Design and Development of 20 kN·m Deadweight Torque Standard Machine

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Abstract:

A deadweight torque standard machine of rated capacity 20 kN·m (20 kN·m-DWTSM) was designed and developed, following the development of a 1 kN·m torque standard machine (1 kN·m-DWTSM) at NMIJ/AIST. This machine has a variety of features enabling it to perform precise measurements of torque, including double aerostatic bearings used in the form of a fulcrum. This paper outlines the torque standard machine.

1. Introduction

A deadweight torque standard machine of rated capacity 20 kN·m (20 kN·m-DWTSM) was designed and developed, following the development of a 1 kN·m torque standard machine (1 kN·m-DWTSM) [1][2][3] at the National Metrology Institute of Japan (NMIJ), in the National Institute of Advanced Industrial Science and Technology (AIST). A photograph of the torque standard machine is shown in Fig. 1. Many techniques used for the 1 kN·m-DWTSM were also used for the 20 kN·m-DWTSM.

The measurement axis of this machine is horizontal, that is, the standard machine adopts a horizontal structure. The calibration range is from 200 N·m to 20 kN·m, and the equipment

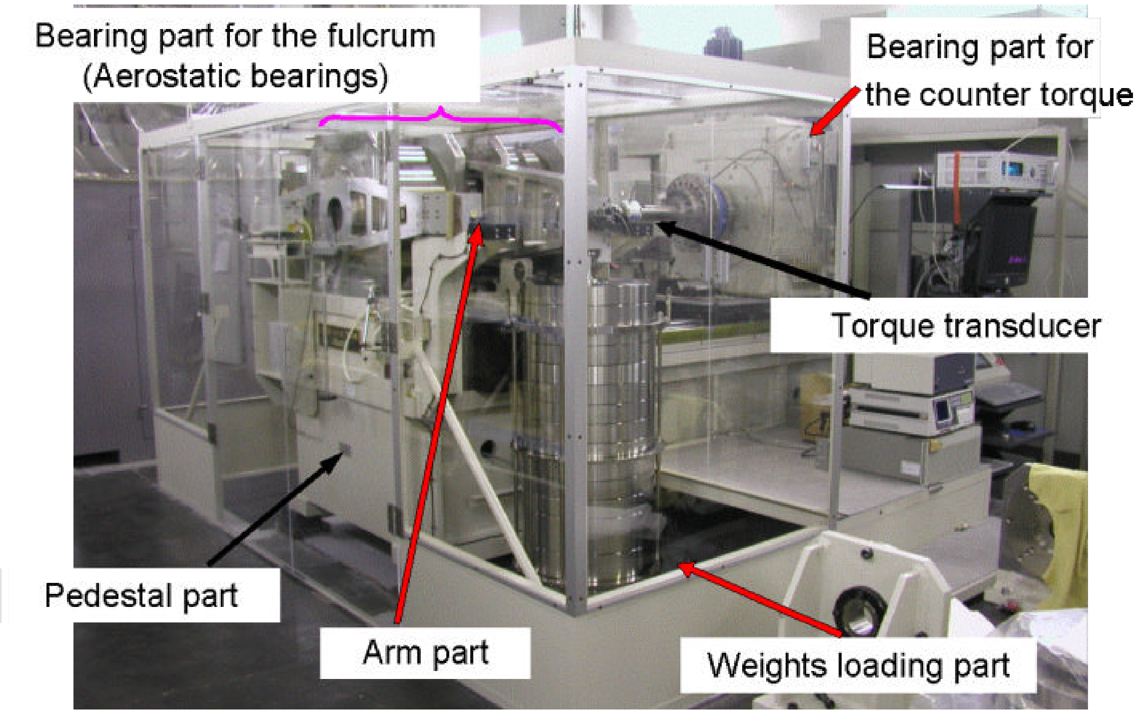

Fig. 1 Photograph of 20 kN·m-DWTSM

can handle over-torque of up to 110 % of the rating. There is a double arm with a nominal one arm length of 1000 mm. Fully automatic control is available during torque measurement as well as manual control, thus enabling unforeseen new torque measurement techniques to be developed in the future. The total weight of the equipment is about 13.2 t without deadweights, and the maximum dimensions are 3470 mm (W) x 2820 mm (D) x 3866 mm (H), where the height includes the depth of underground pits for the weight stacks.

The main parts have now been manufactured and are each described below.

2. Bearing Part for the Fulcrum

One of feature of this machine is that the double aerostatic bearings are used in the form of a fulcrum, because of proofing for not only the radial direction due to deadweight loading but also for the bending moment direction due to the weight of the torque transducer itself and misalignment.

Two circumferentially double grooved structures (2x18 nozzles) are adopted in this bearing (see Fig. 2). Almost all of the parts are made of austenitic stainless steel. The bearings operate using a supply of compressed air at a constant pressure of 900 kPa. Stiffness in the radial direction is more than 1.4 kN/mm and the maximum radial load is more than 22 kN. The greatest challenge in manufacturing this part is to adjust the double shaft axes. The authors achieved a shaft alignment of within 5 mm by facing the base surface and by fastening bolts precisely. The sensitivity and stability were measured in order to investigate the influence of fulcrum friction, the results of which will be described in a future report.

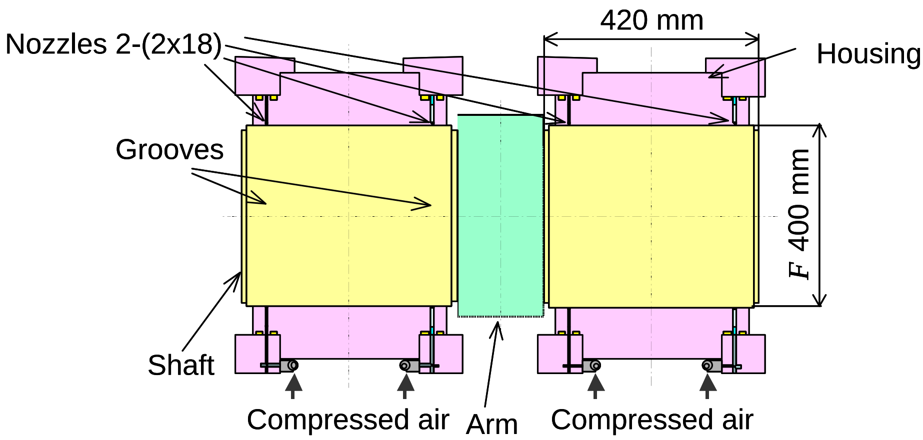

Fig.2 Double aerostatic bearing

3. Arm Part

The arm part was designed to be able to apply both clockwise and anticlockwise torque and to be able to precisely measure the moment-arm length. A schematic of the moment-arm is shown in Fig. 3. The arm was made of the same austenitic stainless steel as the aerostatic bearings. There are linear scales (photoelectric reflection type) at both tips of the arm in order to detect arm inclination and flexure (bending deformation). As shown in Fig. 3, bands made from beryllium copper with a thickness of t_w = 400 mm were used for weighing at both arm ends. Note that if there are initial rolling displacement and stiffness in the metal bands,

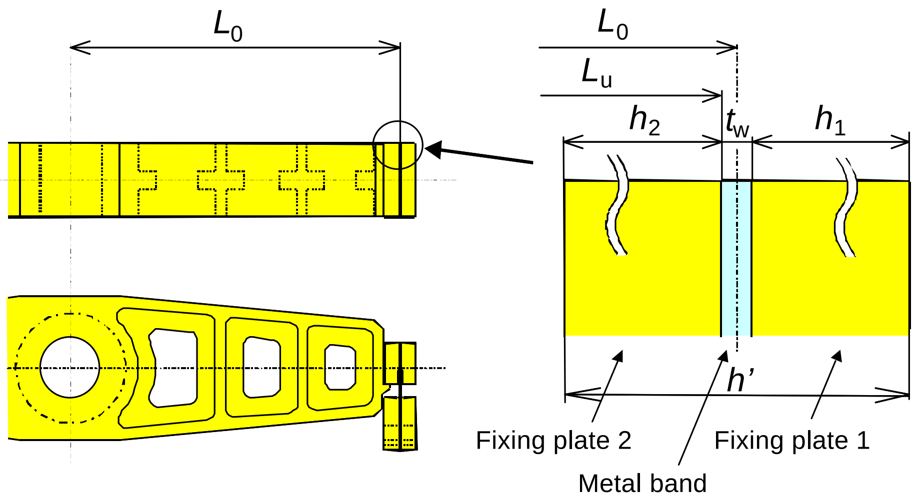

Fig.3 Structure of the moment-arm

loading dependence of arm length occurs, so the spring effect of the metal band must be investigated in a future study.

A 3D coordinate measurement machine (CMM) was used to measure the initial moment-arm length under the temperature environment of 23 C. Using the CMM, the length L_u of the arm main part and thickness t_w (= h' - ($h_1 + h_2$)) were measured. The thickness of the metal band was calculated from the difference in thickness of the fixing plates with or without clamping the metal band (h' or h_1 + h_2). As uncertainty contributions, the uncertainty of reference standard u_{ref} and uncertainties of measurement $u(L_u)$ and $u(t_w)$ were considered. An uncertainty of the reference gauge block, resolution and temperature dependence of the CMM were included in u_{ref}. 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 six or more points (u_{mp}), reproducibility of two times reconstruction of arm and fixing plates (u_{rp}), and the thickness change for three different fastening torques (25, 44 and 59 N·m) of the metal bands (u_{tq}) were taken into consideration.

The measurement results are shown in Tables 1 and 2. Results of initial length measurement were L_0 = 1000.0135 mm for the left-hand side and L_0 = 1000.0452 mm for the right-hand side. The relative expanded uncertainty was $U(L_0)$ = ± 7.6 mm (k=2).

4. Weight Loading Part

The weight loading part consists of linkage deadweight series, weight loading elevators, slider tables to change the weight series, etc. The deadweight series, which are one-inner type, and which have linkage structure and disk shape, were set up under one side tip of the arm. They were made of austenitic stainless steel. The elevators for loading and unloading the deadweights, and slide tables for exchanging three deadweight series (200 N, 500 N and 1 kN-2 kN series) using a crane in the building, were installed on the right or left sides of the arm (see Fig. 4). 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

Table 2 Uncertainty of the initial moment-arm length

Component				Value	Unit
	u_{ref} *			0.39	μm
		$u(\Delta t)$		0.08	K
		$u(a)$		0.68	10^{-6}/K
			$u_{rg}(L_u)$	0.72	μm
			$u_{rp}(L_u)$	1.04	μm
		$u_{//}(L_u)$		1.27	μm
	$u(L_u)$			1.87	μm
		$u(\Delta t)$		0.05	K
		$u(a)$		0.68	10^{-6}/K
			$u_{rg}(t_w)$	0.24	μm
			$u_{mp}(t_w)$	2.26	μm
			$u_{rp}(t_w)$	1.06	μm
			$u_{tq}(t_w)$	2.08	μm
		$u_{//}(t_w)$		3.26	μm
	$u(t_w)$			3.26	μm
$u_c(L_0)$				3.78	μm
$U(L_0)$ (k=2)				7.55	μm

* excluding E-error and probing error of CMM because of comparative calibration with reference GBs

Table 1 Measurement results of the initial moment-arm length

	Left-hand (ACW)	Right-hand (CW)
L_u	999.8109	999.8421
t_w	0.4053	0.4061
L_0	1000.0135	1000.0452

signal from the servo-motor. The composition of the deadweight series is as follows:

(1) 200 N x 11 disks x 1 set

(2) 500 N x 11 disks x 1 set

(3) (1 kN x 12 disks + 2 kN x 5 disks) x 1 set

The mass of each weight 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 m/s^2; uncertainty of measurement of less than 0.5 ppm) at the installation location of the standard machine and the influence of air buoyancy. Using electrical balances, the mass of the weights

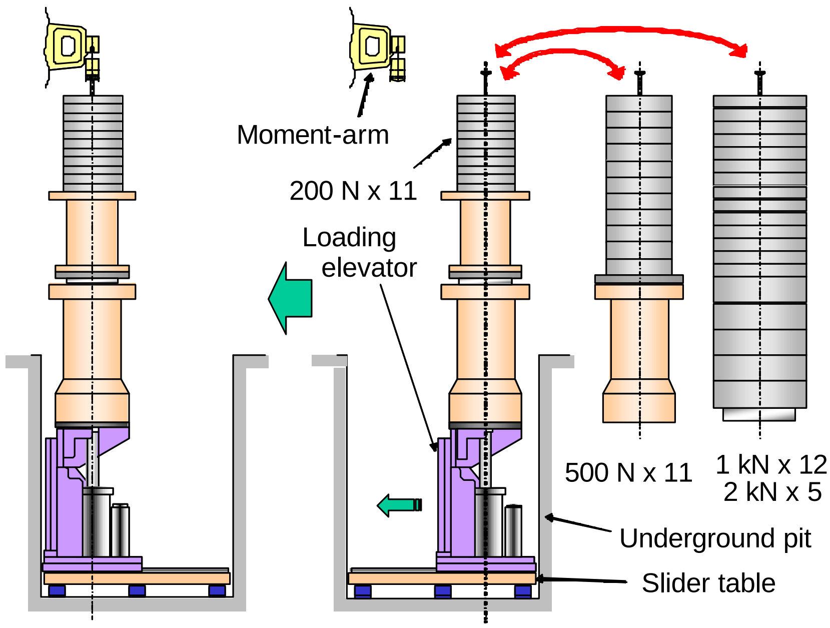

Fig.4 Weight loading part

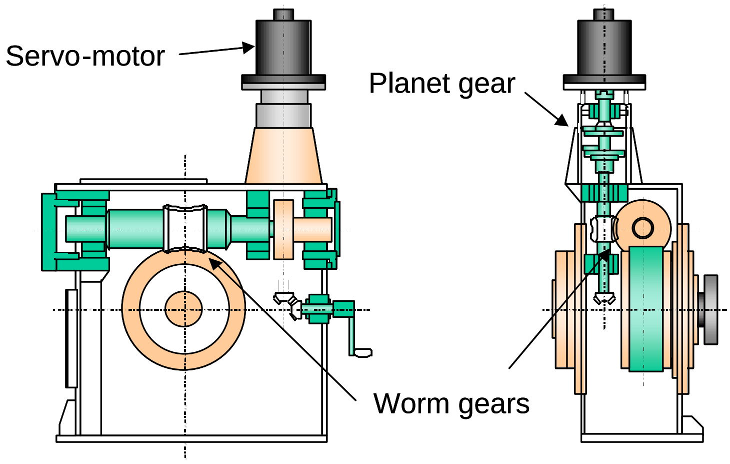

Fig. 5 Bearing part for the counter torque

was measured in comparison to reference weights. As a result, the relative expanded uncertainty of measurement was less than ± 6 ppm.

5. Bearing Part for the Counter Torque

Bearing part for the counter torque returns the inclined arm to the horizontal position with a servo-motor through double angular ball contact bearings and a combination of two worm gears and a planet gear as shown in Fig. 5. A special non backlash mechanism was adopted, and the reduction ratio was 1:25000. The tolerance for adjusting the horizontal arm position is less than $\pm 9.7 \times 10^{-6}$ rad (vertical displacement of ± 10 mm at the arm tip).

6. Installation Part of the Torque Transducer

The installation part of the torque transducer consists of base flanges, diaphragm couplings, friction joints, torque transducer connecting flanges, etc., which are used for mounting the torque transducer onto the torque standard machine. Various attachments were prepared in three sizes to enable torque transducers of various sizes and shapes to be installed on the torque standard machine. Figure 6 shows a typical connection of these parts.

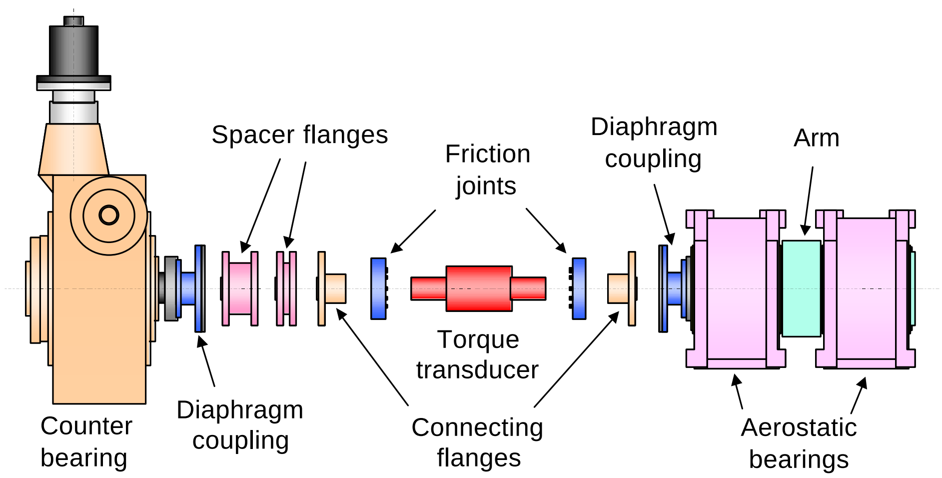

Fig.6 Typical connection along the measurement axis

Regarding installation of the torque transducer, the coupling method might significantly affect the uncertainty of the calibration results, so a detailed examination will be performed in order to assess the influence of parasitic components.

7. Summary

A 20 kN·m-DWTSM was designed and developed. This machine has a variety of features enabling it to generate torque precisely. Specifically, double aerostatic bearings are used in the form of a fulcrum, because of proofing for not only the radial direction due to deadweight loading but also for the bending moment direction due to the weight of the torque transducer itself and misalignment.

The main parts have now been manufactured, mass adjustment and calibration have been carried out, and the initial moment-arm length was measured using the CMM. The next tasks for estimating the Best Measurement Capability are as follows:

(1) Temperature compensation of the moment-arm length under torque calibration environment
(2) Evaluation of the influence of the spring effect in the metal band on the moment-arm length
(3) Preparation of another deadweight series for both arm sides loading (for the arm balance examination)
(4) Examination of the sensitivity of the aerostatic bearing

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