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A NEW PROPOSAL FOR THE DYNAMIC TEST OF TORQUE TRANSDUCERS

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Abstract – This paper presents a new proposal for the dynamic test of torque transducers. The measurement methodology is presented in order to reach traceability in an angular acceleration regime of the measuring shaft. Different approaches to reach a test result are presented. A brief description of the assembly and methodologies applied are followed by the results of preliminary tests.

Keywords: Dynamic torque measurement; Torque metrology; Dynamic traceability; Torque transducers.

1. INTRODUCTION

In the current international traceability chain of torque measurement, dynamic torque transducers used in rotational regimes, such as engine test benches, turbines, power generators, brake testers, and electric and pneumatic fasteners, have tracked their calibration to static standards. This constitutes a gap in the traceability chain for the measurement, providing an opportunity and need for new research applications. Research on the dynamic traceability of torque has been done with different approaches, such as presented in [1-4].

The calibration methodology proposed in this article is based on the generation of a reference torque value by measuring the angular acceleration applied to a rotating inertial body attached to a measuring shaft to which the transducer under test is coupled.

The equation governing a generated reference torque is based on Newton's first law adapted to rotation, described by (1).

$$\tau = \theta \cdot \dot{\omega} \qquad (1)$$

Where τ is the inertial torque, θ is the mass moment of inertia and $\dot{\omega}$ is the first derivative of the angular speed, which corresponds to the angular acceleration.

There is the controlled speed step profile which will generate the acceleration impulse ramps. The different combinations of acceleration and mass moment of inertia values generate a range of reference torque curves [5, 6]. Inside the methodology, different approaches can be applied to the interpretation of data and the different calibration results and uncertainties of measurement are reached.

2. MATERIAL

In Fig. 1, there is shown the measurement assembly used to apply the principle and present the data evaluation methodologies proposed. The acceleration is applied by an electric AC motor and the angular velocity is controlled by a driver control. The measuring axis is primarily composed of the device under test (DUT) which measure the torque signal and also the speed, with an optical encoder incorporated. Attached to the DUT and supported by two bushings there is the inertial axis with the bending reference inertial body. Torque and speed data are acquired by the same DAQ system, which guarantees there will be sufficient synchronization between the quantities. Acceleration is calculated offline by the differentiation of the speed data.

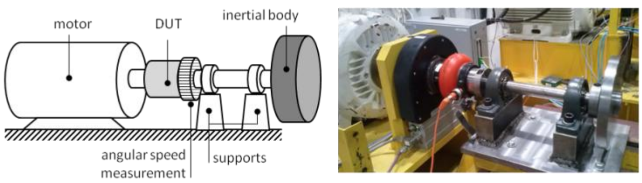

Fig. 1. (left) Sketch assembly for testing the proposed principle; (right) Test bench with transducer and disc mounted.

3. MEASUREMENT PRINCIPLE

The proposed dynamic regime, with acceleration and deceleration regimes during the application of one defined speed interval and the corresponding torque responses, is shown in Fig. 2. Two torque values are obtained: the net value measured by the torque transducer (τ_M), which is the output signal based on the sensor's nominal sensitivity obtained from its previous static calibration and the reference inertial torque (τ_R), evaluated from the acceleration of the reference inertial bodies (θ_R).

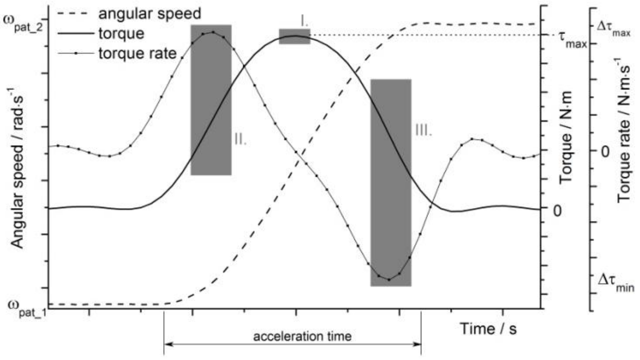

Fig. 2. Speed step applied for the inertial reference torque with torque curve and torque rates curve shown.

From [5] the torque curve response from τ_M can be evaluated in three different regions as shown in the grey areas of Fig. 2: Region *I* refer to the torque peak, a more stable data area, while Regions *II* and *III* refer respectively to the highest torque rates for increment and decrement of the torque curve, where data has larger dispersion.

Intrinsic to the graphic we can expect for contributions originated by some mechanical and data acquisition parameters [7] to the evaluation of the torque response such as: the differences between measured torque and inertial torque in the different areas, differences from regions *II* to *III* indicating some mechanical hysteresis, influence from the data processing method and from the controllability of the drive control unit. This research tries to put together these main propositions with the necessity of testing the concept used by the physical principle. In the sequence there are the three different approaches to calculate some proposed calibration results.

The driving was applied through three sequential speed steps in the nominal speed interval from 157 rad·s^{-1} to 209 rad·s^{-1}, a regime of peak acceleration of 163 rad·s^{-2}, for zero torque and then at nominal peak torque of about 8.0 N·m generated by the coupling of an inertial reference disc with a nominal net θ_R of 0.04957 kg·m^2. The data acquisition rate used was 50 Hz and both speed and torque signals were filtered with identical low pass Bessel type with 20 Hz cut-off frequency.

3.1. Direct comparison of torque curves (torque deviation)

If there is a association between τ_M and $\tau_{R,}$ the result will appear as a direct torque comparison. This parameter must be done point by point of the synchronized curves. The calculated torque deviation E appears like in (2).

$$E(i) = \bar{\tau}_R(i) - \bar{\tau}_M(i) \qquad (2)$$

Where i is the time index for the synchronized ramps, i.e. the instant of the curve where the deviation is calculated. Table 1 shows the values calculated for the reference inertial torque through a range of selected indexed intervals from the whole driving period. The different regions are identified and each index interval corresponds to a period of 0.02 s, equivalent to the 50 Hz acquisition rate.

The torque rate ($\Delta\bar{\tau}_R$) indicates how dynamic is the measurement process and identifies similar regimes on both sides of the torque curve. The increasing tendency of the relative E is a result from the calibration and can indicate a difficult that the sensor has to follow the dynamic torque applied during the acceleration regime.

For the hysteresis evaluation, indexed points referring to a same nominal torque can be compared. For example, #5 and #11 correspond respectively to 7.477 N·m and 7.540 N·m, which are nominally very close values, but the relative torque deviation jumps from 0.13% to 0.40%. This can be interpreted as a dynamic hysteresis indication.

Peak value is highlighted (index #8) and it is possible to check a almost null torque rate for that point.

Table 1. Reference and measured torques and the referred torque deviation.

#Index		$\bar{\tau}_R$ / N·m	$\bar{\tau}_M$ / N·m	E / N·m	$E/\bar{\tau}_M$ / (%)	$\Delta\bar{\tau}_R$ / N·m·s^{-1}
Region II	0	4.118	4.105	0.012	0.30	---
	1	4.981	4.973	0.008	0.17	41
	2	5.781	5.776	0.005	0.092	37
	3	6.479	6.475	0.004	0.064	31
	4	7.049	7.043	0.006	0.081	25
	5	7.477	7.467	0.010	0.13	18
Region I	6	7.765	7.748	0.017	0.21	11
	7	7.923	7.900	0.024	0.30	5
	8	7.970	7.940	0.030	0.38	-0.1
	9	7.919	7.886	0.033	0.42	-5
	10	7.778	7.744	0.033	0.43	-10
Region III	11	7.540	7.510	0.030	0.40	-15
	12	7.189	7.164	0.025	0.35	-21
	13	6.704	6.684	0.020	0.31	-28
	14	6.070	6.052	0.018	0.29	-35
	15	5.286	5.269	0.018	0.34	---

3.2. Evaluation of the calculated mass moment of inertia

The obtained values of τ_M and $\dot{\omega}$ can be combined to generated a so called calculated mass moment of inertia (θ_c). From (1) it would be expected that this value should be constant for the whole driving regime, but that is not what happens [6]. Equation (3) shows this crossed relation of reference and measured quantities to calculate a third one to be analysed.

$$\theta_c(i) = \frac{\bar{\tau}_M(i)}{\dot{\omega}(i)} \qquad (3)$$

Differently from the previous approach, now the results represent only constant quantity, which should correspond to the inertia values of the reference bodies θ_R.

This approach allows the data measured to be evaluated for each instant *i*, for each ramp, for the group of the three ramps or for the specified interesting regions.

In table 2 there are presented the θ_c values for the different regions and also the parameter considering all data in the curve. It is possible to see that the value θ_c in the peak region gives a good representation of the whole curve.

Table 2. Means for θ_c on each region.

	Total	Region I	Region II	Region III
θ_c / kg·m^2	0.04941	0.04940	0.04950	0.04933

From this table it is also possible to observe that, as it happens with E, there is a tendency in the data. At the begining of the curve (region II), θ_c is closer to θ_R than on the descendent side (region III).

3.3. Linear fitting

Similar to the previous approach, the linear fitting gives a more general and fast idea of the behavior of the sensor once it uses, through computational tools, all pairs of $\bar{\tau}_M(i)$ and $\dot{\boldsymbol{\omega}}(\boldsymbol{i})$ from the data results.

The calculated θ_c reached a value of 0.04942 kg·m^2, coherent with the total mean value from previous approach. Fig. 3 shows all data together with the fitted line (red).

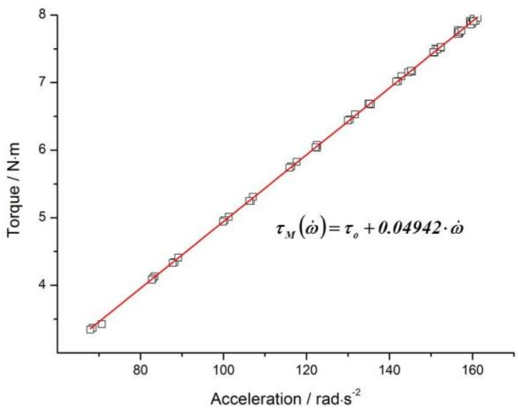

Fig. 3. Linear fit for all data.

4. UNCERTAINTY OF MEASUREMENT

The diagram in Fig. 4 presents the main identified contributions for the evaluation of the uncertainty of measurement dealing with τ_M, τ_R and $\dot{\omega}$.

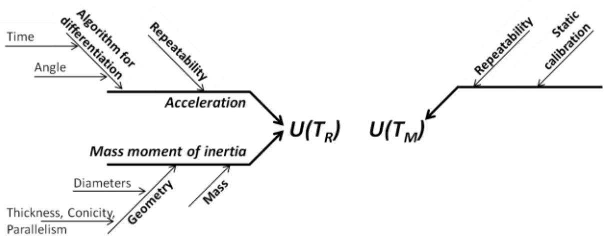

Fig. 4. Main contributions for the uncertainty of measurement.

Table 3 shows the type B contributions for the uncertainty parameters. The graph in Fig. 5 shows the combined and both types A and B of standard uncertainties for each indexed point of the torque curve. This can be applied for the direct comparison method while the uncertainty values showed in graph of Fig. 6 gives a better idea of how to treat the uncertainty evaluation in the approach of calculating the mass moment of inertia.

Table 3. Contributions for the uncertainty of measurement.

Quantity	Nominal	Standard uncertainty (u)
External diameter	0.2 m	2.50·10^{-07} m
Internal diameter	0.038 m	2.50·10^{-07} m
Mass	9.56905 kg	2.50·10^{-05} kg
θ_R	0.04957 kg·m^2	1.43·10^{-7} kg·m^2
Encoder uncertainty	0.034907 rad	0.017453 rad
Time (acquisition)	0.02 s	5.773·10^{-10} s

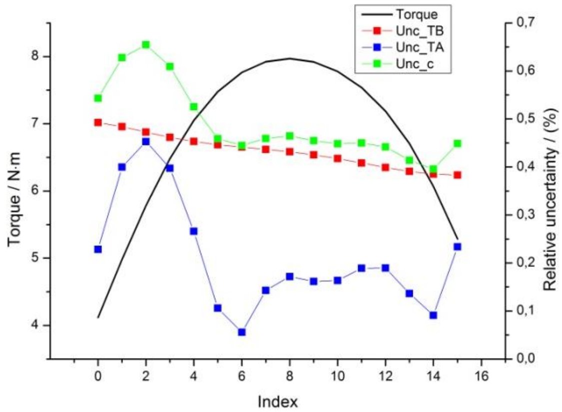

Fig. 5. Uncertainties of measurement of the reference torque (τ_R).

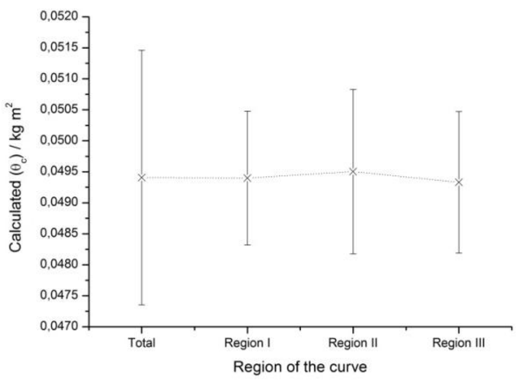

Fig. 6. Uncertainty of measurement of the calculated mass moment of inertia (θ_c).

5. CONCLUSIONS

The principle of generating an inertial torque based on the product of the mass moment of inertia and acceleration quantities showed promising to serve as a reference value in the dynamic test of torque transducers.

An acceleration regime is proposed and an test assembly is constructed. The metrological evaluation of these magnitudes are held. Conclusions lead to the dependence of the responses of the sensors on the characteristics of the drive such as the torque rates, the maximum nominal torque values reached and the acceleration profile applied.

Three different approaches are shown in order to interpret the measured data and show a result of the proposed test. The application of identical digital filters allows the direct comparison of synchronized torque values.

Future work should note the need to apply different regimes and improve the adaptation of the test assembly of the standard in a more practical and comprehensive measurement methodology.

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