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ESTABLISHMENT OF 20 kN·m TORQUE STANDARD MACHINE AT NIM

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Abstract – A set of 20 kN•m deadweight torque standard machine is newly established at National Institute of Metrology (NIM). The torque standard machine is capable of realizing torque from 100 N·m to 24 kN•m both in clockwise and anti-clockwise direction. The torque machine adopts the H-type air bearing with low friction to support the arm lever at the fulcrum, the weight loading system which consists of five groups of weights may generate five different torque ranges, as a result when the torque transducers with different rated capacities are calibrated, there needs not exchange weights and no counter-torque occurs during the loading process. This paper introduces the mechanical structure and working principle 20 kN•m torque standard machine, the uncertainty evaluation and results of performance test are described. The results show that the repeatability of the machine is better than 2×10^{-5}, the uncertainty of the machine is less than 2×10^{-5} (*k*=2).

Keywords: Torque standard machine, air bearing, arm lever, weight loading system, uncertainty.

1. INTRODUCTION

With the development of the wind power, shipbuilding and other industries, the demand for large torque measurement is increasing. As the national metrology institute, NIM is responsible for establishing and maintaining national torque standards and providing calibration services for customers in various sectors of industry. NIM force and torque laboratory maintains 5 sets of torque standard machine, including 50 N•m, 1 kN•m, 5 kN•m torque standard machines with the knife-edge support and 1N•m, 100 N•m torque standard machine with the air bearing support, these torque standard machines are capable of realizing the torque in the range of 1 mN•m-5 kN•m. In order to meet the requirement of large torque measurements, a set of 20 kN•m torque standard machine has been developed at NIM since 2012, the range of the torque machine is from 100 N•m to 24 kN•m, the uncertainty is smaller than 2×10^{-5} (*k*=2).

2. THE MECHANICAL STRUCTURE OF 20 KN·M TORQUE STANDARD MACHINE

20 kN•m torque standard machine consists mainly of air bearing, arm lever part, weight suspension part, weights loading system, transducer couplings, counter bearing part and pedestal part. 20 kN•m torque standard machine is shown in Fig.1.

Fig.1 20 kN•m torque standard machine

2.1. Air bearing

The H-type air bearing is adopted as the arm lever support to minimize the friction at the fulcrum. The radial load capacity is 60 kN, the axial load capacity is 15 kN, the horizontal bending moment capacity is 3400 N·m. The residual friction of air bearing is smaller than 60 μN•m. The working pressure of compressed air supplied to the air bearing is 6 bar. The structure of the air bearing is shown in Fig.2.

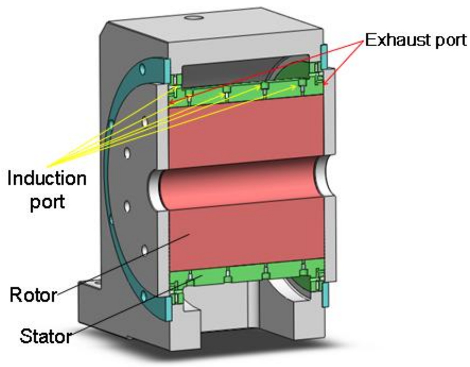

Fig.2 Structure of air bearing

2.2. Arm lever part

The arm lever part consists of the main shaft, front and rear arm, upper and lower connection plate, left and right side knife fixed hook, weight mound, servo lifting protection mechanism and horizontal position monitoring component. The structure of the arm lever is shown in Fig.3.

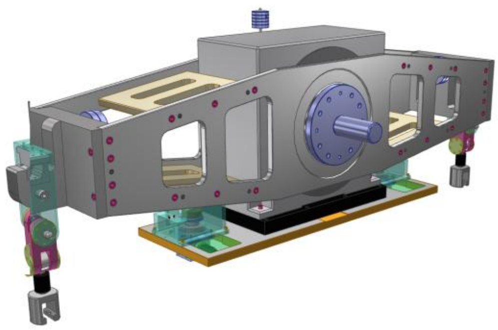

Fig.3 Structure of arm lever

Considering the structure of the air bearing, working space of weights loading system as well as measurement and adjustment of the arm lever, the arm lever adopts the multi-components frame structure. The nominal length of the arm lever is chosen to be 1600 mm. The invar alloy with the low thermal expansion coefficient is used as the materials of the arm lever in order to reduce the uncertainty caused by length change of arm lever due to the temperature variation.

The arm servo lifting protection mechanism is equipped to avoid the greater impact on the air bearing while mounting the transducer and the excessive displacement of the arm lever when subjected to greater impact. The servo motor together with force sensor is used to control mechanism movement, so that the arm lever can be clamped while the torque transducer is installed and the swing amplitude of the arm lever may be limited to a set range. when the torque machine works. The maximum offset of the arm lever is set to 10 mm.

The laser displacement sensor is adopted to measure the horizontal position of the arm lever. After loading the arm lever losts its initial balance, by controlling the counter bearing drive to apply a reverse torque on the reverse section the arm lever is adjusted to the initial horizontal position. the control accuracy of the arm lever is better than 0.03mm /m.

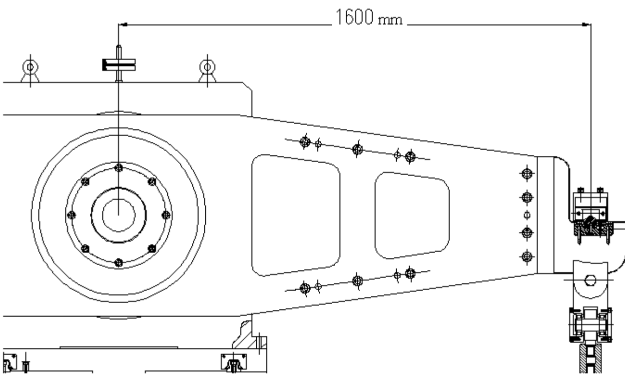

Fig.4 Length of arm lever

The length of the arm lever is measured on the high-precision coordinate measuring machine by length and precision engineering division of NIM. The schematic diagram of arm lever length is shown in Fig.4.

In the arm lever assembly state, the length of the arm lever and parallelism between central line of the main shaft and side knife edge of the arm lever are measured in the coordinate measuring machine, according to the measuring result, grinding side knife seats precisely, then the arm lever is measured again, until the length of the arm lever and parallelism meet the design requirement. The measuring results of the arm lever are listed in Table 1

Table 1 Measuring result of the arm lever

Length		Left arm	1600.081 mm
		Right arm	1600.087 mm
parallelism	In horizontal direction	between left knife edge and central line of the spindle	0.001 mm
		between right knife edge and central line of the spindle	0.003 mm
	In vertical direction	between left knife edge and central line of the spindle	0.004 mm
		between right knife edge and central line of the spindle	0.006 mm

2.3. Weight suspension part

The force generated by the weights is applied on the arm lever by a side knife-edge suspension component which has good reliability and stability.The side knife-edge is made of the special powder metallurgy high-speed steel and subject to reliable aging, ultra-finishing and mirror grinding. The suspension part is divided into two stages which are carried by needle roller bearings, the suspension structure is a cross joint mechanism that may produce the degree of freedom of X-Z and Y-Z in two directions so that the force generated by the weight is applied vertically to the side knife edge of the arm lever. The weight suspension part is shown in Fig.5.

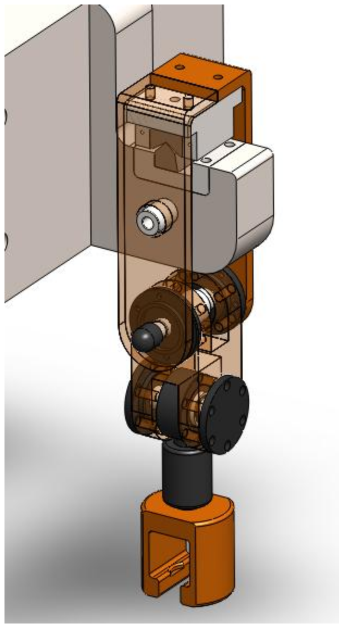

Fig.5 Weight suspension part

2.4. Weight loading system

The machine has two sets of weights which are at two sides of arm lever and may generate clockwise and anticlockwise torque separately. Each set of weights consists of 5 groups weights which include 12 pieces of 62.5 N weight, 12 pieces of 125 N weight, 12 pieces of 312.5 N weight, 12 pieces of 625 N weight and 12 pieces of 1250 N weight. Groups of weights which are placed on the turntable can be loaded by weight loading lifter. The loading time is adjustable. The different groups of weights can be selected by rotating the turntable. The weights are made of stainless steel (316L). The weights of each group are connected in series by 3 external rings with tapered guide positioning pins, each piece of weight and ring is precisely processed to ensure the loading weights in series have miinmal swing, The maximum swing amplitude of the weights is less than 2 mm. The configuration of the weights loading system is shown in Fig.6.

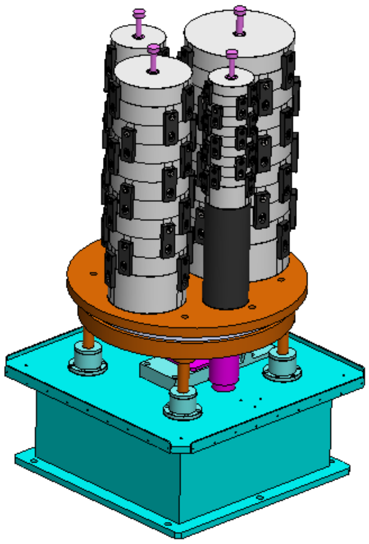

Fig.6 Configuration of the weights loading system

3. PERFORMANCE EXPERIMENTS

3.1 Repeatability test

The repeatability experiments were carried out in the range of 100 N•m-24 kN•m. Six torque transducers with nominal capacities of 1 kN•m, 2 kN•m, 5 kN•m, 10 kN•m, 20 kN•m and 50 kN•m 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 formula (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.7- Fig.11. The results indicate the repeatability of 20 kN·m torque standard machine is better than 2×10^{-5}.

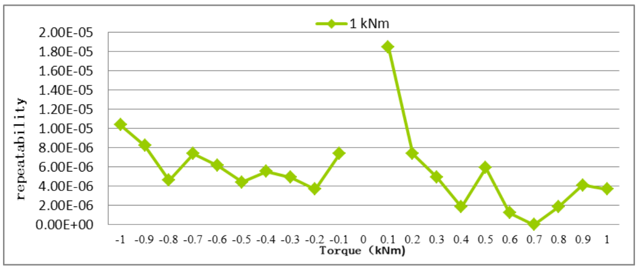

Fig.7 The results of repeatability test in 1kN·m segment

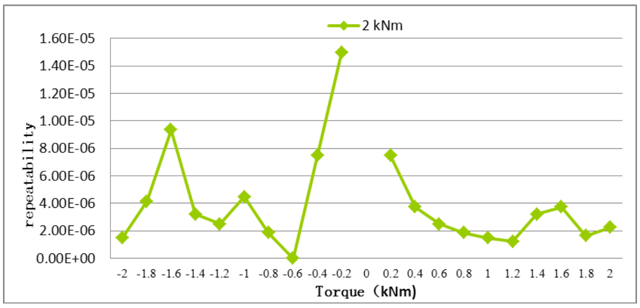

Fig.8 The results of repeatability test in 2kN•m segment

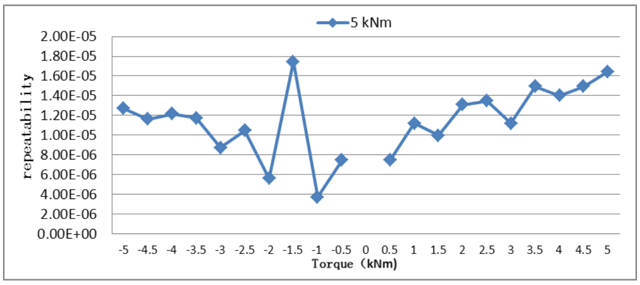

Fig.9 The results of repeatability test in 5kN•m segment

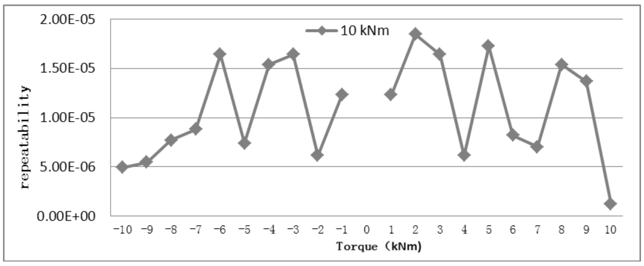

Fig.10 The results of repeatability test in 10kN•m segment

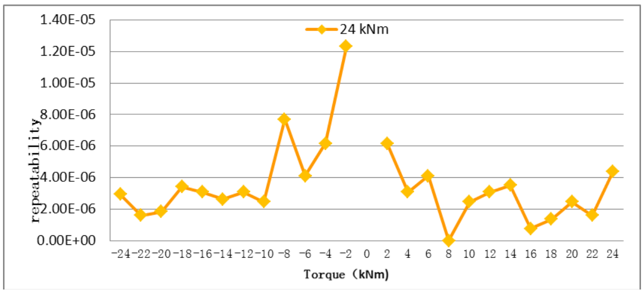

Fig.11 The results of repeatability test in 20kN•m segment

3.2 Sensitivity test

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 applying the torque which is shown in table 1, while the output signal of torque transducer was stable, additional small weights were added on the top weight used until the output signal had visible change. Table

2 shows the results of the sensitivity test of the torque machine.

Table 2 The results of the sensitivity test

Applied torque	Corresponding weights mass (at right side)	Corresponding weights mass (at left side)	Added small weights mass	Relative sensitivity
(N·m)	(kg)	(kg)	(mg)	
100	6.377345	6.377369	20	3.14E-06
200	12.75469	12.754737	20	1.57E-06
2000	127.546897	127.547375	200	1.57E-06
20000	1275.46897	1275.47375	2000	1.57E-06
24000	1530.56276	1530.56850	2000	1.31E-06

4. EVALUATION OF UNCERTAINTY

The uncertainty evaluation of deadweight torque standard machine has been introduced in some papers, 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 equation (2)

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

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

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

$$=4.6\times10^{-6}$$

The relative expanded uncertainty $U_{c,r}$ (k=2) is calculated by formula (4)

$$U_{r,c} = 2u_{r,c} = 9.2\times10^{-6} \quad (4)$$

Table 3 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	1	2.0×10^{-7}
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	0.9×10^{-2}
Arm lever's length $u_{r,L}$	Length measurement	u_{r,L_1}	/	2	2.5×10^{-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	$\sqrt{3}$	2.5×10^{-9}
The influence by lever inclination		$u_{r,a}$	Rectangular	$\sqrt{3}$	1.2×10^{-9}
The influence by weight swing		$u_{r,b}$	Triangle	$\sqrt{3}$	2.9×10^{-7}
The influence by non-coaxality of rotation axis and counter axis		$u_{r,t}$	Rectangular	$\sqrt{3}$	1.0×10^{-10}
The influence by friction torque		u_{r,M_f}	Rectangular	$\sqrt{3}$	1.8×10^{-6}

5. CONCLUSION

20 kN•m torque standard machine adopts the air bearing with low friction to support the arm lever to reduce the friction at the fulcrum to minimum, the invar alloy with low expansion coefficient is used as the material of the arm lever to reduce the uncertainty caused by the arm length change due to temperature variation, the force generated by the weights is applied on the arm lever by the side knife-edge suspension component which has good reliability and stability, the weight loading system may generate five different torque ranges so that when the torque transducers with different rated capacities are calibrated, there no counter-torque occurs during the loading process. The torque machine is capable of realizing clockwise and anticlockwise torque in range of 100 N•m-24 kN•m, the expanded uncertainty(k=2) is smaller than 2×10^{-5}.

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