

# TORQUE STANDARD COMPARISON AMONG PROVINCES LABORATORIES IN CHINA

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## Abstract:

To estimate the situation of torque standard machines in different provinces' laboratories within China, a torque standard comparison was carried out, for the first time. Results were obtained and then analysed, with values of  $E_n$  being calculated. The characteristics and the performance of the torque transfer standard transducer were indicated. We also discuss some problems during the comparison.

**Keywords:** torque comparison; province laboratory; torque transfer standard

## 1. INTRODUCTION

In recent years, more and more provinces' laboratories have built torque standard machines. In China there are two traceability systems; one is to NIM (National Institutes of Metrology of China) and the other to the military system of China (CIMM). Some laboratories derive traceability from NIM and others from CIMM. To estimate the situation of the province laboratories' torque measuring capabilities, the Hubei Institute of Metrology and Testing Technology piloted this comparison in 2019.

In total, eight laboratories took part in this comparison. It covered the middle, eastern, western, and northern areas of China. It made sense to perform this comparison because no similar exercise had previously been carried out

In this paper, we present the procedure, test results and analysis, performance of the torque transducer and some discussions.

## 2. EQUIPMENT AND MACHINES USED

The torque transfer standards are two transducers: one of 100 N·m capacity and the other of 2 kN·m capacity. Both are type Dm-TN from GTM. These two transducers are equipped with ETP (hydraulic brake) and couplings. All of them are fitted to the torque standard machines' shafts for better alignment and performance.

The torque standard machines at all laboratories were made by different machine manufacturers. To achieve the best accuracy of the measurements, we use the machine of 100 N·m or 2 kN·m. The test points are selected at 50 % and 100 % of the machine capacity.

The amplifier 2026B has an accuracy of 0.005 %.

## 3. PROCEDURE

The test procedure is according to the Chinese verification guideline of torque standard machine: JJG 769. All laboratories were set to three groups according to the different machine manufacturers. The transfer route map is shown in Figure 1. It makes a closed loop for each group.

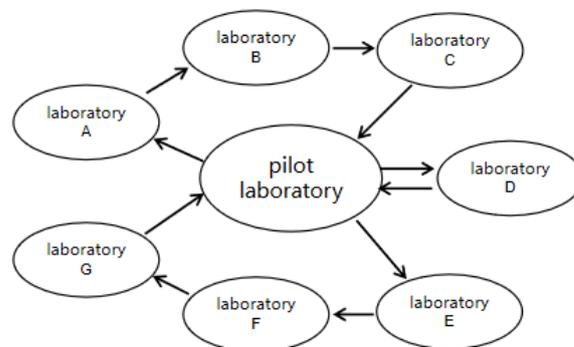


Figure 1: Route map of comparison

The test was carried out in clockwise torque, including four points: 50 N·m, 100 N·m, 1 kN·m and 2 kN·m. The test points of 50 N·m and 100 N·m are with rotation at three positions: 0°, 120° and 240°. The 1 kN·m & 2 kN·m positions were not rotated, because the equipment of 100 N·m kit is light, but the equipment of 2 kN·m kit is too heavy. Figure 2 is a comparison test steps chart of 100 N·m torque sensor.

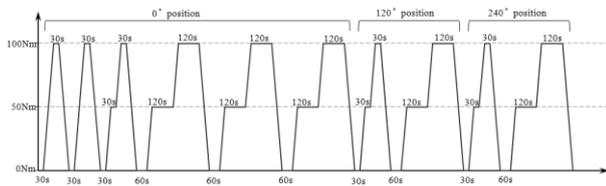


Figure 2: Test steps for 100 N·m

## 4. TEST DATA

### 4.1 Measurement Deviation

The measurement deviation is equal to the difference between the measurement value and the reference value divided by the reference value, expressed as a relative error. Considering that the uncertainty of the measurement results of each laboratory is close (all around 0.04 %), the reference value is calculated by the arithmetic mean method. For example, in each comparison group, the pilot laboratory participated in two comparison measurements, and the reference laboratory participated in one. The average value of the above measurement results can be calculated to obtain the reference value. To ensure the comparability of the results, each comparison group has a reference value and an uncertainty, so we end up with three reference values, each with an uncertainty.

Table 1, Table 2, and Table 3 show the measurement deviation of the three comparison groups.

Table 1: Measurement deviation, 1st group

Torque	Pilot	Lab A	Lab B	Lab C
50 N·m	-0.012 %	-0.020 %	0.043 %	-0.010 %
100 N·m	-0.014 %	-0.017 %	0.044 %	-0.013 %
1 kN·m	0.008 %	---	-0.001 %	-0.026 %
2 kN·m	0.006 %	---	0.000 %	-0.021 %

Table 2: Measurement deviation, 2nd group

Torque	Pilot	Lab D
50 N·m	0.002 %	-0.005 %
100 N·m	-0.001 %	0.003 %
1 kN·m	0.008 %	-0.016 %
2 kN·m	0.007 %	-0.013 %

Table 3: Measurement deviation, 3rd group

Torque	Pilot	Lab E	Lab F	Lab G
50 N·m	-0.005 %	-0.004 %	-0.005 %	0.024 %
100 N·m	-0.004 %	-0.005 %	-0.006 %	0.022 %
1 kN·m	0.004 %	0.005 %	0.001 %	-0.014 %
2 kN·m	0.001 %	0.002 %	0.008 %	-0.011 %

### 4.2 Uncertainty

Table 4, Table 5, and Table 6 show the uncertainty of the comparative measurement results of each laboratory in the three comparison groups. The sources of uncertainty in each laboratory include extended uncertainty of the torque standard machine, measurement repeatability, azimuth error, resolution of the measuring instrument, zero error, alignment and temperature. Here, the coverage factor  $k = 2$ .

Table 4: Relative expanded uncertainty, 1st group

Torque	Expanded uncertainty / %				
	Pilot	Lab A	Lab B	Lab C	Reference value
50 N·m	0.040	0.040	0.050	0.036	0.021
100 N·m	0.040	0.040	0.051	0.036	0.021
1 kN·m	0.036	---	0.049	0.034	0.023
2 kN·m	0.036	---	0.049	0.034	0.023

Table 5: Relative expanded uncertainty, 2nd group

Torque	Expanded uncertainty / %		
	Pilot	Lab D	Reference value
50 N·m	0.038	0.034	0.025
100 N·m	0.038	0.034	0.025
1 kN·m	0.036	0.034	0.024
2 kN·m	0.036	0.034	0.024

Table 6: Relative expanded uncertainty, 3rd group

Torque	Expanded uncertainty / %				
	Pilot	Lab E	Lab F	Lab G	Reference value
50 N·m	0.036	0.044	0.040	0.047	0.021
100 N·m	0.036	0.044	0.040	0.046	0.021
1 kN·m	0.036	0.040	0.040	0.046	0.020
2 kN·m	0.036	0.040	0.040	0.046	0.020

### 4.3 Normalized Deviation Value $E_n$

All the comparison test data were collected and analysed, and the normalized deviation value  $E_n$  calculated as in equation (1).

$$E_n = \frac{x' - x}{\sqrt{U'^2 + U^2}}, k = 2. \quad (1)$$

where  $U'$  is the extended uncertainty of a measuring point in a laboratory, and  $U$  is the extended uncertainty of a reference value at a measurement point.

The comparison criteria are:

- $|E_n| \leq 1$ , Satisfied
- $|E_n| > 1$ , Not satisfied

Figure 3, Figure 4, and Figure 5 show the histograms of three groups' laboratories inner petals  $E_n$  value. The pilot laboratory comparison data is involved in the calculation of the reference value and uncertainty in each petal. Lab A, whose results are shown in Figure 3, did not participate the comparison of 1 kN·m and 2 kN·m.

In Figure 3, Figure 4, and Figure 5, the  $E_n$  values of each laboratory were less than 1, with satisfactory results. Lab B is the only one which takes its traceability from CIMM in all laboratories, resulting in larger  $E_n$  values of 0.79 and 0.80 at torque levels of 50 N·m and 100 N·m respectively. All other laboratories, which are traceable to NIM, show relatively smaller  $E_n$  values.

This shows that the difference of the traceability mechanism (the upper-level measurement technical institution) cause small difference in the torque standard machine's test result, and the traceability to the same measurement technical institution can ensure the consistency of the torque standard machine value.

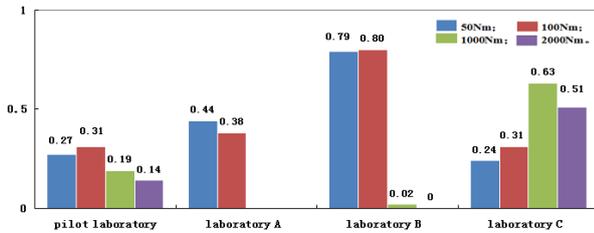


Figure 3: Laboratory comparison results, 1st group

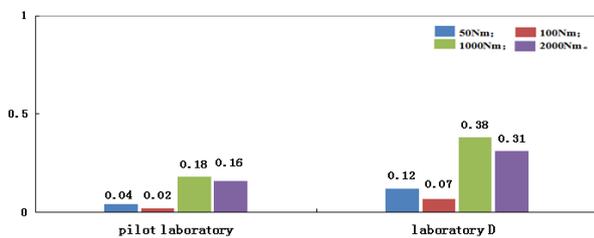


Figure 4: Laboratory comparison results, 2nd group

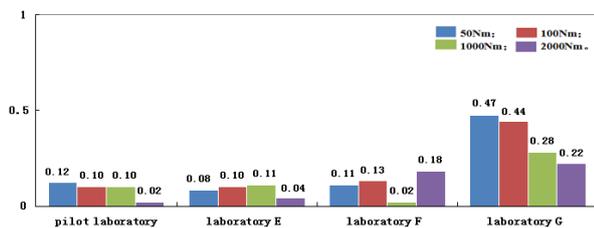


Figure 5: Laboratory comparison results, 3rd group

## 5. PROBLEM & DISCUSSION

### 5.1 Stability Test

To verify the stability of the Dm-TN/100 N·m and Dm-TN/2 kN·m transducers, repeated sets of tests at comparison points of 50 N·m, 100 N·m, 1 kN·m and 2 kN·m were carried out.

Figure 6 and Figure 7 show the stability test result of the two torque transducers mentioned

above over a 10-month period. Test data shown in the figure indicate that the fluctuations of the two torque transducers are less than 0.05 %.

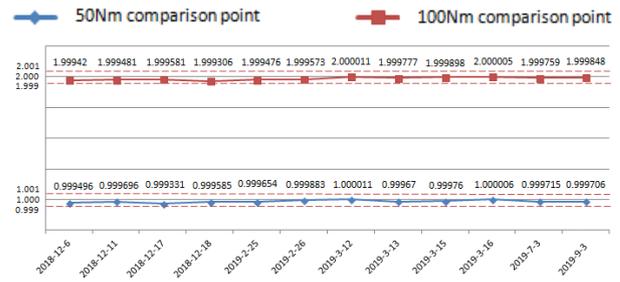


Figure 6: Stability test on transducer of 100 N·m

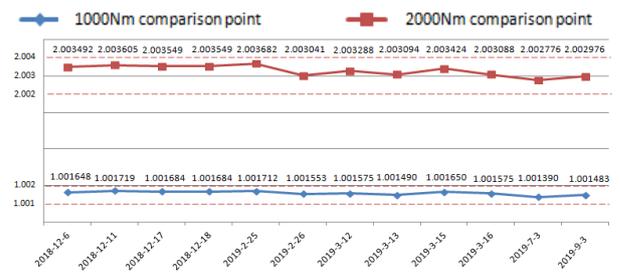


Figure 7: Stability test on transducer of 2 kN·m

### 5.2 Warming Up Transducers

Before each test, it is necessary to ensure that the torque transducer's temperature is consistent and stable with the laboratory temperature. The pilot laboratory stipulates that the torque transducer should be placed in the laboratory for more than 12 hours. Then connect the comparison transfer standard to the torque standard machine and connect the transducer to the instrument as a whole body to warm up. To verify the influence of the warm-up time on the performance of the torque transducers, the test was conducted with a small change in environmental conditions. The test result is shown in Table 7.

Table 7: Effect of warm-up time on measured data

Warm-up time	Temperature / humidity	Output at 50 N·m / mV/V	Variation / %
0.5 h	18.4 °C / 41 % RH	0.998 930	---
1 h	18.6 °C / 40 % RH	0.999 134	0.02
1.5 h	18.8 °C / 38 % RH	0.999 360	0.02
2 h	19.1 °C / 41 % RH	0.999 504	0.01
3 h	18.7 °C / 39 % RH	0.999 518	0.00
4 h	18.6 °C / 40 % RH	0.999 512	0.00

### 5.3 Temperature Change of Transducers

The humidity varies minimally during the test, while the temperature changes widely. The temperature decreases and rises rapidly in 2.5 h. It can be seen in the analysis data, compared to the initial test value, the ones after 2.5 h has changed by -0.03 %. That is to say, the rapid change of

temperature in a short time has a greater impact on the performance of the sensor, and it is not suitable for the temperature characteristic 0.01 %/10 K which is given by the torque sensor manufacturer. Therefore, the temperature change needs special attention during the test of the high-accuracy torque sensor and ensuring the stability of the temperature is essential for accurate measurement, see Table 8.

Table 8: Effect of temperature on torque sensor

Time	Temperature / humidity	Output at 50 N·m
0 h	20.6 °C / 67 % RH	0.999 960 mV/V
0.5 h	20.1 °C / 65 % RH	0.999 952 mV/V
1 h	19.3 °C / 65 % RH	0.999 905 mV/V
1.5 h	18.5 °C / 63 % RH	0.999 817 mV/V
2 h	19.0 °C / 62 % RH	0.999 742 mV/V
2.5 h	19.6 °C / 61 % RH	0.999 634 mV/V

#### 5.4 Alignment Effect

Due to manufacturing and installation errors, deformation after loading, and temperature changes, the drive shaft and driven shaft of the torque standard machine will cause changes in the relative position of the two shafts, and often cannot guarantee strict alignment. In order to ensure the correct transmission of the torque value and reduce the influence of processing and installation on the torque measurement results, we use the shaft locking device ETP to connect the torque standard machine through the flexible coupling and the torque sensor, so as to ensure that the torque machine and torque sensor have good alignment. But can this connection form ensure accurate measurement even when the alignment is poor?

A test ever did in a laboratory. The magnetic dial base is sucked on the movable shaft head, and the movable shaft head is rotated one week. The maximum change of the dial indicator reading is 0.82 mm. The movable end of the main shaft of the torque standard machine is adjusted to ensure that the alignment reaches 0.05 mm. Table 9 is the detection data of the torque sensor before and after the adjustment of the torque standard machine. The alignment has a greater influence on the detection data of the torque sensor, and the difference between the two reaches nearly 0.03 %. This shows that the flexible coupling can improve the impact of the different shafts of the torque standard machine on the performance of the sensor, but this improvement is not large, that is, the flexible coupling cannot be expected to help the torque sensor achieve accurate measurement when the alignment of the torque standard machine is poor.

Table 9: Effect of alignment condition on torque indication

Measuring point	Value before adjustment	Value after adjustment
50 N·m	0.999 987 mV/V	0.999 715 mV/V
100 N·m	2.000 237 mV/V	1.999 859 mV/V

On the other hand, it is believed that the alignment condition of the torque standard machine can be determined by the corner test of the torque sensor. However, the author found through multiple sets of tests that before the adjustment of the alignment of the torque standard machine, the test data shows that the azimuth errors are less than 0.01 %, this shows that the test data of the rotation angle may not necessarily determine the alignment condition of the torque standard machine.

#### 5.5 Effect of Connectors

In this comparison, to discuss the role of torque connectors in the comparison, the pilot laboratory and laboratory B jointly discussed. Laboratory B measures the 100 N·m sensor three times. The first two installation conditions are that the coupling connector and the shaft head of the torque machine are connected by another connector, as shown in Figure 8; the third installation situation is that the coupling connector is directly connected to the shaft head of the torque machine is shown in Figure 9, that is, there is no connecting piece at the third installation.

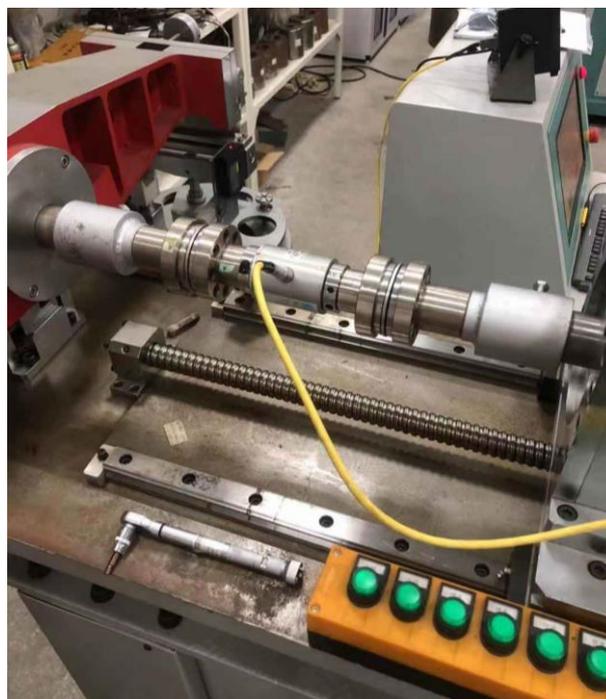


Figure 8: The first two installations



Figure 9: The third installation

The three measurements data are shown in Table 10. This table shows that the time interval between the first and second measurements has reached more than 7 months. The installation condition of these two measurements is consistent, and the variation of the measurement data is within 0.02 %, which further confirms the good stability of the torque sensor. The third measurement only has one less connector than the previous two measurements, but the measurement data changes by about 0.01 %. This indicates that different connectors have little influence on the measurement data of torque measurement system (torque sensor, flexible coupling, hydraulic brake).

Table 10: Three measurements of the 100 N·m sensor

Date	Temp. / humid.	Output at 50 N·m / mV/V	Change / %	Output at 100 N·m / mV/V	Change / %
18/01/19	20.0 °C / 62 % RH	1.000 054	---	2.000 592	---
09/09/19	22.5 °C / 52 % RH	1.000 129	0.007	2.000 935	0.017
16/09/19	22.4 °C / 45 % RH	1.000 048	-0.008	2.000 691	-0.012

## 6. SUMMARY

Test data indicated that all laboratories'  $|E_n|$  values are smaller than 1. The difference between the measurement results of each laboratory and the reference value is within reasonable expectations, and the comparison results are acceptable.

The mechanical alignment is very important.

The temperature effects must be considered during the comparison test.

The stability of the transducer is one of the keys.

The results provide experience for the development of high-accuracy torque measurement in China.

## 7. REFERENCES

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