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Calibrating a Super-large Range Clamping Ring Type Torque Transducer with Similarity Method

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Abstract

In traditional calibration, we must use a torque standard machine which measuring range is larger than that of the calibrated torque transducer. With the rapidly development of power machinery, its torque has been larger than 100kNm now, but it is difficult to establish corresponding torque standard machine in so large range. We developed a similarity method in calibrating those super-large range clamping ring type torque transducer in 30kNm torque standard machine. Testing a series of specimens with same method, similarity in geometry, time and kinetic, but in different similarity rates, we obtain the largest similarity rates in 12.5 with uncertainty ≤0.5%. It means that we can calibrate a 375kNm clamping ring type torque transducer on a 30kNm torque standard machine with uncertainty ≤0.5%. In the same reason, with the similarity method, larger torque transducer can be calibration. The theorem, testing, data processing, uncertainty analysis are described with detail in this paper.

1. Introduction

For common torque transducer calibration, the transducer is directly measured and calibrated on a torque calibration standard equipment. Precision of the calibrated transducer is obtained by calculating the corresponding values between input standard torque and output of the calibrated transducer. With rapidly development of dynamic machinery power, driving torque has been greatly improved. For example, output torques of marine engines is usually over 100kNm. To calibrate these super-large torque transducers with traditional methods, there should be corresponding equipment. However, establishment of such torque standard machine over 100kNm needs large amount of money, therefore has little feasibility. In order to solve the problem, we've carried out the study of using similarity method to measure super-large torques, since most of these torque transducers are non-broken shaft clamp-ring type transducers. It has been proved from practice that the method is feasible.

2. Principles

Normally, there are three methods of studying the laws between various quantities, namely, mathematics method, direct experiment method and simulation experiment method. Simulation experiment method establishes models based on similarity theory. By model experiment, certain laws are obtained. Then the obtained laws are extended to practical objects. Clamp-ring resistance-strain torque transducer is a kind of non-broken shaft torque transducer. Its working principle is as shown in figure 1:

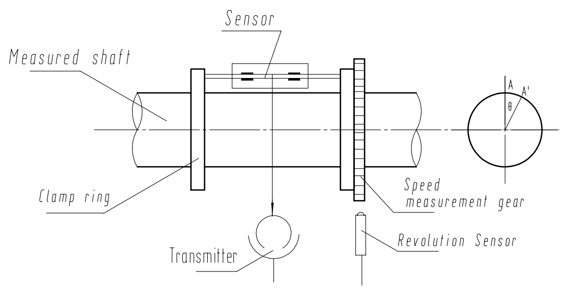

Figure 1. Clamp-ring torque transducer

During calibration, this kind of transducer is clamped onto the standard shaft. The standard equipment inflicts standard torque, and the standard shaft turns and distorts. The transducer detects the torsion-distortion angle of the shaft and calculates the output torque. The sensitive elements of different transducers are the same. Only size of the clamp ring and data setting are changed. Therefore, they are in accordance with similarity law. Calibration data of small-sized standard shaft can be converted into data of large-sized standard shaft through similarity operation, thus completing measurement and calibration of large-sized torque transducers.

3. Theoretical Basis

Similarity law: For matters having the same feature, if they are similar with each other under single-valued condition and the similarity rules composed of physics quantity of single-valued condition are identical numerically, these matters must be similar.

Material mechanics equations show that torsion-distortion angle of the shaft torque is calculated according to the following equation:

$$\theta = \frac{M \cdot l}{J \cdot G} \qquad (1)$$

· where:

θ — torsion-distortion angle

M — torque

l — distortion length

J — polar moment of inertia

G — elastic modulus of shear

İf there are two shafts, when $\theta_1 = \theta_2$,

· According to the feature of the transducer, distortion length is unchanged. $l_1=l_2$

· Since the materials of the two standard shafts are the same, G is unchanged. $G_1=G_2$

$$C_M = \frac{M_2}{M_1} \quad \text{— kinematic similarity}$$

$$\left.\begin{aligned} C_J &= \frac{J_2}{J_1} \\ C_l &= \frac{l_2}{l_1} = 1 \end{aligned}\right\} \text{— geometrical similarity}$$

C_M, C_J, C_l — similarity multiples

The similarity index is

$$\frac{C_M \cdot C_l}{C_J} = \frac{M_2}{M_1} \cdot \frac{J_1}{J_2} = \frac{M_2}{M_1} \cdot \frac{d_2^4}{d_1^4} = 1 \qquad (2)$$

The similarity index equals to 1, which is in accordance with similarity law.

Therefore, when torsion of the two shafts under rotation condition accords with similarity law, their calibration can be done using similarity principles. Large shaft torque (large range torque) can be calibrated on small shaft and then converted into large shaft values.

4. The Test Equipment and the Test Methods Using Similarity Method

Measuring test shafts with similarity method are shown in figure 2. The test shaft is mounted on 30kNm equipment, one end being fixed and balance-adjustable, and the other end inflicting standard torque. Same transducer and secondary meter are used to avoid errors.

İf l is equalIt is obtained the similarity multiple from fundamental principle that

$$K = \frac{M_1}{M_2} = \left(\frac{d_2}{d_1}\right)^4 \frac{h_1}{h_2} \qquad (3)$$

First we calculate the theoretical value, then carry out the experiment. From theoretical and experimental data, one can obtain theoretical and actual similarity multiples. The ratio of difference between theoretical similarity multiple K_L and experimental similarity multiple (i.e., actual similarity multiple) K_S to theoretical similarity multiple is the relative error of this method (similarity method).

$$\delta = \frac{K_S - K_L}{K_L} \times 100\% \qquad (4)$$

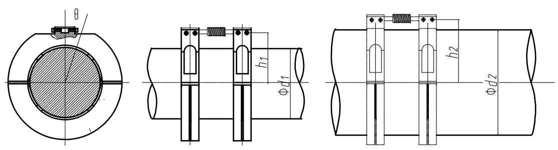

Figure 2. Test shafts with similarity method

A group of test shafts as shown in figure 2 are designed, manufactured and tested. Their grouping is shown in table 1 and 2. Applying standard torque to standard machine to make output torsion angles identical. After permutation and combination of the data, data listed in table 1 and 2 are obtained.

5. Calculation and Experimental Data

Table 1. Same material, not segmented by the same shaft, heat-treated separately, integral clamp ring

Shaft diameter ratio	d100/d90	d160/d90	d214/d90	d160/d100	d214/d100	d214/d160
Theoretical similarity multiple	1.4401	7.0469	18.4976	4.8937	12.8445	2.6249
Actual similarity multiple	1.4294	6.9959	18.3047	4.8735	12.9719	2.6353
Error	0.743%	0.723%	1.043%	0.412%	0.99%	0.397%

Table 2. Same material, segmented by the same shaft, heat-treated in the same furnace, integral clamp ring

Shaft diameter ratio	d214/d90	d214/d100	d214/d110	d210/d90	d214/d160
Theoretical similarity multiple	18.315	12.766	9.256	17.166	2.608
Actual similarity multiple	18.447	12.856	9.230	17.286	2.607
Error	0.72%	0.50%	0.28%	0.70%	0.05%

Shaft diameter ratio	d210/d100	d210/d110	d160/d90	d160/d100	d160/d110
Theoretical similarity multiple	11.965	8.676	7.022	4.895	3.549
Actual similarity multiple	12.035	9.650	7.062	4.931	3.540
Error	0.58%	0.30%	0.57%	0.50%	0.25%

6. Evaluation of Uncertainty

The first experiment uses integral clamp rings, with same material, not segmented by the same shaft and not heat-treated in the same furnace. We obtain six groups of data , only two groups are fine. From which one can observe the influence of G. For example,

Suppose G is 8.15×10^{10}N/M^2. If difference between G is 0.03×10^{10}N/M^2, the relative error hereby caused will be 0.37%.

The second experiment uses integral clamp rings, with same material, segmented by the same shaft and heat-treated in the same furnace, so G is identical. Thus, in ten groups of obtained data. except for two groups which similarity multiples exceed 13, the other eight groups errors are all around 0.5%. This is caused by mounting error.

Now we'll evaluate the uncertainty of the second experiment, using type A evaluation of standard uncertainty. We regard the similarity error as the difference between experiment average and theoretical value. Since the errors are expressed as percentage, they are irrelevant with the original values, thus avoiding the impossibility of obtaining average due to values of each group being expressed differently. There are eight groups of which the similarity multiples are under 12.5. After data treatment,

$$U_A = \sqrt{\frac{0.50^2 + 0.28^2 + 0.05^2 + 0.58^2 + 0.30^2 + 0.57^2 + 0.50^2 + 0.25^2}{8}}$$

$$= 0.42\%$$

The uncertainty u obtained by using similarity method is less than 0.5%.

7. Conclusions

It is proved from experiment that based on similarity theory, using similarity method to measure large torques is feasible, provided that the similarity multiples are within 12.5. The uncertainty is less than 0.5%.

According to similarity calculation theory, theoretical calculation equation and relative parameters during actual experiment, it can be seen that errors are mainly caused by G, measurement errors of diameter, height, distortion length, distortion height and mounting error. If the standard shaft is made of the same material, segmented by the same shaft and heat-treated in the same furnace, G will be basically identical, geometric dimensions are measured more precisely and integral clamp ring is adopted, there will be better results.

8. References

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