducer with a rated capacity of 1 N·m was developed in parallel with the development of the 10-N·m-DWTSM. The stability of the 1 N·m TMD has been evaluated over a period of one year.

Keywords: Torque standard, Uncertainty, Sensitivity

1. INTRODUCTION

There is a growing demand for dissemination of a small-rated-capacity torque standard of less than 5 N·m from various industries in Japan. A 10 N·m dead weight torque standard machine (10-N·m-DWTSM) has been under development since 2006 at the National Metrology Institute of Japan, the National Institute of Advanced Industrial Science and Technology (NMIJ/AIST). The hardware and software components of the 10-N·m-DWTSM have been almost completed. The uncertainty of the torque realized by the 10-N·m-DWTSM is still being evaluated, and torque measuring devices (TMDs) with small rated capacity of less than 10 N·m are being calibrated by using the 10-N·m-DWTSM in order to evaluate the Calibration and Measurement Capability (CMC).[1]

The authors' interest shifted to the sensitivity limit of the fulcrum, which is one of the most important issues in the evaluation of a deadweight type TSM. In particular, a TSM with small rated capacity should be much more sensitive to changes in microscopic torque than a TSM of intermediate or large capacity. The authors investigated the sensitivity limit of the fulcrum by measuring the inclined level of the moment-arm when small weights were loaded, under the condition that the height position of the centre of gravity in the moment-arm was adjusted to the lower side from the measurement axis to keep it balanced (keep it on the horizontal line).[1] As a result, the sensitivity limit was a relative value of 5×10^{-6} for 1 N·m. In the next step, some weights were attached on the moment-arm to adjust the height position of the centre of gravity to the upper side, so that the sensitivity limit of the fulcrum was improved under real calibration conditions, where the torque transducer was installed on the 10-N·m-DWTSM. In this case, the moment-arm can no longer maintain a horizontal position without feedback control when the weights are unloaded at the tip of the moment-arm; that is to say, the moment-arm is unstable under this condition.[2] Thus, the sensitivity limit of the fulcrum cannot be investigated by using the method described in the literature.[1] In addition, because weights of various mass are loaded at the tip of the moment-arm, the height position of the centre of gravity might change. The sensitivity limit of the fulcrum depends on the height position of the centre of gravity. Therefore, the sensitivity limit of the fulcrum should be investigated under real calibration conditions.

In this study, the sensitivity limit of the fulcrum under real calibration conditions was evaluated by using a torque transducer with a rated capacity of 1 N·m installed on the 10-N·m-DWTSM.

The transducer used for the experiment (TP-1N-0302) was developed at NMIJ in cooperation with Showa Measuring Instruments Co., Ltd., a manufacturer of strain gauge sensing devices. It has the smallest capacity of the transducers owned by NMIJ. The development of an accurate torque transducer with small rated capacity is as important as the development of a TSM with small rated capacity in advancing the dissemination of a small torque standard. The performance of the TP-1N-0302 is being evaluated continuously. In this study, the stability over a

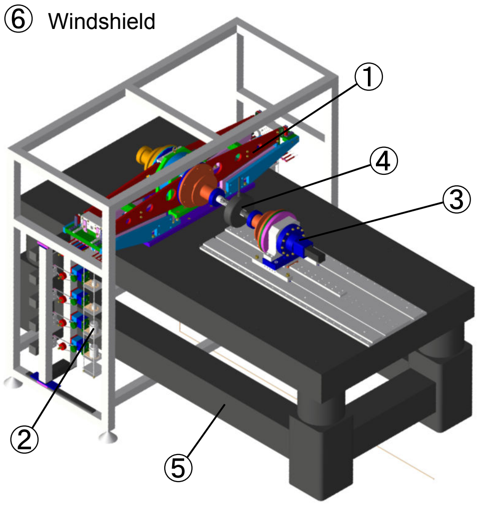


Fig. 1. Schematic of 10-N·m-DWTSM.

Fig. 2. Weights to adjust height position of the centre of gravity.

period of approximately one year was evaluated.

2. 10-N·m-DWTSM AND TP-1N-0302

A schematic diagram of the 10-N·m-DWTSM is shown in Fig. 1. The basic hardware components of the 10-N·m-DWTSM are: (1) a moment-arm, (2) weight loading components, (3) a counter bearing drive, (4) an installation component for a torque transducer, (5) a pedestal, and (6) a windshield.

There are some possible methods to improve the sensitivity limit of the fulcrum, for example, eliminating the rotational friction in the fulcrum, protecting the 10-N·m-DWTSM from airflows, and adjusting the height position of the centre of gravity. An aerostatic bearing is adopted as the fulcrum supporting the moment-arm to minimize the rotational friction. The 10-N·m-DWTSM is completely covered with the windshield to block airflows from the air-conditioning and the movement of people. The height position of the centre of gravity is adjusted to the upper side from the fulcrum point by using weights attached on the top of the moment-arm, as shown in Fig. 2. Under these conditions, the sensitivity limit of the fulcrum is improved although the moment-arm is unstable. Ordinary calibration

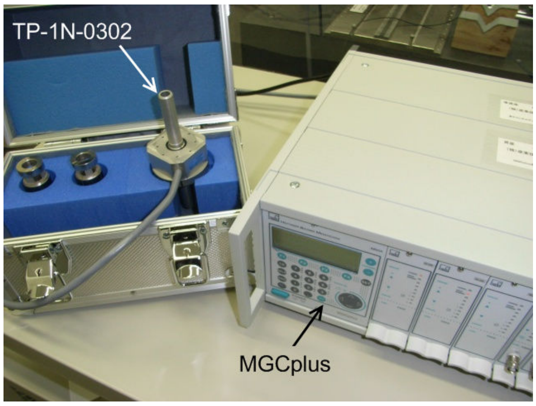


Fig. 3. Photograph of TP-1N-0302 and MGCplus.

is done under these conditions (so called “real calibration conditions”).

Figure 3 shows the TP-1N-0302, together with an indicator/amplifier (MGCplus system). The TP-1N-0302 transducer was used in various experiments for evaluating the 10-N·m-DWTSM.

3. EXPERIMENTS

3.1. Sensitivity of the fulcrum

The sensitivity limit of the fulcrum was investigated by using the TP-1N-0302 under the real calibration conditions. Figure 4 shows the loading position of the weights in the weight loading components. The loading cycle for this experiment is shown in Fig. 5. The experimental conditions are described in Table 1. The masses of the small weights are shown in Table 2. The weights to generate the radial load were loaded on both 5th stages in the weight loading components. The weights were 1 kg, 100 g, and 10 g. If the weights are loaded on one side of the weight loading components in each case, the generated torques, T, are 10 N·m, 1 N·m, and 0.1 N·m. The bigger the radial load is, the worse the sensitivity limit of the fulcrum becomes. Small weights of 0.5 mg, 1 mg, 10 mg, and 100 mg were used for measuring the sensitivity limit of the fulcrum. The torques generated by the small weights, T', are shown in Table 2. The small weights were loaded on the 1st stage in the weight loading components attached to the clockwise side of the moment-arm. Loading and unloading of the small weights were automated by the control system of the weight loading components.

The experimental procedure was as follows. First, the TP-1N-0302 was installed on the 10-N·m-DWTSM at the 0^{o} position, and the weights to generate the radial load were loaded on both 5th stages. Next, the clamp systems unlocked the moment-arm, and the counter bearing drive started control to maintain the moment-arm at the horizontal position. Then, data acquisition started after the output of the TP-1N-0302 stabilized. This took approximately 20 minutes. Control of the counter bearing drive was stopped during data acquisition. The output of the TP-1N-0302 was measured while the small weights were loaded and unloaded five times, as shown in Fig. 5. The output was measured for one minute after loading or unloading of the small weights.

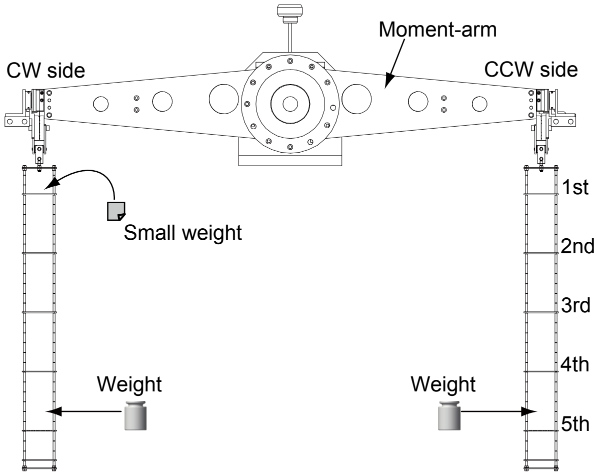


Fig. 4. Loading position of the weights in the weight loading component.

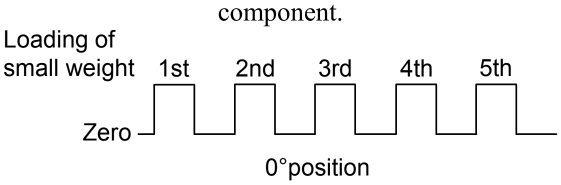


Fig. 5. Loading cycle for measuring the sensitivity limit of the fulcrum.

Table 1 Experimental conditions.

	Mass of the weights loaded on both 5th stages of the weight loading components	Torque generated when both weights were loaded on one side of the moment arm, T / N·m
Case 1	1 kg - 1 kg	10
Case 2	100 g - 100 g	1
Case 3	10 g - 10 g	0.1
Case 4	Without weight	- - -

Table 2 Mass of the small weights.

Mass / mg	Equivalent torque, T' / µN·m
100	500.0
10	50.0
1	5.0
0.5	2.5

3.2. Stability of TP-1N-0302

Although it is extremely difficult to manufacture a precise torque transducer with small rated capacity, the authors tried to develop a new 1 N·m transducer (TP-1N-0302) in cooperation with Showa Measuring Instruments Co., Ltd. The stability of the TP-1N-0302 has been evaluated over a period of one year by using the 1-kN·m-DWTSM, another TSM at NMIJ. Figure 6 shows the loading cycle of the calibration according to the guidelines for the torque calibration laboratories, JMIF015.[3] Two calibration steps (0.5 N·m and 1 N·m) were selected because the minimum torque range and step of the 1-kN·m-DWTSM were both 0.5 N·m. The mounting position was changed to three directions (0°, 120° and 240°). The TP-1N-0302 was calibrated separately for the clockwise (CW) and the counter-clockwise (CCW) directions. The reading corresponding to each torque step was noted 50 seconds after the torque was applied or removed. The time interval between two successive loading cycles was two minutes. The MGCplus(ML38) was used as an indicator/amplifier. A Bessel filter with a cut-off frequency of 0.1 Hz was employed as a low pass filter.

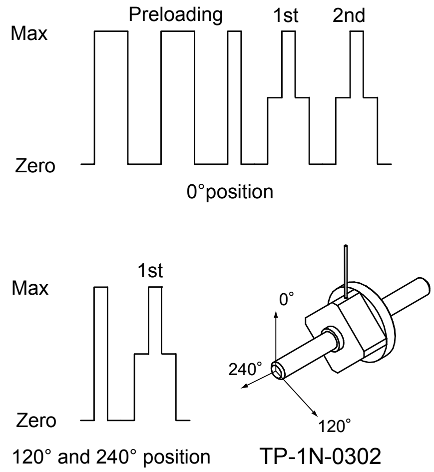


Fig. 6. Loading cycle for calibration of TP-1N-0302.

4. RESULTS AND DISCUSSION

4.1. Sensitivity of the fulcrum

Defined symbols are as follows: q_k is the output variation when the small weight was loaded, where k is number of times; $\bar{q}$ is the arithmetic mean; and $s(\bar{q})$ is the experimental standard deviation of the mean. Figure 7 shows the relationship between the mass of the small weights and $\bar{q}$. The horizontal and vertical axes both indicate logarithmic scales. In all cases, the outputs of the TP-1N-0302 changed when 0.5 mg was loaded on the weight loading components. The outputs were approximately the same value in all cases. Figure 8 shows the relationship between the mass of the small weights and $s(\bar{q})$. The maximum value of $s(\bar{q})$ in all cases was 1.2×10^{-6} mV/V. This value was nearly the same as the resolution of the TP-1N-0302. Table 3 shows the relative sensitivity limit of the fulcrum, u_{sr}, and the relative reproducibility of the sensitivity limit, u_{ssr}. Here u_{sr} is T'/T and u_{ssr} is T''/T, where T'' is the torque calculated from $s(\bar{q})$. u_{ssr} was one digit smaller than u_{sr} for each case, as shown in Table 3. u_{sr} was 2.5×10^{-6} in case 2, which was half of the value in the previous evaluation.[1] When the calibration range of the 10-N·m-DWTSM was expanded down to 0.1 N·m, u_{sr} was 2.5×10^{-5} and u_{ssr} was 1.7×10^{-6}. The smaller the calibration torque becomes, the higher the influence of the sensitivity limit on the uncertainty of the 10-N·m-DWTSM becomes. This experimental method has the disadvantage that the sensitivity of the fulcrum depends on the resolution capability of the TMD. The resolution of the TP-1N-0302 with MGCplus(ML38) was 1×10^{-6} mV/V. This is equivalent to a torque of 0.86 µN·m. Actually, the magnitude of the indication fluctuation of the TP-1N-0302 when installed on the 10-N·m-DWTSM was approximately 3×10^{-6} mV/V. Thus, the load of the 0.5 mg weight was the minimum load that can be sensed by the TP-1N-0302. If a

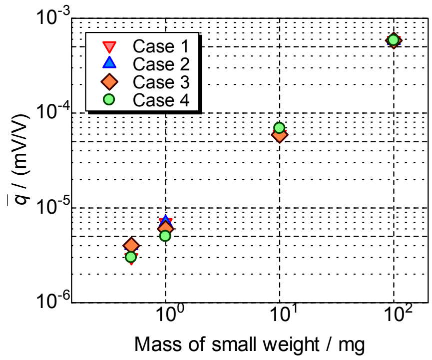


Fig. 7. Relationship between mass of the small weights and the arithmetic mean $\bar{q}$.

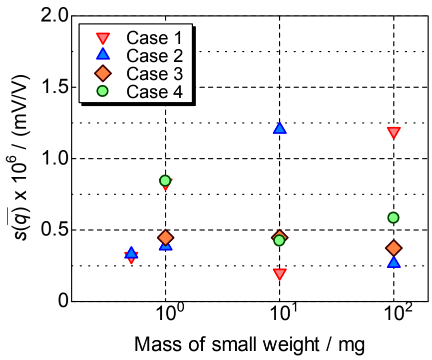


Fig. 8. Relationship between mass of the small weights and experimental standard deviation of the mean.

Table 3 The relative sensitivity limit of the fulcrum, u_{sr}, and the relative reproducibility of the sensitivity limit, u_{ssr}.

	u_{sr}	u_{ssr}
Case 1	2.5×10^{-7}	2.7×10^{-8}
Case 2	2.5×10^{-6}	2.8×10^{-7}
Case 3	2.5×10^{-5}	1.7×10^{-6}
Case 4	-----	-----

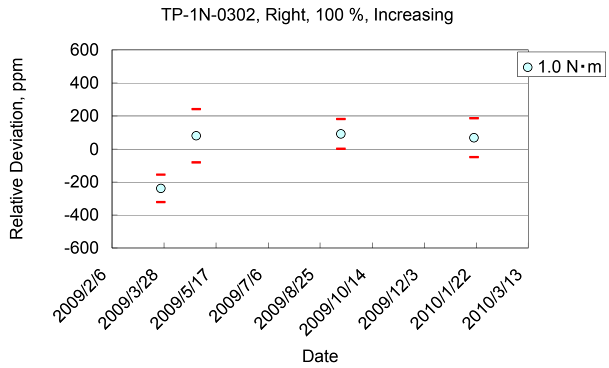
highly accurate transducer having a rated capacity smaller than 1 N·m is developed and a weight having a mass smaller than 0.5 mg is prepared, u_{sr} could be made smaller.

4.2. Stability of the TP-1N-0302

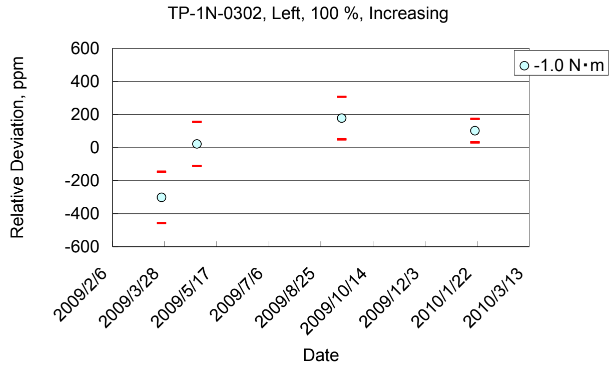
Figure 9 shows the relationship between the calibration dates and the relative deviations. Initially, the outputs of the TP-1N-0302 varied largely because the measurements might have been performed immediately after manufacturing. However, the outputs of the TP-1N-0302 have certainly stabilized after one year. The relative deviation of the last half year was less than 7.6×10^{-5}.

5. SUMMARY

In the development of a torque standard machine with small rated capacity, it is important to improve the sensitivity limit of the fulcrum. Also, it is very important to evaluate the sensitivity limit of the fulcrum. In this study, the sensitivity limit of the fulcrum under real calibration



(a) Clockwise



(b) Counter-clockwise

Fig. 9. The stability of the TP-1N-0302.

conditions was investigated by using a torque transducer with a rated capacity of 1 N·m (TP-1N-0302) installed on the 10-N·m-DWTSM. Some weights were attached on the moment-arm to adjust the height position of the centre of gravity to the upper side, so that the sensitivity limit of the fulcrum was improved. The output differences were observed when small weights from 0.5 mg to 100 mg were loaded on the weight loading components. As a result, the output of the TP-1N-0302 showed a notable change when a 0.5 mg weight was added on the weight loading components. When the calibration range of the 10-N·m-DWTSM was expanded down to 0.1 N·m, the relative sensitivity limit of the fulcrum and its relative reproducibility were 2.5×10^{-5} and 1.7×10^{-6}. In addition, the stability of the TP-1N-0302 has been evaluated over a period of one year. The relative deviation of the last half year was less than 7.6×10^{-5}. Stability evaluation will be continued in the future.

REFERENCES

[1] A. Nishino, K. Ogushi and K. Ueda, "SENSITIVITY EVALUATION OF THE FULCRUM IN THE 10 N·m DEAD WEIGHT TORQUE STANDARD MACHINE AND PERFORMANCE EXAMINATION OF A 1 N·m TORQUE MEASURING DEVICE", *XIX IMEKO World Congress*, pp. 333-338, Lisbon, Portugal, Sept. 2009.

[2] K. Ohgushi, T. Ota, K. Katase and T. Tojo, "Sensitivity Measurement in the 1 k N·m Torque Standard Machine – An Aerostatic Bearing for the Fulcrum Unit –", *Proc. APMF 2000*, pp. 99-104, 2000.

[3] JMIF-015, Guidelines for the calibration laboratory of torque measuring devices (2004).