Dynamic Traceability for Force and Torque at Inmetro

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Abstract: The demands for increasing reliability in the dynamic measurements used in the industry are growing. These abroad several quantities in different areas of metrology, but more emphatically in the mechanical ones. For the last years, the Laboratory of Force at the Brazilian National Metrology Institute (Lafor/Inmetro) is working on the development of the dynamic traceability for the quantities force and torque. The proposals are presented, together with brief discussions based on the experience achieved with the experiments carried out in the lab.

Keywords: Dynamic Force, Dynamic Torque, Traceability, Dynamic measurements.

1. INTRODUCTION

In all fields of industry, the dynamic measurements are playing the majority of applications. However, the traceability of the sensors is provided statically, what generates a gap in the metrological chain for some quantities.

The force and torque fields are facing this challenge and there are current proposals and investigations going on at the Force Laboratory of the National Metrology Institute of Brazil (Lafor/Inmetro) on searching for new principles, methodologies and reference systems in order to reach dynamic traceability.

Both quantities have very similar principles for their realization and consequently, historic of development very close. The Technical Committee TC3 of the Imeko, for instance, works with both quantities together and there was created a specific session for the discussions around the dynamic traceability of these quantities.

The paper presents a compilation of proposals currently running at Inmetro. Although there are no details about the specific and numerical results of the experiments, the main objective is to bring a milestone to the last years' chronogram where the dynamic traceability for force and torque is being studied in the Brazilian NMI.

1.1. What is a dynamic measurement regime?

A dynamic regime can be define in terms of characteristics directly comparable to the static profiles. Following, these main characteristics of a dynamic regime are identified:

- High variation rates (transients)
- Transducer is moving in space (angular or linear displacements)
- Needs for higher acquisition rates and digital filtering
- Usually another quantity is necessary for the description of the regime (acceleration, speed, frequency)

2. DYNAMICS FOR FORCE

Inmetro is working on the application of a methodology described in the Standard ISO 4965 [1] for the calibration of the uniaxial force of fatigue test machines. According to the standard, dynamic errors of the force experienced by the test-piece come from the result of the inertial forces acting on the load cell of the machine and any dynamic errors in the electronics of the force indicating system.

The calibration parameters are defined by the frequency range, the force range, the directions of the force (compression or tension) and the compliance of the assembly. Once defined the force amplitude, for each frequency, a number of dynamic cycles is applied and the values for peaks and valleys of this amplitude are acquired.

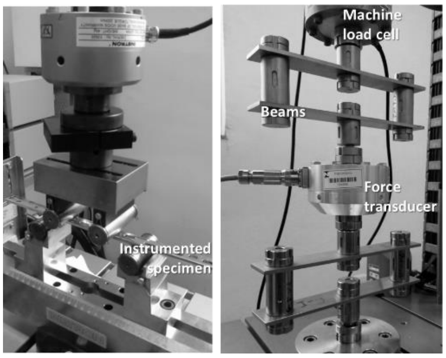

Figure 1 – The different types of DCD coupled to uniaxial fatigue machine.

The calibration reference system contemplates a force sensor, denominated Dynamic Calibration Device (DCD), which is used as reference value for the calibration of the machine's load cell. The DCD shall be able to produce an electrical signal proportional to the force applied on the machine under some specific mechanical condition. There are two main types of DCD (Figure 1): (a) the instrumented replica of a specimen, which has a constant compliance and (b) a device that can have changeable compliances.

The standard defines two methods of calibration, which were carried out at Inmetro: Method A realizes the calibration of the machine in a specific value of compliance and the results of the force indication error is applicable only for this value of compliance; Method B realizes the calibration of the machine involving different values for compliance.

2.1. Method A of ISO 4965

In the first experiments [2], a DCD of an orthopedic implant plate-type was instrumented (Figure 1-left) and Method A was applied.

The dynamic cycles were applied in the machine, both signals of force were measured in the load cell of the machine (F_i) and in the DCD (F_{DCD}) under a defined force amplitude (peaks and valleys) and a frequency range. The correction factor (c) could be calculated as equation 1.

$$c = \frac{\Delta F_{DCD}}{\Delta F_i} \qquad (1)$$

If c is within the intervals [0,90 0,99] or [1,01 1,10], the force signal F_i can be adjusted in order to reduce this to an equivalent error of less than 1%.

The experimental results in [2] showed that the machine under test had, as theoretically expected, an increase in the correction factors following an increase in the frequency range. However, they were not above 1%. It was also concluded that the standard's methodology needed to pass through some revision where referring to the manipulation of the specimen and the maintenance of the load during the whole process.

2.2. Analysis of the DCD design

Inmetro proposed the use of a force transducer and two pairs of beams, to give compliance to the assembly, to compose the DCD design. Figure 1-right shows the used DCD coupled to the uniaxial force test machine. In [3], it was presented an analysis on this design of DCD with different studies applied to it. Different studies and experiments identified some important points as follow:

- ✓ The DCD compliance calculated theoretically, for example in FEM models, must have an experimental checking;

- ✓ Modal analysis is interesting to do if the calibration will run in higher frequencies (> 100 Hz);
- ✓ The alignment in the transmission of the vertical force is hard to be verified, but important mainly for DCDs with high displacement (check design)

2.3. Method B of ISO 4965

In Method B, there is the evaluated compliance envelopment extremes, defined by the compliance of two DCDs. The parameter calculated to compare the force readings, measured in each DCD and frequency values, is the indication error (e), according to equation 2. No correction factor is applicable and the results are interpreted if acceptable ($e < 1\%$) or not acceptable ($e \geq 1\%$).

$$e = \frac{(\Delta F_i - \Delta F_{DCD})}{\Delta F_i} \qquad (2)$$

The experiments reported in [4] highlighted some important points for a correct and reliable measurement proceeding:

- ✓ Necessary a stabilization period, different for each frequency (Figure 2);
- ✓ Precise algorithm for isolating the peaks and valleys (large mass of data);

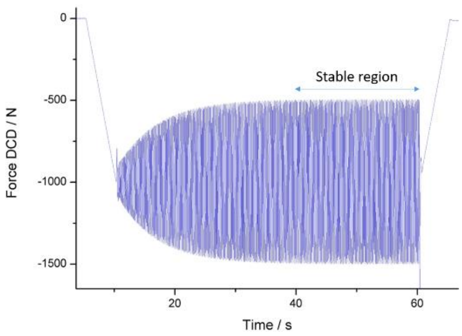

Figure 2 – Stabilization period in the force data measured.

In these experimental results, for example, interpreting figure 3 means that, the machine should not be available for testing specimens with compliances higher than that of the DCD#2.

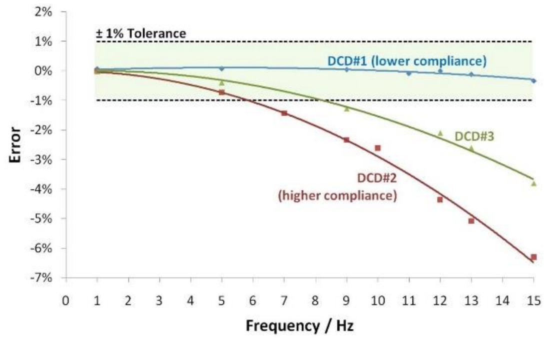

Figure 3 – Indication error for three DCDs with different compliances.

3. DYNAMICS FOR TORQUE

The dynamic traceability of torque is under research at Inmetro. The proposed principle adopt the Second Newton's Law applied to rotational movements, when the reference inertial torque (T_R) is generated by an angular acceleration ($\dot{\omega}$) is applied to a known mass moment of inertia (θ) attached to the torque transducer under calibration [5].

$$T_R = \dot{\omega} \cdot \theta \qquad (3)$$

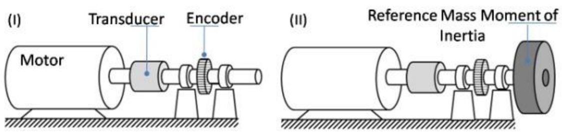

Figure 4 – Assembly for the generation of (I) the tare inertia torque and (II) the reference inertial torque.

The load profile is similar to the pulse and there it is possible to evaluate the behavior of the torque transducer under high torque rates. The proposed assembly is identified in figure 4.

The acceleration profile is applied during angular speed steps driven by the electric motor. Figure 5-left shows the speed step graph and the inertial torque generated (pulse) during the acceleration period. This graph also gives an idea of how is the entire proceeding, when the measurement shaft is driven with sequential steps, being accelerated and then decelerated. Different combinations of mass moments of inertia and accelerations can generate a vast range of torque profiles. The capacity of a system to reach high torque rates will depend on the capacity of the electric motor to accelerate the shaft within its limits of maximum acceleration torque.

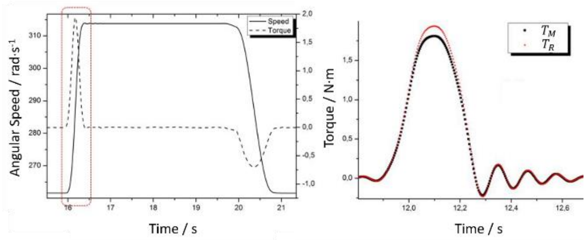

Figure 5 – (left) Angular speed step and inertial torque pulse; (right) Measured torque and reference inertial torque.

The calibration torque curve is characterized with well-defined parameters such as the peak torque, maximum torque rate, acceleration or deceleration, and clockwise or anticlockwise.

During the acceleration period, both acceleration and the torque measured by the transducer (T_M) were acquired. Post processing is important for the filtering of the signals and synchronization of these curves (Figure 5-right). After synchronization, with indexation in "i", the indication error (E_i) can be calculated, according to (4), for each nominal point in the load curve.

$$E_{(i)} = \bar{T}_{M(i)} - \bar{T}_{R(i)} \quad (4)$$

This calibration proceeding is complementary to the static calibration, so it is important to highlight that it is not a substitutive proposal.

4. OUTLOOK

The traceability for force and torque are still on the research levels. The dynamic calibration of fatigue machines is more advanced and Inmetro is joining a research project at the Interamerican Metrological System (SIM) called "Industrial Dynamic Measurements", involving NIST, INTI, CENAM and INM, and with the main objective of researching different forms of realizing dynamic traceability to dynamic force applications.

Dynamic torque traceability is still in the bases of research. The method proposed by Inmetro is different from the others presented by PTB, when the first deals with the analysis in the time domain and the last evaluates oscillatory excitation in the frequency domain. The demands for better understanding the behavior of the sensors during dynamic use are growing and the use of static calibration results is being more questionable each day.

References:

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