

DYNAMIC CALIBRATION OF TORQUE TRANSDUCERS APPLYING ANGULAR SPEED STEPS

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Abstract: The traceability of the torque quantity finds a gap when there is a regime with torque variation rates, once the traditional calibration methods define the references to be of null torque variation (static) or of low torque rate (continuous). This paper presents a method for providing torque traceability to rotating sensors under higher torque variation rates. The principle is presented and then followed by the method description for obtaining the calibration results.

Keywords: Dynamic torque, Torque metrology, High torque variation rate, Torque transducer, Angular acceleration.

1. INTRODUCTION

The current traceability for torque transducers used in dynamic applications is based on both static proceedings and static standard systems. However, in regimes where it is important to have the measurement of torque during periods with high variation rates, there is a demand for different patterns.

The traditional calibration standard [1] defines the reference value as a completely static one, coming along with a large period of stabilization during the load sequences. Although there is no detailed proceeding on how to apply or to generate it, [1] also presents the continuous calibration method, an alternative to the static one, what can reduce the total calibration time in 1/10.

However, rapid changes in torque values cause unwanted effects on transducer behaviour such as creep phenomena and high reversibility errors, beyond the necessity of the equipment to be able to detect these fast readings [2]. A critical torque rate of around $17 \text{ N}\cdot\text{m}\cdot\text{s}^{-1}$ is found in [3] where the linearity deviation results are totally disturbed, which is attributed to dynamic effects and that could not be followed by the simple continuous proceeding. In [4] it is shown that the different digital filtering parameters and the rates of torque application influence directly on the stability of the readings.

First approaches to the traceability of dynamic torque were presented in [5, 6], where an oscillatory (sinusoidal) regime was applied together with the frequency domain analysis of data, and also presented in [7], where complementary dynamic interpretation is applied to the transducer's common static calibration results.

The method proposed in this paper was first introduced in [8] where the principle of applying reference dynamic torque (T) to the transducer through the acceleration ($\dot{\omega}$) of a part (body) with a known mass moment of inertia (θ) is basically described, as summed in equation 1.

$$T = \theta \cdot \dot{\omega} \quad (1)$$

In a rotating shaft, the dynamic regime proposed corresponds to the acceleration period between two angular speed values (speed step). With the speed signal measured, acceleration data can be reached through its differentiation, as shown in Figure 1.

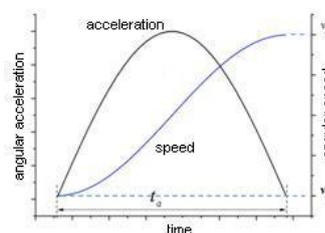


Figure 1. Angular speed step corresponding to an acceleration ramp

This period of acceleration presents high torque rates and to develop strategies for reaching the torque traceability during this regime is the challenge proposed by this research.

2. METHODOLOGY

The proposed method should (a) identify a time dependency of the quantity, (b) prioritize the application of torque rates, (c) evaluate the differences between the values read in the transducer (calibration curves) and those generated in the reference, (d) evaluate hysteresis between regions' different direction loading, (e) evaluate the susceptibility to different kinematic conditions, (f) occur throughout the range of application of torque and (g) assess reproducibility in sequential loadings.

A sequence of operation is proposed in order to get a logical path to reach the proposed torque profile and the range of stimulations necessary to better evaluate the sensor under different kinematic conditions. Figure 2 shows the proposed mechanical system including a driver (electric

motor), the transducer and the inertial shaft, which depending on the configuration can reach different reference values of mass moment of inertia.

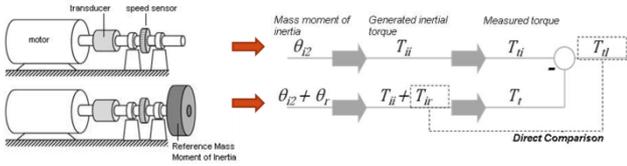


Figure 2. Assembly with the sensor in line with different configurations of inertia

Figure 3 shows the sequence of operation of this system to get sequential loadings varying the conditions of inertia and accelerations.

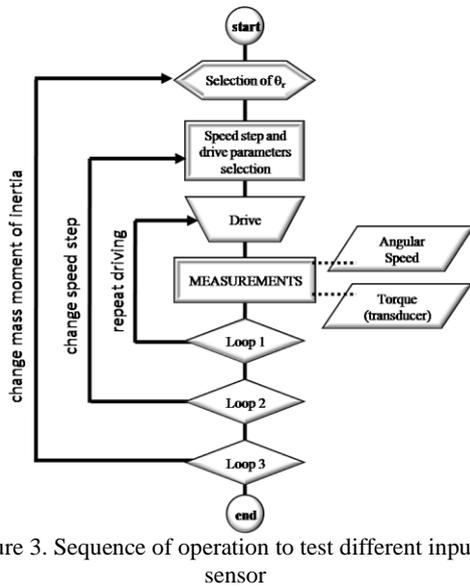


Figure 3. Sequence of operation to test different inputs to the sensor

Two methods of analysis are proposed based on the relation between the quantities involved.

The first method is called "direct calibration" and uses equation 2 to evaluate the results, comparing a reference torque (T_{ir}) to the measured torque value at the transducer (T_{tl}), all based on a time indexation i .

$$E_{(i)} = T_{tl(i)} - T_{ir(i)} \quad (2)$$

The second method is called "indirect calibration" and deals with relation between the reference acceleration and the torque value measured at the transducer, where equation 3 is a re-arrangement of equation 1. Equation 3 relates the calculated slope (θ_s) to the reference mass moment of inertia (θ_r) of the disc attached to the measured shaft.

$$\theta_s = \frac{T_{tl}}{\dot{\omega}} \quad (3)$$

$$E_{\theta} = \theta_s - \theta_r \quad (4)$$

Equation 4 shows the evaluation of results considering these two quantities.

3. PRELIMINARY RESULTS AND DISCUSSION

Figure 4 shows the error results of the direct calibration method for two inertial disc conditions (D20 and D40) and same acceleration profiles.

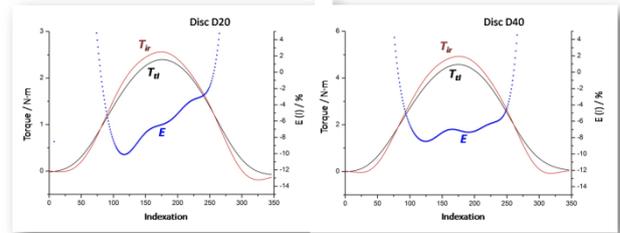


Figure 4. Error result according to the method of direct calibration

Figure 5 shows the graphical interpretation of equation 4 for the two conditions of discs of inertia while Figure 6 highlights the evaluation of linearity using the same data measured from the second disc.

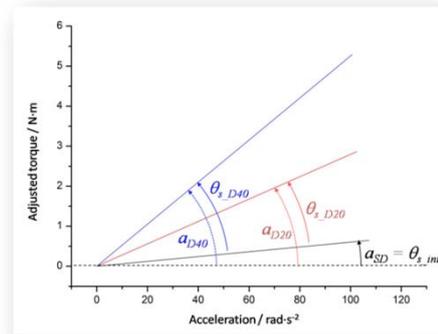


Figure 5. Relations between the calculated angular coefficients

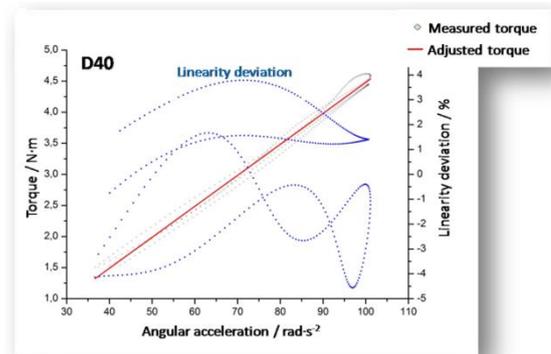


Figure 6. Linearity deviation for the D40 inertial disc

In the fullpaper a more detailed description of the methodology applied to the loading experiments and how to reach these results will be shown, together with a deeper discussion about the methods presented and how to better introduce them into a calibration result of a sensor, complementing the static information.

The paper gives focus to the needs of better evaluating, in the time domain, those regimes of torque with the variation of the quantity.

With this experiments, the physical principle was validated and due to the equipment used a torque rate of $17 \text{ N}\cdot\text{m}\cdot\text{s}^{-1}$ was reached. The direct calibration method showed the temporal dependency of errors and the indirect method evaluates hysteresis and linearity deviations to the principle.

Inertias and accelerations are combined to give different torque load profiles, where calibration results are complex and evaluable through a matrix relating the analyzed parameters and the applied load profiles. The direct and indirect calibration results can join the same "calibration report".

4. REFERENCES

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