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Temperature Performance and Calibration of Torque Sensor

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Abstract. Torque sensors are widely used in the field of industrial machinery, they are an important guarantee for the control accuracy of material torsion test equipment. The working environment of torque sensor application site is complex, which is often different from that of calibration in the laboratory. Based on its measurement principle, the metering performance of torque sensor will be different under different Temperature conditions. In this paper, the performance differences of common strain torque sensors under different environmental conditions are analyzed, and the temperature performance evaluation method are introduced. The structure and performance of torque standard machine and thermal insulation coupling which can be used for temperature test, as well as a series of calibration tests and results carried out by using this device.

Keywords. Torque sensor, temperature performance, thermal isolation coupling, temperature test, calibration

1. Introduction

Torque sensor can sense torque and convert it into measurable electrical signal [1]. Torque sensor is widely used in industrial measurement and control and production and life process, especially in the industry of tools, motors, wind power and other industries [2]. With the continuous development of market demand, torque sensors with various principles and structural types have emerged to adapt to different applications. In order to ensure the accuracy and reliability of the torque sensor, it is necessary to measure it accurately.

At present, the technical performance test of torque sensor is usually carried out in accordance with relevant regulations under laboratory environmental conditions. However, its service conditions have many special working conditions different from the test conditions, such as high and low temperature environment. The sensitivity of resistance strain torque sensor to the changes of environmental conditions determines the differences performance between the laboratory and the actual working environment, which also makes the performance data obtained under the conventional measurement conditions have some applicability problems.

This paper aims to analyze the environmental adaptability of torque sensor under different environmental conditions, and study its measurement technology in high and low temperature environment, so as to realize the temperature performance test of

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various types of sensors, and provide data support for its reliability in different applications.

2. Torque Sensor

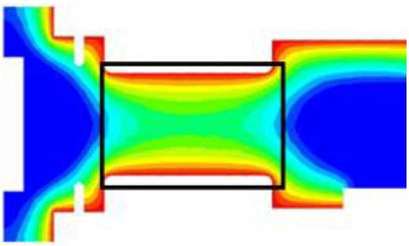
2.1. Characteristics and Types of Torque Sensors

Torque sensors have a wide range of applications, and have a variety of principles and structural types. According to the time characteristics of the measured value of the torque sensor, it can be divided into static state, steady state and dynamic state. Static torque sensors are usually strain type principle, and its structure includes circular shaft type, multi column type and so on. Steady-state rotating torque sensors include strain type, piezomagnetic type, photoelectric type and so on. In addition to the torque measurement function, the wireless transmission of measurement signal is also one of its important functions. Dynamic torque [3] sensors are usually piezoelectric and strain type. According to different response frequency requirements, the structural types and measurement principles are different. The torque sensor based on strain type principle is one of the most widely used torque sensors with high accuracy and good structural adaptability.

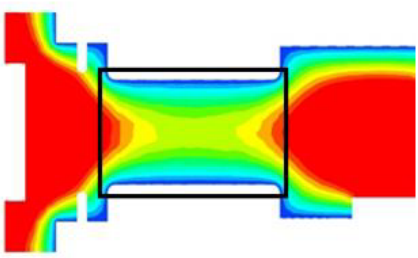
2.2. Temperature Sensitivity of Resistance Strain Torque Sensor

The resistance strain type torque sensor is mainly composed of an elastic sensing element [4] that senses torque and a resistance strain gauge bridge pasted on the surface of the elastic element. Elastic elements are usually made of steel or aluminum metal materials. Because the elastic modulus of these materials will be different at different ambient temperatures, the strain of the sensor elastic element after bearing will vary with the temperature.

As shown in figure 1, the simulation results of temperature and elastic modulus of the elastic element of an aluminum torque sensor at a certain time in the process of temperature balance are shown. The elastic modulus of each part of the elastic element has a certain corresponding relationship with the actual temperature, and the difference is obvious. On the one hand, this phenomenon shows that the output sensitivity of the sensor will be different at different temperatures. At the same time, it also shows that the use before the internal and external heat balance of the elastic element will lead to a large drift of its measurement data.



(a) Temperature distribution



(b) Modulus of elasticity

Figure 1. Simulation analysis of torque elastic element.

In order to reduce the sensitivity difference of resistance strain sensor in vary temperature environment, the method of adding temperature compensation circuit [5] is often used to improve this phenomenon. However, even if these temperature compensation measures are adopted, different batches of sensors will show different degrees of influence due to the existence of material differences and patch process differences.

Therefore, for the strain type torque sensor used in measurement occasions with high accuracy requirements, the actual measurement of temperature sensitive performance should be carried out to judge the applicability, or if necessary, corresponding correction measures should be taken to improve the data accuracy and reliability.

3. Measurement Technology of Torque Sensor

3.1. Measurement Method of Torque Sensor

At present, for the measurement of torque sensor, when measuring the indication accuracy after matching with the instrument, it can be carried out with reference to the metrological verification regulation [6] of JJG 995-2005 “verification regulation of static torque measuring devices”. When only the metrological performance of torque sensor is measured, it can be carried out with reference to JJG391-2009 "verification regulation of force transducers" [7]. In the former, there is no relevant content on the evaluation of environmental adaptability, only the ambient temperature condition is 20 ℃± 5 ℃; the latter specifies two technical indexes related to temperature influence: zero output temperature influence and rated output temperature influence.

Because torque sensor and force sensor are load sensors, their measurement principle and structure group are very similar, so their measurement procedures and evaluation methods can also be similar. According to the above procedure documents, two technical indexes related to temperature influence are evaluated according to the change of every 10K, and they are calculated according to formula (1) and formula (2).

$$Z_t = \frac{\frac{\theta_{0t}-\theta_{0s}}{\theta_f}}{\frac{T-T_s}{10}} \cdot 100\% \tag{1}$$

$$S_t = \frac{\frac{(\theta_{ft}-\theta_{0t}) - (\theta_{ft}-\theta_{0s})}{\theta_f}}{\frac{T-T_S}{10}} \cdot 100\% \tag{2}$$

In the formulas:

Z_t—zero output temperature influence;

θ_{0t}, θ_{0s}—average values of the corresponding no-load output at temperature (T) and normal temperature (T_s)

θ_f —rated output at normal temperature [8]

T, T_s—temperature in the non temperature test and the normal temperature test respectively;

S_t—rated output temperature influence;

θ_{ft}, θ_{fs}——average values of the corresponding rated output at temperature (T) and normal temperature (T_s)

3.2. Torque Standard Device with Temperature Test Environment

In order to test the torque sensor in different temperature environments, the unit has developed a torque standard device. The torque range is 100Nm ~ 10kNm and the temperature range is - 60°C ~ 150°C.

The structural design of the device is shown in figure 2. The standard torque is realized by adding weights hung at both ends of the lever to produce torque relative to the central axis. In addition to the weight system, lever system, support system, torque loading system and coupling system [9] that realize the conventional torque loading function, a large working space is specially designed for placing the special temperature test chamber.

Figure 2. Torque standard device with temperature test environment.

The temperature test chamber adopts split design to facilitate the installation and disassembly of torque sensor. During the experiment, the torque sensor is placed in the test chamber, and the torsion bearing shafts at both ends of the sensor pass through the round holes at both ends of the temperature test chamber through a special thermal insulation coupling and are coaxially connected with the torsion application shaft of the torque standard device.

In order to ensure the stability and comparability of the measurement results, it is necessary to realize the accurate and stable control of each temperature point in the measurement process. At the same time, it is also necessary to realize the internal and external heat balance of the elastic elements of the sensor, which requires to minimize the heat exchange between the internal and external environment of the incubator.

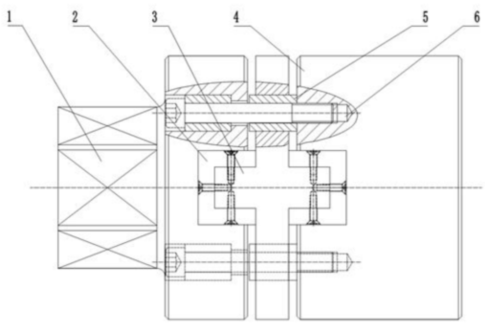
Through the matching design of the coupling and the reserved hole position of the test chamber, only about 1mm gap is left around the coupling during actual work. While ensuring that the test chamber will not have the impact of additional loads such as friction on the coupling, reduce the convection of internal and external air as far as possible, so as to realize the gap sealing.

3.3. Design of Thermal Isolation Coupling

In the test, the standard device should not only realize the accurate transmission of large load, but also ensure the thermal balance of the torque sensor to fully isolate the internal and external environment of the test chamber. In order to limit the heat conduction energy in the process of torque transmission to the greatest extent, a special thermal insulation coupling sleeve group composed of thermal insulation materials and metal materials is designed for the device.

Because most of the thermal insulation materials are non-metallic materials, materials that can bear large loads, such as fiber-reinforced plastics, usually have weak torsional performance, and the processing tolerance is not easy to ensure, so they are not suitable for the realization of complex structures. Therefore, when the torque is large, the design of directly using thermal insulation materials to transmit torque is not desirable.

The thermal insulation coupling has been functionally decomposed and assembled as a whole, the structural is shown in figure 3. Through function conversion, while realizing the complete heat insulation function as much as possible, the heat insulation raw materials used for torque transmission only bear pressure, so as to achieve the simultaneous realization of torque transmission and heat insulation.



1—Convex torsion shaft, 2—Insulation trough,

3—Combination disc, 4—Concave torsion shaft,

5-Insulation sleeve, 6- insulation bolt group

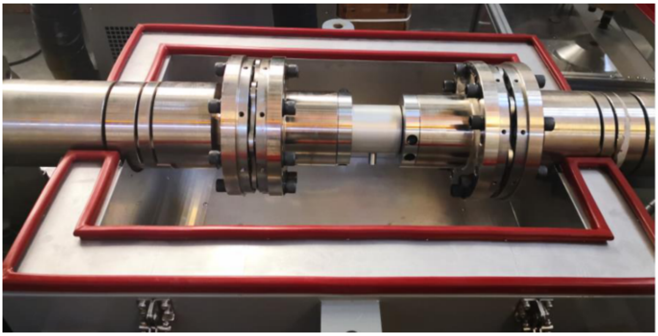
Figure 3. Thermal isolation torque coupling.

4. High and Low Temperature Test of Torque Sensor

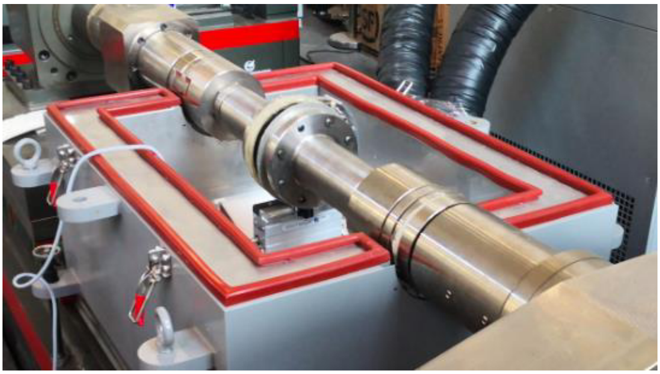
4.1. Sensor Selection and Installation

A circular shaft structure torque sensor and a flange torque sensor based on strain measurement principle were tested at different temperatures. The rated torque of both sensors is 5000Nm.

The installation method of the sensor on the standard device is shown in figure 4. As shown in figure 4(a), the two ends of the circular shaft sensor and the torsion shaft of the device are respectively connected in series with hydraulic holding brake coupling, elastic coupling, thermal insulation coupling, rigid adapter and other coupling sets. As shown in figure 4(b), both ends of the flange sensor are respectively connected with a set of adapter flange and thermal insulation coupling in series.



(a) Acircular shaft sensor



(b) A flange sensor

Figure 4. Installation method of temperature test.

Before the test, use the temperature test chamber to locally control the temperature of the sensor. After reaching the preset temperature, continue to maintain the constant temperature for more than 4 hours to ensure that the temperature of the sensor itself is fully stable.

4.2. Test Data and Results of the Circular Shaft Sensor

The test temperature and data of the circular shaft torque sensor are shown in tables 1 and 2. The maximum influence of zero temperature of the sensor is -0.01% FS / 10K, and the maximum influence of rated output temperature is -0.281% FS / 10K. Relatively, the zero temperature compensation effect of this sensor is much better than the sensitivity temperature compensation effect.

Table 1. Positive moment test data of the circular shaft sensor.

Temperature (°C)	Zero output (mV/V)	Z_t (%FS/10K)	Rated output (mV/V)	S_t (%FS/10K)
20	-0.0185	/	2.00170	
-10	-0.0187	-0.003	1.98913	-0.209
-5	-0.0188	-0.006	1.99070	-0.220
5	-0.0188	-0.010	1.99363	-0.269
20	-0.0188	/	1.99973	/
40	-0.0189	-0.010	2.00910	0.185
60	-0.0189	-0.005	2.01765	0.199
20	-0.0192	/	2.00149	/

Table 2. Inverse moment test data of the circular shaft sensor.

Temperature (°C)	Zero output (mV/V)	Z_t (%FS/10K)	Rated output (mV/V)	S_t (%FS/10K)
20	-0.0178		-2.00123	/
-10	-0.0177	-0.002	-1.98933	-0.198
-5	-0.0178	0.000	-1.99060	-0.213
5	-0.0178	0.000	-1.99280	-0.281
20	-0.0179	/	-2.00047	/
40	-0.0180	0.005	-2.00907	0.196
60	-0.0182	0.004	-2.01770	0.206
20	-0.0182	/	-2.00161	/

As shown in figures 5 and 6, the zero output and rated output curves of the circular shaft sensor are shown. There is an obvious continuous drift in the zero output of the sensor during the temperature test, resulting in the failure of the zero output to return to the initial state during the subsequent normal temperature (20 °C) test. In addition, the rated output of the sensor varies greatly at different temperatures, but basically remains linear.

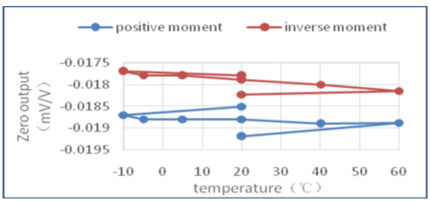


Figure 5. Variation of zero output of the circular shaft sensor.

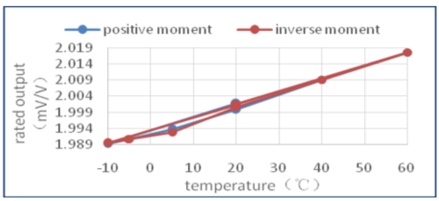


Figure 6. Variation of rated output of the circular shaft sensor.

4.3. Test Data and Results of the Flange Sensor

The test temperature and data of the flange torque sensor are shown in tables 3 and 4, the zero output and rated output curves are shown in figures 7 and 8. The maximum influence of zero output is 0.005% FS / 10K, and the maximum influence of rated output is -0.012% FS/10K. The results show that the temperature compensation of zero and sensitivity both are ideal.

Table 3. Positive moment test data of the flange sensor.

Temperature (°C)	zero output (Nm)	Z_t (%FS/10K)	Rated output (Nm)	S_t (%FS/10K)
20	1.4350	/	5000.1	/
-5	1.0725	-0.003	4999.9	-0.002
5	1.3630	-0.001	5000.2	0.002
20	1.5250	/	5000.3	/
35	1.5565	0.002	4999.4	-0.010
50	1.3735	0.000	4999.3	-0.006
20	1.3805	/	5000.3	/

Table 4. Inverse moment test data of the flange sensor.

Temperature (°C)	zero output(Nm)	Z_t (%FS/10K)	Rated output (Nm)	S_t (%FS/10K)
20	-0.1470		-5001.5	/
-5	-0.5505	0.003	-5002.7	0.010
5	-0.5370	0.005	-5002.0	0.007
20	-0.5820	/	-5001.2	/
35	-0.5050	0.005	-5000.6	-0.012
50	-0.6980	0.004	-5000.2	-0.008
20	-0.4045	/	-5000.6	/

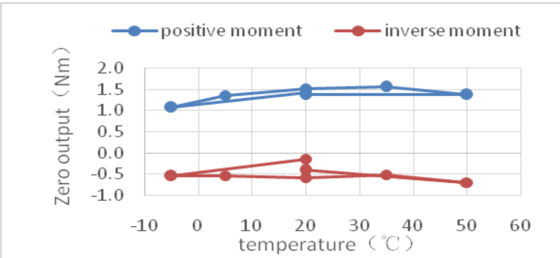


Figure 7. Variation of zero output of the flange sensor.

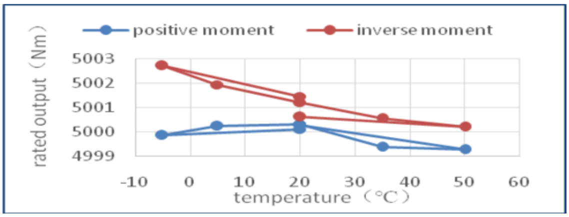


Figure 8. Variation of rated output of the flange sensor.

5. Concluding Remarks

The test results show that the torque standard device with temperature environment and its thermal insulation coupling have good application effects, and can provide high-quality testing services.

Considering that many actual working conditions of torque sensor are more severe working sites, in addition to the ambient temperature, factors such as bending moment [10] will have varying degrees of impact on the measured data. In order to improve the reliability, we should fully understand the actual working state and carry out corresponding measurements to make a more comprehensive evaluation of the sensor.

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