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THE DEVELOPMENT OF 100 Nm TORQUE STANDARD MACHINE AT NIM

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Abstract − A set of 100 Nm torque standard machine is newly developed at National Institute of Metrology (NIM). By adapting the air bearing with low friction as the arm lever fulcrum, the low expansion alloy (INVOR) as the arm lever material and the accurate machining and adjustment technology, the uncertainty of 100 Nm torque standard machine is minimized. This machine is capable of realizing torque from 1 Nm to 100 Nm both in clockwise and anti-clockwise direction. The working principle and mechanical structure of the machine are introduced, the uncertainty assessment and results of performance test are described. The results show that the repeatability of 100 Nm torque machine is better than 2×10^{-5}, the uncertainty is smaller than 2×10^{-5} (k=2).

Keywords: torque standard machine, air bearing, flexible coupling.

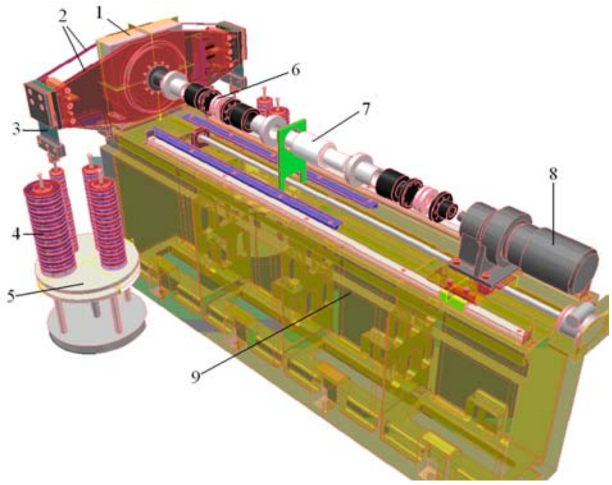
1. INTRODUCTION

The accurate torque measurements and controls are widely applied in many industrial sectors to ensure the product quality and the safety. National metrology institutes are responsible for realizing and maintaining torque standards and for disseminating torque quantity through the transfer torque standards. The National Metrology Institutes such as PTB[1] (Germany), NPL (U.K.) and others have established the high precision torque standard machines based on the air bearing technology. In China three sets of torque standard machines including 50 Nm, 1 kNm, 5 kNm torque standard machines with the knife-edge fulcrum had been established at NIM in the past years. In order to meet the requirement of high precision torque measurement, a set of high precision 100 Nm torque standard machine based on the air bearing technology has been developed by NIM. The torque range of 100 Nm torque standard machine (TSM) is from 1 Nm to 100 Nm, the uncertainty is smaller than 2×10^{-5} (k=2).

2. THE CONSTRUCTION AND WORK PRINCIPLE OF 100 Nm TSM

100 Nm TSM consists of the main unit and control unit. The mechanics construction of 100 Nm TSM[2] is shown in Fig.1.

100 Nm torque standard machine consist mainly of air bearing, two-arm lever, weights loading system, flexible couplings, counter bearing part and pedestal part.



1.Airstatic bearing，2.Arm lever，3.Thin metal band，4.Weights，5.Turntable，6.Flexible coupling，7.Torque transducer，8.Couter bearing drive，9. Pedestal part

Fig.1 Mechanics construction of 100 Nm TSM

The air bearing is used to support the lever to keep the friction at fulcrum to a minimum. The H type air bearing is adapted which is axial fixed, the gap of the stator and the rotor is 5 μm, the friction torque is proved to be smaller than 11 μNm.

Considering synthetically the construction characteristic of the air bearing, sensitivity and stability of the arm lever, working space of weights loading system as well as accurate measurement and adjustment of the arm lever, the multi-components frame construction is adopted as arm lever system. In order to minimize the uncertainty caused by the variety of arm lever length, special care has to be taken to the material of arm lever, the low expansion alloy (INVOR) with the linear thermal expansion coefficient of $6*10^{-7}$/K is used as the material of arm lever. The nominal length of the arm lever is chosen to be 400 mm. The horizontal position of the arm lever is determined by means of a laser sensor and adjusted by controlling the counter bearing drive.

The machine has two sets of weights which are at two sides of arm lever and may generate clockwise and

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anticlockwise torque separately. Fig.2 shows the configuration of the weights loading system. Each set of weights consists of four groups weights which include 10 pieces of 2.5 N weight, 10 pieces of 5 N weight, 10 pieces of 12.5 N weight and 10 pieces of 25 N weight. Four groups weights which are placed on the turntable can be loaded by weight loading lifter. The different groups of weights can be selected by rotating the turntable. Each group weight at left side and right side may generate torque separately or combined to generate the torque in the different range. The force is introduced free from bending moment via thin metal bands. The flexible couplings are used in the rotation axis and counter axis to reduce the influence of parasitical component.

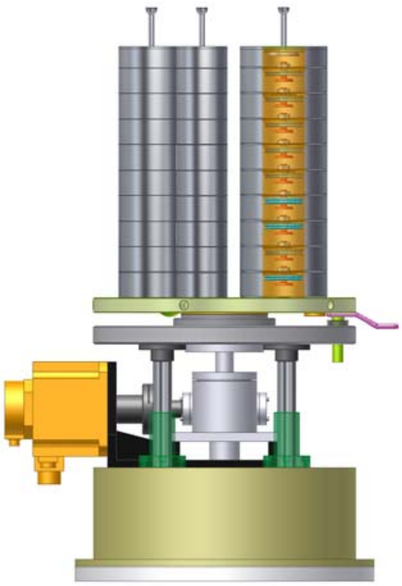

Fig.2 The configuration of the weights loading system

3. PERFORMANCE EXPERIMENTS

3.1 Repeatability test

The repeatability experiments were carried out in the range of 1 Nm-100 Nm. Five TT1 type torque transducers with nominal capacities of 5 Nm, 10 Nm, 20 Nm, 50 Nm and 100 Nm were used in the tests. The measurements for each torque transducer were done in clockwise and anti-clockwise direction. Each measurement sequence includes three preloading and three increasing measurements at initial mounting position of torque transducer (0°), one preloading and one increasing measurement at each of other two rotational positions of torque transducers (120° and 240°). The repeatability is calculated by (1).

$$R = \frac{\sqrt{\dfrac{\sum_{j=1}^{n}(X_j - \overline{X})^2}{n-1}}}{\overline{X}} \times 100\% \qquad (1)$$

Where, n is the number of the increasing series at 0° position, X_j and $\overline{X}$ are the deflection and average value of deflections with increasing test torque at 0° position respectively.

The results of repeatability test are shown in Fig.3. The results indicate the repeatability of 100 Nm TSM is better than 2×10^{-5}.

3.2 Sensitivity test

In order to measure the influence of friction torque on the machine, the sensitivity tests were carried out by means of the milligram weights as well as torque transducers and measuring amplifier. Mounting the torque transducer on the torque machine and supplying the torque which is shown in table 1, while the output signal of torque transducer was stable, additional small weights (as small as possible) were added on the top weight used until the output signal had visible change. Table 1 shows the results of the sensitivity test of the machine.

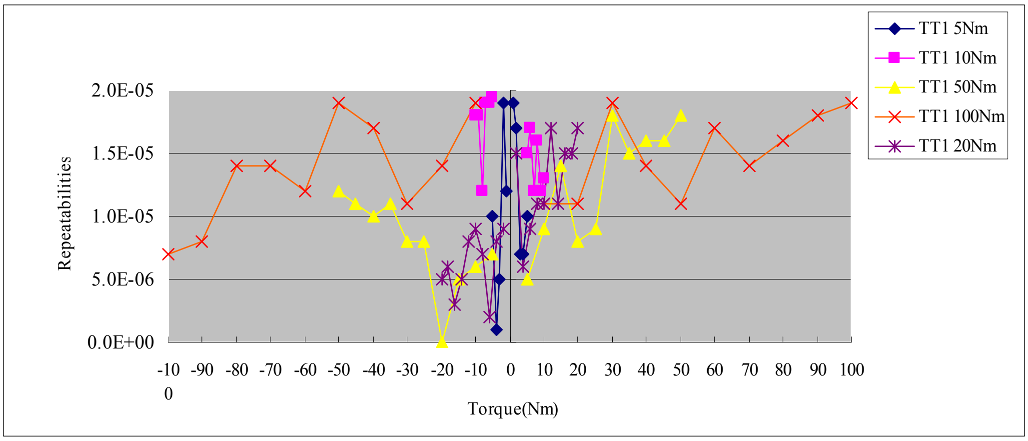

Fig.3 The results of repeatability test

Table 1 The results of the sensitivity test of the machine

Torque transducer	Supplied torque (Nm)	Corresponding weights mass (kg)	Added small weights mass (mg)	Relative sensitivity
TT1/5 Nm	1	0.25	3	1.2E-05
	2	0.5	5	1.0E-05
	5	1.25	5	4.0E-06
TT1/ 20 Nm	20	5	20	4.0E-06
TT1 100 Nm	100	25	50	2.0E-06

4. EVALUATION OF UNCERTAINTY

The uncertainty evaluation of deadweight torque standard machine has been introduced in some papers[3], the details about the uncertainty evaluation are not discussed in this paper. The source of uncertainty, probability distribution, distribution factor and relative standard uncertainty are listed in table 2.

The uncertainty caused by arm lever's length is obtained by (2)

$$u_{r,L} = \sqrt{u_{r,L_1}^2 + u_{r,L_2}^2 + u_{r,L_3}^2} \qquad (2)$$

The relative standard uncertainty $u_{r,c}$ is calculated as (3)

$$u_{r,c} = \sqrt{u_{r,m}^2 + u_{r,g}^2 + (u_{r,\rho_a}^2 + u_{r,\rho_w}^2)(\frac{\rho_a}{(\rho_w - \rho_a})^2 + u_{r,L}^2 + u_{r,\alpha}^2 + u_{r,b}^2 + u_{r,t}^2 + u_{r,M_f}^2} \qquad (3)$$

$=8.0\times10^{-6}$

The relative expanded uncertainty $U_{c,r}$ is calculated by (4)

$$U_{r,c} = 2u_{r,c} \qquad (k=2) \qquad (4)$$

$=1.6\times10^{-5}$

Table 2 The table of uncertainty budget

Source of uncertainty		$u_{r,i}$	Probability distribution	Distribution factor	Relative standard uncertainty
The mass measurement of weights		$u_{r,m}$	/	$\sqrt{3}$	1.2×10^{-6}
The gravitational acceleration measurement		$u_{r,g}$	Normal	3	6.6×10^{-8}
The variety of air density		u_{r,ρ_a}	Rectangular	$\sqrt{3}$	1.9×10^{-2}
The density measurement of the weights material		u_{r,ρ_w}	Normal	3	8.7×10^{-3}
Arm lever's length $u_{r,L}$	Length measurement	u_{r,L_1}	/	2	1.3×10^{-6}
	The influence by temperature change	u_{r,L_2}	Rectangular	$\sqrt{3}$	0.7×10^{-6}
	The influence by deformation	u_{r,L_3}	Rectangular	$\sqrt{3}$	4.5×10^{-9}
The influence by lever inclination		$u_{r,a}$	Rectangular	$\sqrt{3}$	4.5×10^{-9}
The influence by weight swing		$u_{r,b}$	Triangle	$\sqrt{6}$	1.6×10^{-6}
The influence by non-coaxality of rotation axis and counter axis		$u_{r,t}$	Rectangular	$\sqrt{3}$	5.0×10^{-10}
The influence by friction torque		u_{r,M_f}	Rectangular	$\sqrt{3}$	7.0×10^{-6}

5. CONCLUSION

By adopting the air bearing with low friction as the arm lever fulcrum, the low expansion alloy (INVOR) as the arm lever material and the accurate machining and adjustment technology, the uncertainty of 100 Nm torque standard machine is minimized. Each group weights at left side and right side of arm lever may generate torque separately or optionally combined to generate the torque. The machine may realize torque in range of 1 Nm - 100 Nm in clockwise and anticlockwise direction. The force is introduced free from bending moment via thin metal bands. The flexible couplings are used in the rotation axis and counter axis to reduce the influence of parasitical component. The experiment results show that the repeatability of 100 Nm torque machine is better than 2×10^{-5}, the uncertainty is smaller than 2×10^{-5} (k=2).

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