

DEVELOPMENT OF THE 1 kN·m TORQUE STANDARD MACHINE

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Abstract: Research is being conducted at the National Research Laboratory of Metrology (NRLM), Japan, for the purpose of creating a technical base for a national torque standard and constructing a widely accepted torque traceability system. As part of the research, a torque standard machine of rated capacity 1 kN·m was developed. This machine has a variety of features enabling it to perform precise measurements of torque, including the correction of the lever length due to deadweights loading and an aerostatic bearing in order to minimize torque loss caused by friction at the fulcrum. In this paper, the torque standard machine is outlined.

Keywords: Torque standard, Torque measurement, Lever/Mass system

1 INTRODUCTION

Research is being conducted at the National Research Laboratory of Metrology (NRLM), Japan, for the purpose of creating a technical base for the national torque standard and constructing an effective torque traceability system [1]. Domestically, from a hardware perspective, torque standard machines and torque transfer standard devices are required for the establishment of the torque standard. As for the software, standard documents and guidelines must be prepared quickly and accurately. Solutions for various technical problems regarding the accreditation of calibration laboratories are also required. Internationally, national torque standard machines have been established or are now being established in Germany [2], Italy [3], England [4] and China [5] among others. In addition, preparation of inter-comparisons for achieving international recognition is currently being performed. Therefore, in Japan, the torque standard needs to be fixed at an early stage to contend with inter-comparisons.

This report introduces the first torque standard machine with a rated capacity of 1 kN·m developed at the NRLM, where a lever/mass system has been utilized.

2 COMPOSITION OF THE TORQUE STANDARD MACHINE

A schematic view of the torque standard machine is shown in Fig. 1. This equipment is fabricated to generate precise torque using a lever and deadweights. The measurement axis of this machine is horizontal, that is, the horizontal-structure type was adopted in the standard machine. The calibration range is from 5 N·m to 1 kN·m. According to a survey on sales of the torque measurement device in Japan, it is known that this torque range is the most commonly used in the industrial field. In addition, applying both a right-hand (clockwise) and left-hand (anti-clockwise) torque can be applied on the machine.

The torque standard machine consists of the following parts:

- (1) Pedestal parts which have high stiffness and which support torque occurring with deadweights and the lever.
- (2) Bearing parts for the fulcrum which are mainly equipped with an aerostatic bearing unit in order to keep the friction at the fulcrum to a minimum.
- (3) Lever parts which can accommodate the lever for the application of both the right- and left-handed torque, and which have an observation system for inclination level, flexure and length of the lever.
- (4) Weight loading parts which consist of linkage deadweight series, weight loading elevators, turntables to change the weight series, and so on.
- (5) Bearing parts for counter torque necessary for reacting to the generated torque and returning the inclined lever by weight loading to the horizontal position.
- (6) Installation parts of the torque transducer which include base flanges, a diaphragm

coupling, friction joints, torque transducer connecting flanges among others. They are used for mounting the torque transducer onto the standard machine with arranging these axes.

(7) Control / Display / Operating equipment

Below, each part is explained in detail.

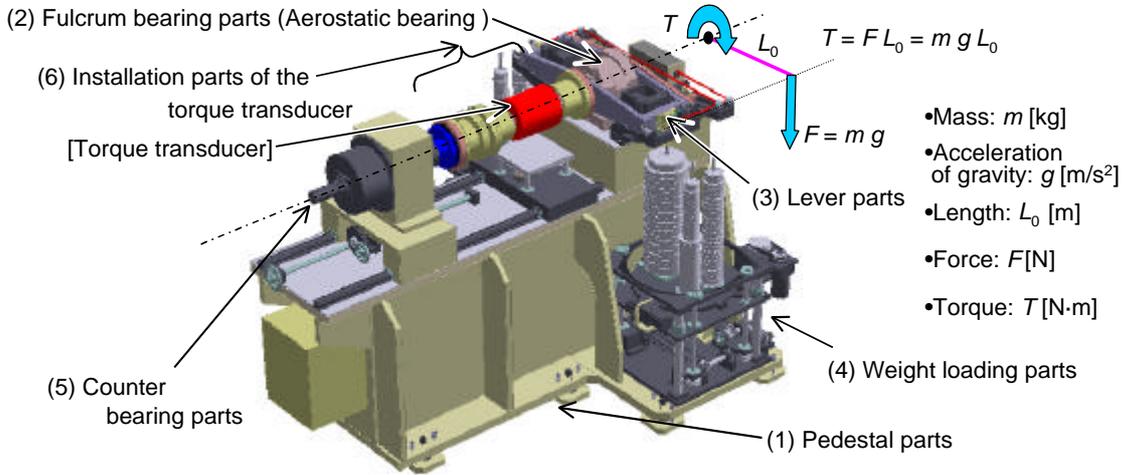


Figure 1. Schematic view of the 1 kN·m torque standard machine

3 BEARING PARTS FOR FULCRUM

The aerostatic bearing unit, which is one of the main components of the torque standard machine, is used for the lever fulcrum. A circumferentially double grooved structure (2x8 nozzles) was adopted in this bearing (see Fig. 2). The bearing operates using a supply of compressed air at a constant pressure ranging from 600 to 800 MPa. Rigidity in the radial direction is more than 1 kN/mm and the maximum radial load is more than 3.4 kN. The sensitivity was measured in order to investigate the influence of fulcrum friction. However, the result will be described in another report.

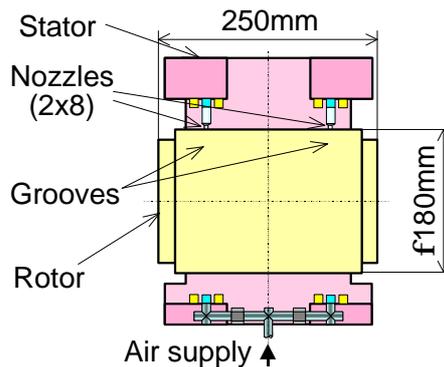


Figure 2. Structure of the aerostatic bearing

4 LEVER PARTS

The schematic of the lever parts is shown in Fig. 3. The lever, in which the nominal one-arm length is 500 mm and full-length is 1000 mm was made of austenitic stainless steel. There are linear scales (photoelectric reflection type) at both tips of the lever in order to detect lever inclination and flexure. In addition, a laser interferometer system was set up for measuring the change of the lever length due to deadweight loading at the moment.

As shown in Fig. 4, bands made from beryllium copper with a thickness of $t_w = 100 \mu\text{m}$ were used for weighing at both lever ends. Here, if the tensile stress distribution in the thickness direction of the metal band is not axisymmetric, the reference line (loading point) could shift from the center of the metal band. However, according to the consideration from the theory of bending of a thin plate [6], the uniform tensile stress in the thickness direction is expected to occur without fail because the metal band thickness is sufficiently smaller than the curvature radius. Therefore, the center of the metal band can be recognized as the loading point. This fact has been supported in the experiment result obtained by Roeske [7].

A 3D coordinate measurement machine (CMM) was used for the measurement of initial lever length under the temperature environment of 20 degrees centigrade. Figure 5 shows the main dimensions of the lever. Using the CMM, the length L_u of the lever main parts and thickness $t_w (= h' - h_1)$ were measured. Because the thickness of the metal band and fixing plates was suspected to alter due to the fastening torque of the bolts (these bolts are used to clamp the metal band), h' and h_1 were measured under three different fastening torques, i.e., 70, 110 and 138 N·m. Here, h' was measured for the state of clamping the metal band. On the other hand, h_1 was measured for the state of fastening the fixing plates without the metal band.

Lever length L_0 was calculated using the following equation:

$$L_0 = L_u + t_w/2 = L_u + (h' - h_1)/2 \tag{1}$$

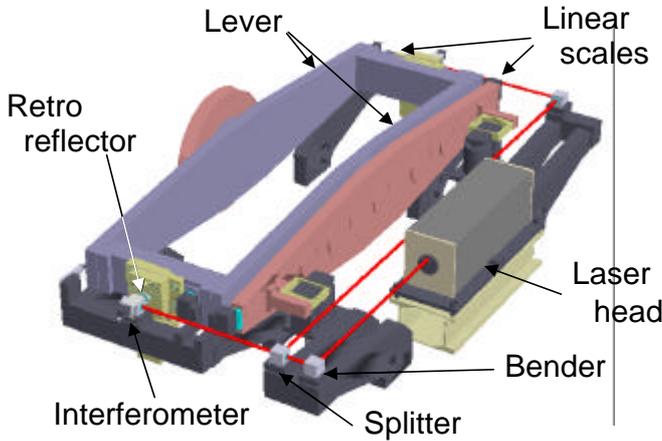


Figure 3. Lever parts

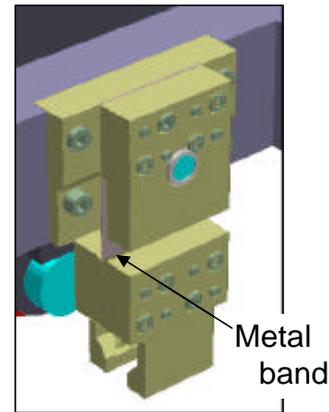


Figure 4. Metal band and its fixing plates

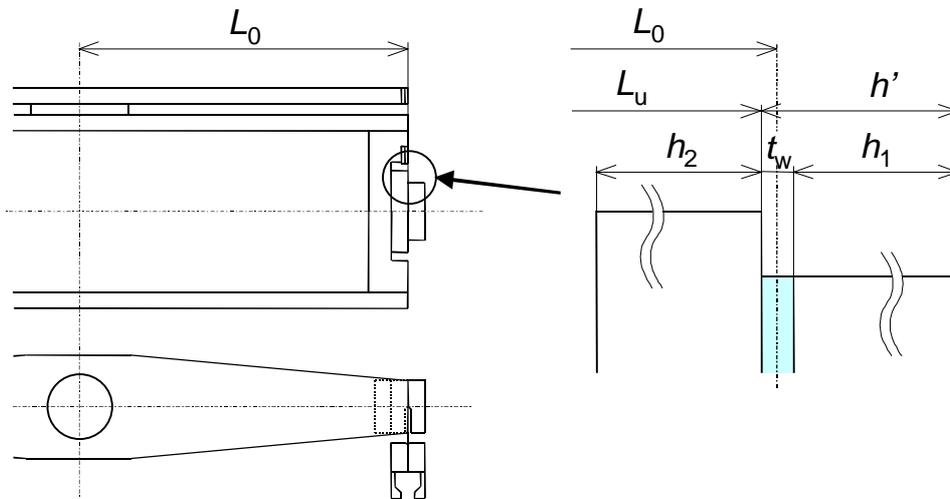


Figure 5. Dimensions of the lever

Measurement uncertainty $u(L_0)$ was calculated using the following equation:

$$u^2(L_0) = u^2_{cmm} + u^2(L_u) + u^2(t_w) \tag{2}$$

As uncertainty elements, the uncertainty of CMM u_{cmm} (the uncertainty of the gauge block for reference standard is included) and uncertainties of measurement $u(L_u)$ and $u(t_w)$ were considered. Because it is currently very hard to calculate u_{cmm} precisely, the estimation was carried out by overestimating the uncertainty in consideration of an indication error at the time of the gauge block measurement E and a probing error R . For L_u and t_w , the temperature compensation error (including the uncertainty of the thermometer; $u(Dt)$), the uncertainty of the coefficient of expansion ($u(a)$), repeatability of three times measurement (u_{rg}), the difference in the measurement position of eight or more points (u_{mp}), reproducibility of two times or more of lever or fixing plates reconstruction (u_{rp}) and the thickness change for the three different fastening torques of metal bands (u_{tq}) were taken into consideration.

The measurement results of the thickness h_1 , h' , and then t_w are shown in Fig. 6. No significant difference is observed for t_w whereas h' and h_1 alter in proportion to the change of the fastening torque from 75 to 138 N·m. It was found that the reproducibility of $\pm 0.4 \text{ mm}$ was obtained by fastening with the uniform torque of 110 N·m.

Measurement results are shown in Table 1 and Table 2. As results of the measurement, $L_0 = 500.0174 \text{ mm}$ for the left-hand side and $L_0 = 500.0149 \text{ mm}$ for the right-hand side were obtained, respectively. The relative expanded uncertainty was $U(L_0) = \pm 9.7 \text{ ppm}$ ($k=2$). Since the environmental temperature in the torque calibration room is 23 ± 1 degrees centigrade, temperature compensation is still required to estimate the uncertainty more accurately. In addition, because flexural deformation of the lever occurs with deadweight loading, we will use the laser interferometer system to confirm whether a variance in the lever length in the case of actual application affects the evaluation of the uncertainty of torque measurement.

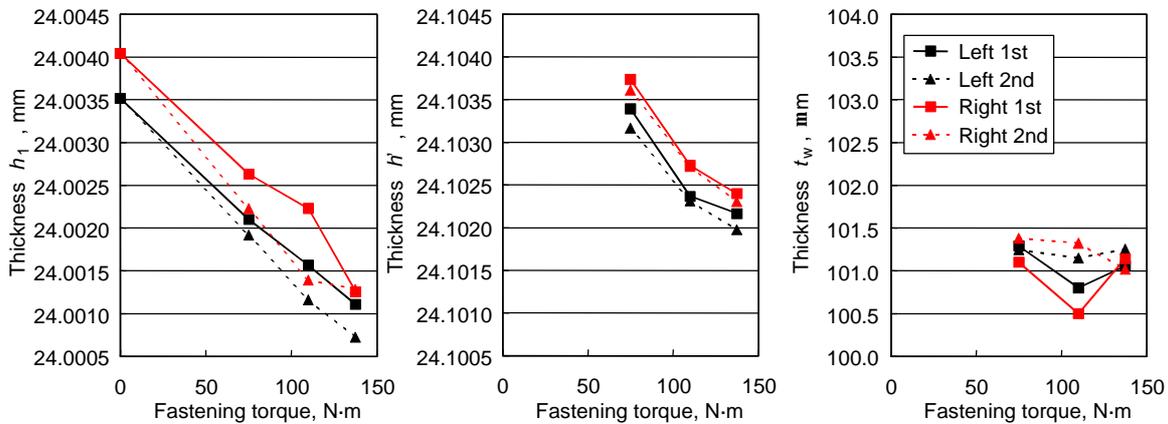


Figure 6. Measurement results of metal band and fixing plates thickness

Table 1. Measurement results of initial lever lengths

	Left-hand (ACW)	Right-hand (CW)
L_u , mm	499.96693	499.96446
t_w , mm	0.10097	0.10091
L_0 , mm	500.01742	500.01491

Table 2. Uncertainty of measurement

u_{cmm}		1.25	mm	
	$u(Dt)$	0.085	K	
	$u(a)$	0.20	$10^{-6} / K$	
		$u_{rg}(L_u)$	0.60	mm
		$u_{mp}(L_u)$	0.80	mm
		$u_{rp}(L_u)$	1.39	mm
		$u_{il}(L_u)$	1.71	mm
$u(L_u)$		1.84	mm	
	$u(Dt)$	0.134	K	
	$u(a)$	0.20	$10^{-6} / K$	
		$u_{rg}(t_w)$	0.41	mm
		$u_{mp}(t_w)$	0.82	mm
		$u_{rp}(t_w)$	0.24	mm
		$u_{tq}(t_w)$	0.19	mm
	$u_{il}(t_w)$	0.96	mm	
$u(t_w)$		0.96	mm	
$u(L_0)$		2.42	mm	
$U(L_0) \quad (k=2)$		4.85	mm	

5 WEIGHT LOADING PARTS

Deadweight series, which are one-inner type and which have linkage structure and disk shape (see Fig. 7), were set up under both tips of the lever. They were made of austenitic stainless steel. The elevators for loading and unloading the deadweights, and turntables for changing three deadweight series (10 N, 20 N and 100 N series) by rotation, were installed to the right and left sides of the lever, respectively. Weight loading/unloading can be controlled by counting the number of rectangular wave signals from the platform scale under each weight series, and the pulse signal from the servo motor.

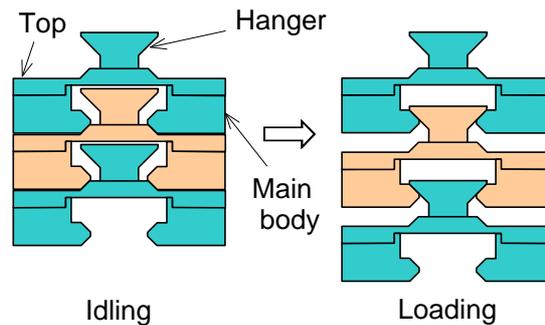


Figure 7. Linkage structure of weights series

Formation of the deadweight series is as follows;

- (1) 10 N x 11 disks x 2 sets,
- (2) 20 N x 22 disks x 2 sets,
- (3) 100 N x 22 disks x 2 sets.

The mass of all of the weights was adjusted to objective values with the relative deviation of less than ± 1 ppm, in consideration of the acceleration of gravity ($g_{local} = 9.7994848 \text{ m/s}^2$; uncertainty of measurement is less than 0.5 ppm) at the installation location of the standard machine and the influence of air buoyancy, using the following equation,

$$m_A = \frac{F}{g_{\text{local}}} \frac{1}{1 - r_{\text{as}}/r_s} \quad (3)$$

where F is the force [N], r_{as} is reference air density (1.2 kg/m^3) and r_s is reference density of the weight (8000 kg/m^3). Using electrical balances, the mass of the weights was measured in comparison to reference weights. As a result, the relative expanded uncertainty of measurement was less than ± 4 ppm.

6 BEARING PARTS FOR COUNTER TORQUE

Bearing parts for the counter torque return the inclined lever to the horizontal position with a servo motor through double angular ball contact bearings and a harmonic drive as reduction gear, with reduction ratio of 1:5000. Adjustment tolerance for the horizontal lever position is less than $\pm 1^\circ$ ($\pm 2 \text{ mm}$ at the lever tip).

7 INSTALLATION PARTS FOR TORQUE TRANSDUCER

Various attachments, such as base flanges, diaphragm coupling and friction joints, were prepared in three sizes so that torque transducers having a variety of sizes and shapes could be installed on the torque standard machine. Figure 8 exemplifies the typical connection of these parts. Since friction joints are used, it is easy not only to align the axes of the torque transducer and other installation parts, but also to mount both the shaft- and flange-type torque transducers on the machine with preparing simple attachments.

In the installment of the torque transducer, the coupling method might have a large influence on the uncertainty of the calibration results. Peschel [8] has reported the results of detailed experiments regarding this point. Although our torque standard machine has adopted one-sided single coupling, detailed examination including the influence of parasitic components will be henceforth performed in order to find the best coupling method.

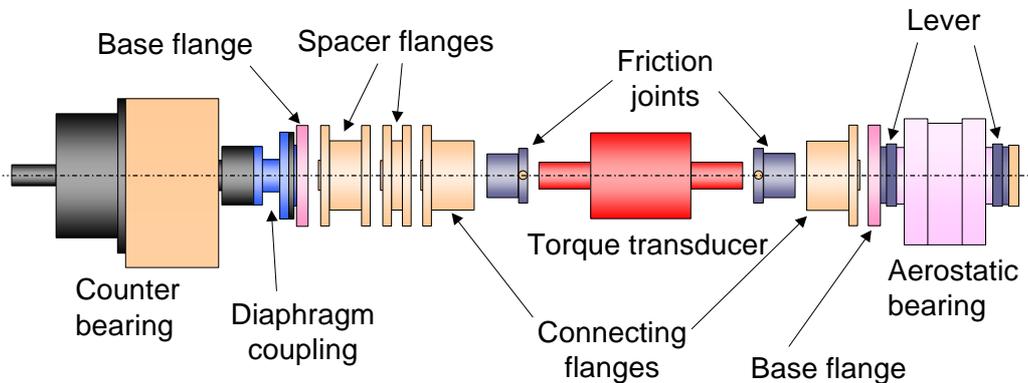


Figure 8. Connection example of installation parts for the torque transducer

8 CONTROL, DISPLAY AND OPERATION EQUIPMENT

Using this torque standard machine, the overloading test and the creep tests can be carried out automatically, in addition to the normal preloading test and the calibration test according to a time sequence defined in advance. Manual operation is also available for the purpose of development of the new measurement technique of the torque which cannot be assumed at the present stage.

9 CONCLUSION

The first torque standard machine of rated capacity $1 \text{ kN}\cdot\text{m}$ using a lever/mass system was developed as part of research with the goal of establishing a setup/maintenance/dissemination system of the torque standard in Japan. The initial lever length and mass correction/measurement of deadweights were completed. In order to estimate the best

measurement capability of the torque standard machine, we are currently investigating the sensitivity of the lever (friction of the aerostatic bearing) and change of the lever length during actual application including deadweight loading, and are also optimizing the installation of the torque transducer.

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