ACTA IMEKO
ISSN: 2221-870X
July 2017, Volume 6, Number 2, 50-53

The establishment of a 1 N·m torque standard machine at NIM

Zhang Zhimin[1], Zhang Yue[1], Meng Feng[1], Zhang Wei[1],Hu Gang[1], Li Tao[2], Ji Honglei[2]

[1]*National Institute of Metrology, Beijing 100029, China*
[2]*Shanghai Marine Equipment Research Institute, Shanghai 200031, China*

ABSTRACT
1 N·m torque standard machine was established at National Institute of Metrology (NIM) in 2013. The torque standard machine adopts deadweight and moment-arm type. The static air bearing with low friction is used to support the moment-arm, the invar alloy with the low expansion coefficient as the material of the moment-arm, the specially designed weight suspension part and weight loading system may ensure the applied force by small weights accurately and reliably. The mechanical structure of the machine is introduced, the results of performance test and uncertainty assessment are described. The expanded uncertainty (k = 2) is smaller than 5 × 10^{-5} in the range of 100 mN·m - 1 N·m, smaller than 1× 10^{-4} in the range of 10 mN·m - 100 mN·m.

Section: RESEARCH PAPER

Keywords: torque standard machine; air bearing; weight loading system; repeatability; uncertainty

Citation: Zhang Zhimin, Zhang Yue, Meng Feng, Zhang Wei,Hu Gang, Li Tao, Ji Honglei, The establishment of a 1 N·m torque standard machine at NIM, Acta IMEKO, vol. 6, no. 2, article 8, July 2017, identifier: IMEKO-ACTA-06 (2017)-02-08

Section Editor: Min-Seok Kim, Research Institute of Standards and Science, Korea

Received June 29, 2016; **In final form** May 24, 2017; **Published** July 2017

Funding: This work was supported by the General Administration of Quality Supervision, Inspection and Quarantine of P.R.China, the project Number: 201110002

Corresponding author: Zhang Zhimin, e-mail: zhiminzhang@nim.ac.cn

1. INTRODUCTION

Torque, as a basic parameter, is widely used in automobile, communications, aerospace, shipping and other fields. In recent years with the development of the electronic, automobile, aerospace and medicine industry, there is a growing demand for small torque measurements. Micro-motors have wide applications in the aerospace and automobile sectors, where accurate torque measurements of micro-motors is essential. Slight torque tightening tools are widely used for mobile phones, hard drives, cameras, laptop computers, automobile electronics and medicine devices. By using the tightening tools equipped with torque sensors, precise torque control is achieved and product quality is guaranteed. The establishment of a small torque standard machine may provide reliable technical support for various industries. The National Metrology Institute is responsible for establishing and maintaining national torque standards, ensuring accuracy and consistency of torque dissemination and providing calibration services for customers in various sectors of industry. In order to meet the requirements for small torque measurements, a set of 1 N·m torque standard machines has been established at NIM in 2013. The range of the small torque machine is from 1 mN·m to 1 N·m. The expanded uncertainty (k = 2) is smaller than 5 × 10^{-5} in the range of 100 mN·m - 1 N·m, and smaller than 1 × 10^{-4} in the range of 10 mN·m - 100 mN·m.

2. THE CONSTRUCTION OF A 1 N·m TORQUE STANDARD MACHINE

The machine consists mainly of an air bearing, a moment-arm part, 2 weight suspension parts, 2 weight loading systems, a counter bearing part, transducer couplings, a mounting platform and a pedestal part. The mechanical construction of the 1 N·m torque standard machine is shown in Figure 1.

An X-type air bearing is adopted to support the moment-arm in order to minimize the friction at the fulcrum. The air bearing is in axial positioning, the gap of the stator and the rotor is 5 μm, the friction torque is smaller than 0.3 μN·m

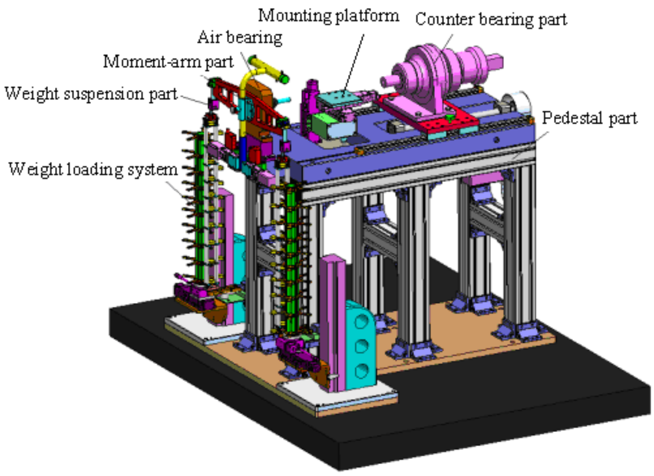

Figure 1. Mechanical structure of the 1 N·m torque standard machine.

according to the test report of the manufacturer (CEH XL60_45s, Germany). The work pressure of compressed air supplied to the air bearing is 4.2 bar. The moment-arm adopts the single beam structure; its nominal length is 250 mm. The balance beam is equipped in a way that the mass center of the moment-arm may be adjusted. The overload protection part is used to control the swing amplitude of the moment-arm to ensure the moment-arm in the normal work status. Invar alloy with low thermal expansion coefficient is adopted for the moment-arm materials in order to reduce the uncertainty caused by the length change of the moment-arm due to the temperature variations. The designed weight suspension assembly may keep the force, applied by small weights, vertically downward and free from parasitic forces.

The machine includes two sets of weight loading systems which are at two sides of the moment-arm and can generate clockwise and anticlockwise torque separately. The torque range of the machine runs from 1 mN·m to 1 N·m, divided into five torque range segments: 1 N·m, 500 mN·m, 200 mN·m, 100 mN·m and 10 mN·m. Each torque range segment includes 10 torque steps. Each weight loading system consists of 5 groups of weights, a load frame and a weight support frame. Each group of weights includes 10 pieces of 0.4 N weight, 10 pieces of 0.2 N weight, 10 pieces of 0.08 N weight, 10 pieces of 0.04 N weight and 10 pieces of 0.004 N weight. The nominal mass values and tolerances of the weights are shown in Table 1.

The load frame has 10 layers of weight trays on which the working weights are placed. The weight support frame includes a 10-story pentagon weight stand. Five groups of weights are placed on the paws of the pentagon weight stand. The different groups of weights may be selected by rotating the weight support frame. Before loading, the support frame with groups of weights is moved horizontally to the set position. The selected weights are transported from the weight support frame to the load frame and torque is applied by lowering or lifting the weight support frame. The structure of the weight loading system is shown in Figure 2.

The transducer that is calibrated on the 1 N·m torque machine is very small. To prevent damage of the calibrated transducer, caused by parasitic forces acting on the transducer, a three-dimensional precision mounting platform is designed which may precisely adjust the position of the transducer in X, Y, Z directions and keep the transducer axis aligned with that of the torque machine so that the transducer is protected from the impact of parasitic forces while mounting.

3. PERFORMANCE EXPERIMENTS

3.1. REPEATABILITY TEST

Repeatability experiments were carried out by using a high precision torque transducer and measuring amplifier. At present the minimum nominal torque of the high precision torque transducer which may be used as torque reference is 1 N·m. Generally, the transducer meets its technical performance requirements within 10 % to 100 % of its nominal load, but cannot guarantee an accuracy less than 10 % of its nominal load. For this machine, repeatability experiments were carried out in the range of 1 mN·m to 1 N·m. A TT1 1 N·m torque transducer and a DMP41 measuring amplifier were used in the tests. Since the lowest ranges of two torque segments are far beyond the lower limit of the 1 N·m torque transducer, only the test results in the torque range segment of 1 N·m, 500 mN·m and 200 mN·m are given.

The measurements were done in clockwise and anti-clockwise direction. The measurement sequence includes three preloadings and three measurements at the initial mounting position of the torque transducer (0°), one preloading and one measurement at each of another two rotational positions of the torque transducers (120° and 240°).

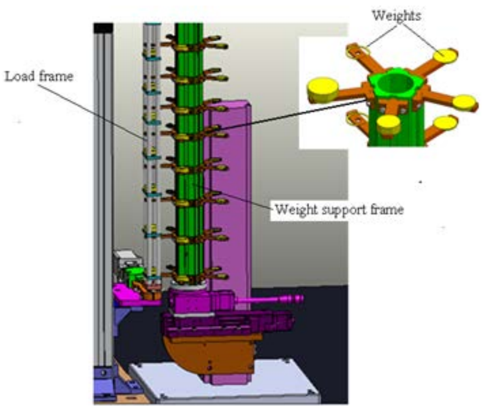

Figure 2. Weight loading system.

Table 1. The nominal mass values and tolerances of the weights.

The weights at the right side			The weights at the left side		
5 groups of weights	nominal mass values (g)	Tolerances (mg)	5 groups of weights	nominal mass values (g)	Tolerances (mg)
0.4 N × 10	40.822090	±0.82	0.4 N × 10	40.821719	±0.82
0.2 N × 10	20.411045	±0.41	0.2 N × 10	20.410860	±0.41
0.08 N × 10	8.164418	±0.16	0.08 N × 10	8.164344	±0.16
0.04 N × 10	4.082172	±0.08	0.04 N × 10	4.082172	±0.08
0.004 N × 10	0.408221	±0.008	0.004 N × 10	0.408217	±0.008

The repeatability is calculated by

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

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 torque at 0° position, respectively.

The results of the repeatability test are shown in Figures 3 to 5. The results indicate that the repeatability of the machine is better than 2.32×10^{-5} in the 1 N·m torque range segment, 2.77×10^{-5} in the 500 mN·m torque range segment, and 3.80×10^{-5} in the 200 mN·m torque range segment.

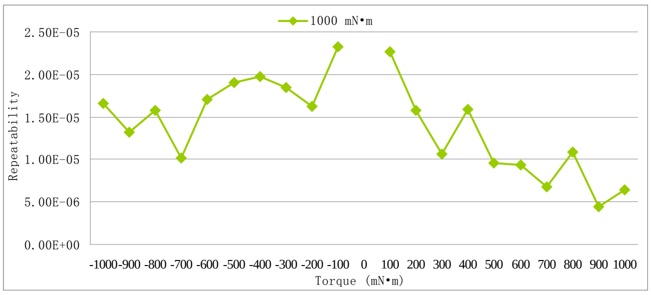

Figure 3. The results of the repeatability test in the 1 N·m torque range segment.

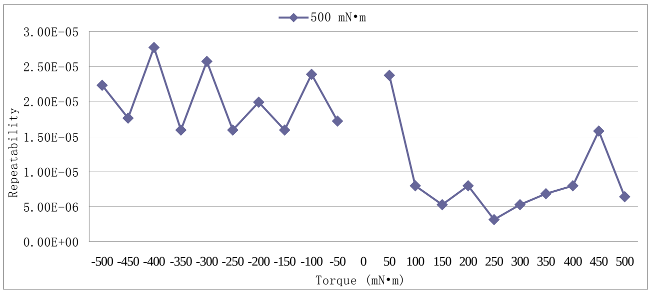

Figure 4. The results of the repeatability test in the 500 mN·m torque range segment.

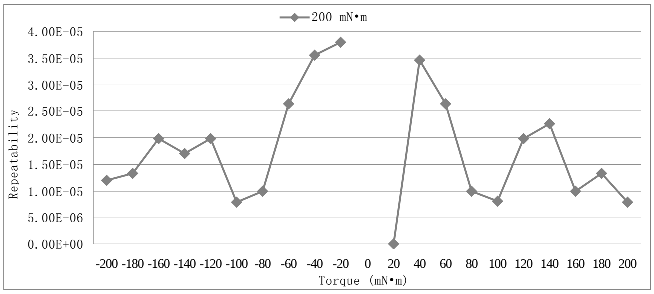

Figure 5. The results of the repeatability test in the 200 mN·m torque range segment.

3.2. SENSITIVITY TEST

The sensitivity tests were carried out by means of the milligram weights as well as torque transducers and the measuring amplifier. The torque transducer is mounted on the torque machine and torques as shown in Table 2 were applied. After the output signal of the torque transducer was stabilized, additional small weights (as small as possible) were added on the top weight until the output signal showed a visible change. Table 2 shows the results of the sensitivity test of the machine.

4. EVALUATION OF UNCERTAINTY

The uncertainty evaluation of the deadweight torque standard machine has been discussed in former papers [3]-[6]. The source of uncertainty, the probability distribution, distribution factor and relative standard uncertainty as well as the relative combined standard uncertainty and the relative combined expanded uncertainty are listed in Table 3. The uncertainties are calculated according to equations (2) to (4).

The uncertainty caused by the arm lever's length is obtained by

$$w_{r,L} = \sqrt{w_{r,L_1}^2 + w_{r,L_2}^2 + w_{r,L_3}^2 + w_{r,L_4}^2} \qquad (2)$$

The relative standard uncertainty is calculated as follows:

$$w_{r,c} = \sqrt{w_{r,m}^2 + w_{r,g}^2 + \left[\left(\frac{w_{r,\rho_a}}{\rho_a}\right)^2 + \left(\frac{w_{r,\rho_w}}{\rho_w}\right)^2\right]\left(\frac{\rho_a}{(\rho_w - \rho_a)}\right)^2 + w_{r,L}^2 + w_{r,b}^2 + w_{r,t}^2 + w_{r,M_f}^2} \qquad (3)$$

and the relative expanded uncertainty (k=2) is calculated by

$$W_{r,c} = 2w_{r,c} \qquad (4)$$

5. CONCLUSION

The 1 N·m torque standard machine adopts an air bearing with low friction to support the moment-arm to minimize the friction at the fulcrum. Invar alloy with low expansion coefficient is used as the material of the moment-arm to reduce the uncertainty caused by the moment-arm length change due to temperature variations. The designed weight suspension system keeps the force generated by small weights vertically downward and free from parasitic forces. The distinctive weight loading system ensures the applied force by small weights accurately and reliably and avoids a reverse process during loading. The torque machine is capable of generating clockwise and anticlockwise torques in a range from 1 mN·m to 1 N·m. The expanded uncertainty (k = 2) is smaller than 5×10^{-5} in the range from 100 mN·m to 1 N·m, and smaller than 1×10^{-4} in the range from 10 mN·m to 100 mN·m.

REFERENCES

[1] Z.M. Zhang, T.Li, Y.Zhang, e.a., "A Full-automatic High Accuracy 100 Nm Torque Standard Machine", Proc. of 19th IMEKO World Congress, Sept. 6-11, 2009, Lisbon, Portugal.

Table 2. The results of the sensitivity test of the machine.

Torque transducer	Applied torque (mN·m)	Corresponding weights mass (g)	Added small weights mass (mg)	Relative sensitivity
TT1/1 Nm	50	20.041105	1	5.0E-05
	100	40.822100	2	5.0E-05
	500	200.411045	5	2.5E-05
	1000	400.822090	10	2.5E-05

Table 3. Uncertainty budget.

Source of uncertainty		$W_{r,i}$	Probability distribution	Coverage factor	Relative standard uncertainty
The mass measurement of weights		$W_{r,m}$	Normal	3	1.2×10^{-5}
The gravitational acceleration measurement		$W_{r,g}$	Normal	3	6.6×10^{-8}
The variety of air density		W_{r,ρ_a}	Rectangular	$\sqrt{3}$	1.9×10^{-2}
The density measurement of the weights material		W_{r,ρ_w}	Normal	3	8.7×10^{-3}
Arm lever's length $W_{r,L}$	Length measurement	W_{r,L_1}	/	2	2.0×10^{-6}
	The influence by temperature change	W_{r,L_2}	Rectangular	$\sqrt{3}$	6.9×10^{-7}
	The influence by deformation	W_{r,L_3}	Rectangular	$\sqrt{3}$	1.9×10^{-9}
	The influence by lever inclination	W_{r,L_4}	Rectangular	$\sqrt{3}$	4.5×10^{-9}
The influence by weight swing		$W_{r,b}$	Triangle	$\sqrt{6}$	1.0×10^{-6}
The influence by non-coaxality of rotation axis and counter axis		$W_{r,t}$	Rectangular	$\sqrt{3}$	5.0×10^{-10}
The influence by sensitivity of the machine		W_{r,M_s}	Rectangular	$\sqrt{3}$	1.44×10^{-5} (500 mN·m)
					2.89×10^{-5} (50 mN·m)
The relative combined standard uncertainty $W_{r,c}$		1.95×10^{-5} (500 mN·m)			
		3.15×10^{-5} (50 mN·m)			
The relative combined expanded uncertainty (k = 2) $W_{r,c}$		3.9×10^{-5} (500 mN·m)			
		6.3×10^{-5} (50 mN·m)			

[2] Z.M. Zhang, Y.Zhang, T.Li, H.L.Ji, "The Design of 1 N·m Torque Standard Machine at NIM", Proc. of Asia-Pacific Symposium on Mass, Force and Torque, Nov. 20-22, 2013, Chinese Taibei.

[3] D. Röske, Uncertainty considerations for the physical quantity torque, China industry system—Technical Seminar of Torque Metrology Technology, 2006, Shanghai, China, pp.193 – 201.

[4] D. Roske, "Metrological characterization of a 1 N·m torque standard machine at PTB", Germany [J]. Metrologia 51, No.1 (2014) 87–96.

[5] Atsuhiro Nishino, Koji Ohgushi and Kazunaga Ueda, "Design and Component Evaluation of the 10 N·m Dead-Weight Torque Standard Machine", Proc. of Asia-Pacific Symposium on Mass, Force and Torque, Oct 24 - 25 2007, Sydney, Australia.

[6] Yon-Kyu Park, Min-Seok Kim, Dae-Im Kang, "Development of a small capacity deadweight torque standard machine", Measurement Science and Technology, Vol. 18, No. 11 (2007) 3273-3278.