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METROLOGICAL CHARACTERIZATION OF A TORQUE SHAFT USED IN A MICROTORQUEMETER

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Abstract. *This study was conceived to characterize the torque bar of an equipment aimed for studies of threaded fastening elements, specially the evaluation of torque applied on dental implants during its insertion. The calibrated equipment with well-defined and substantiated methodologies, made possible the characterization of some parameters of the measurement system with metrological rules. This procedure generates more knowledge about the equipment and the torque measurement processes, adding know-how to the development of new micro torque measurement system.*

Keywords: *Micro torquemeter, torque characterization, BS 7882, torque bar, torque transducer.*

1. INTRODUCTION

The control of the tightening torque of threaded elements (nuts, bolts, etc.) is an important factor in the equipments used in the industry, since, if properly used, they guarantee the repeatability of the tightening of the fastening elements, in the assembly lines of machines and equipments. Torquemeters are already widely available and used in the automation market. On the other hand, there are areas where tightening of threaded elements must be performed with equal care, but with very low torque values to prevent the destruction of the substrate or the element itself, as in the case of fixation of orthopedic implants and especially dental implants. In the case of the dental implants, they must be tightened to torques between 0 Nm and 1 Nm (Mucsi et al., 2014)

In implantology there are torque patterns for the different phases of the rehabilitation, if these torques are superior or inferior to the predetermined limits, it would bring unfavorable results to the cicatrization. The stresses applied to the materials induce the deformation of the material (ARANHA et al., 2014). These deformations may be temporary (elastic) or permanent (plastic). The elastic deformation ceases when the applied force is removed. When the yield strain of the material is exceeded, the deformation become permanent, changing the physical and dimensional properties of the material. In order to avoid this, it is necessary to ensure that the equipment used for the application of torque to these threaded elements is functioning properly and with errors within the limits specified for the desired application. It ensures the fixation of the threaded elements, thus minimizing the risks in their use. On the other side, there are the threaded elements that also need to have their tightening and loosening characteristics tested for the application to which it was developed as well as the material in which it will be applied, ensuring proper functionalization of the component after assembly.(ARANHA et al., 2016)

One way of performing this measurement in the torque meter and checking the behavior of threaded elements is by using torque sensors, which are composed of strain gages coupled to a bar that will undergo torque stresses during the tests.

The measurement of macro stresses, through strain gages, is a process normally used in industry and research, in the development of processes. The torque applied at the end of a fixed point anchor bar can be measured by resistive extensometry. Torsion in the bar about its axial axis generates a longitudinal deformation. This elastic deformation (shear) occurs at 45° to the axial axis of the bar. This shear has behavior that obeys Hooke's law which relates the elastic deformation of a solid with the applied tension. In extensometry a correlation between Hooke's law and Ohm's law is used to obtain an indirect measurement of the deformation. Thus, it is possible to establish an equivalence between the amount of deformation generated by the applied torque and the variation of the electric resistance in the

strain gage. The strain gage must be associated with a Wheatstone bridge type electric circuit. From the elastic deformation, which is proportional to the variation of the electric resistance, we obtain a mV/V value linearly proportional to the micro strain ($\mu\epsilon$) (MUCSI et al., 2016)

2. EXPERIMENTAL PROCEDURE

The standard BS 7882 (BSi, 2008) and the Euramet cg-14 guide (Euramet, 2011) will be used as main references to define the test methodology in the characterization of the torque bar. They show in detail how to perform the tests on a torque meter and get concrete results for measurement performance. For the indication of the strain gage signal installed on the bar, the NI9235 module from National Instruments (NI) was used in conjunction with LabView software from the same manufacturer.

2.1 Characterization of measurement properties

The metrological characterization will define the sensor measurement specifications for the measurement range from (0 to 1) Nm in a static clockwise and counterclockwise torque regime. It will also relate the elastic deformation of the bar due to the application of torque load to the signals generated by the extensometer in mV/V. This will be done through a polynomial equation generated from the calibration of the system. In order to perform the measurements, it was necessary to study and develop a torque arm to apply the loads necessary for the characterization of the measurement system, to precisely determine the torque applied to the torque bar. Along with the torque arm, a set of calibrated weights were made, for application of controlled torque to the torque bars, as shown in Fig. 1.

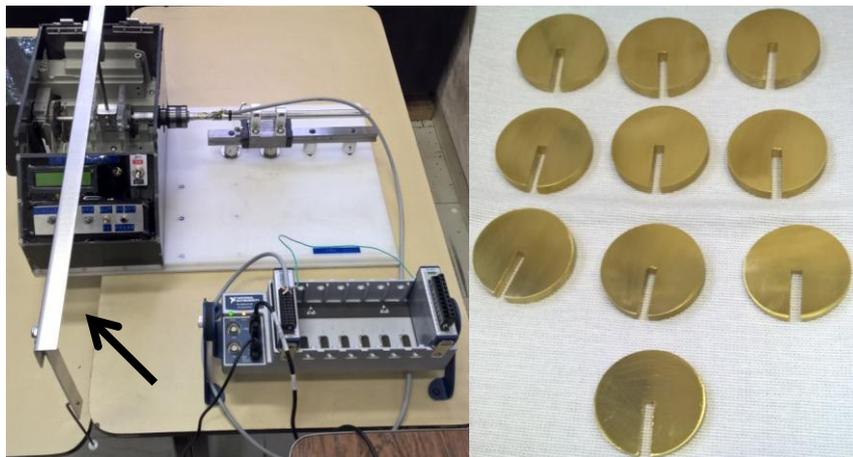


Figure 1. (a) Torque bar installed in the torque measuring system; (b) Set of weights

2.2 Calibration

The calibration was performed in a position defined as 0° and with preload in the measuring system with maximum torque. After registering the zero signal, without applied load, at least five increasing torques equally spaced from zero up to the maximum torque were applied. At the same points loads from the maximum torque down to zero were applied, as shown in Fig. 2. (BSi, 2008; Euramet, 2011; Robinson, 2008).

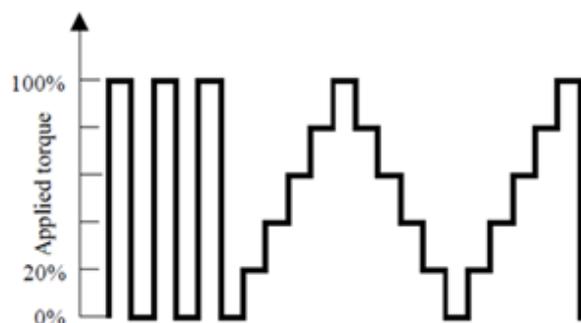


Figure 2. Illustration of the calibration process to be used (Robinson, 2008)

For the calibration process, it was plot of the nominal values (V_n) in newton x meter (N.m) against the values of the strain gage (V_m) in millivolt per volt (mV/V). The nominal values (V_n) are not real values (V_r), but values to which the real values (calibrated values) will be associated. The measurements of the sets were taken in both directions, increasing and decreasing the applied torque. (Euramet, 2011)

The nonlinearity/curve adjustment is obtained from the mean of the results of each calibration point calculated, thus determining the coefficients of a 3rd degree polynomial equation. It is the function of the calibration applied torque and the signal emitted by the extensometer. From the differences between the applied torque average and the calculated values in the polynomial adjustment equation, the nonlinearity value was determined as the maximum of the differences. It is expressed as a percentage of the significant deviation. Nonlinearity is determined from Eq. (1). (BSi, 2008; Euramet, 2011; Robinson, 2008).

$$Max \left[\frac{\bar{d} - d_{comp}}{d_{comp}} \cdot 100 \right] \quad (1)$$

where:

\bar{d} is the average deflection;

d_{comp} is deflection value calculated from the curve fit.

The repeatability is obtained in the calibration process, by adding a second series of torque loads in the torque bar, in zero degree orientation. Thereafter, a comparison of the differences in results between the two series of measures is made. The repeatability of the measurements is considered as the maximum value of the differences, and expressed as a percentage of the mean error of that point. Repeatability is determined from Eq. (2). (BSi, 2008; Euramet, 2011; Robinson, 2008)

$$Max \left[\frac{d_1 - d_2}{\bar{d}} \cdot 100 \right] \quad (2)$$

where:

\bar{d} is the mean deflection;

d_1 is the deflection from first series in the 0° mounting position;

d_2 is the deflection from second series in the 0° mounting position.

The hysteresis is determined by performing the calibration of the torque sensor with an increasing and decreasing series in zero degree orientation, determined from the results of the differences in the same point of torque between the increasing and decreasing series. The hysteresis is taken as the maximum difference of the measurement errors, being expressed as a percentage of the applied torque. Hysteresis is determined from Eq. (3). (BSi, 2008; Euramet, 2011; Robinson, 2008)

$$Max \left[\frac{d_1 - d'_1}{d_1} \cdot 100 \right] \quad (3)$$

where:

d_1 is the deflection for the incremental series;

d'_1 is the deflection for the decremental series.

3. RESULTS AND DISCUSSION

Table 1 shows the three measurement series taken, with applied torques and measured signals. Two of them $V_m 1$ and $V_m 3$ correspond to the increasing torques, while the $V_m 2$ the decreasing of the applied torques. For a calibration, 10 experimental points were performed. The nominal values (V_n) are the torques defined to be applied, in newton x meter (N.m), followed by the real values (V_r) obtained from the calibration of the applied weights. The measured values (V_m) in electrical signal in module NI9235, were obtained in millivolt per volt (mV/V).

Table 1. Results of the calibration procedure relating the nominal value (Vn) against the measured values both increasing and decreasing courses

Vn (N.m)	Vr (N.m)	Vm 1 (mV/V) (increasing)	Vm 2 (mV/V) (decreasing)	Vm 3 (mV/V) (increasing)	Mean value (mV/V)
0.0	0.00000	3.420	3.424	3.424	3.423
0.1	0.09810	3.435	3.438	3.439	3.437
0.2	0.19559	3.449	3.454	3.454	3.452
0.3	0.29349	3.465	3.469	3.470	3.468
0.4	0.38986	3.481	3.483	3.485	3.483
0.5	0.48654	3.496	3.498	3.499	3.498
0.6	0.58289	3.511	3.513	3.514	3.513
0.7	0.67804	3.526	3.527	3.529	3.527
0.8	0.77333	3.541	3.542	3.543	3.542
0.9	0.86635	3.555	3.555	3.557	3.556
1.0	0.96042	3.570	3.570	3.572	3.571

Figure 3 was generated from the calibration data, and the electric signal obtained without the application of torque was taken as zero, therefore, the signal was taken as indicated value minus the signal without applied load. Thus it is possible to better visualize the relationship between applied torque and the resulting signal, where we observe a linearity in the calibration curve.

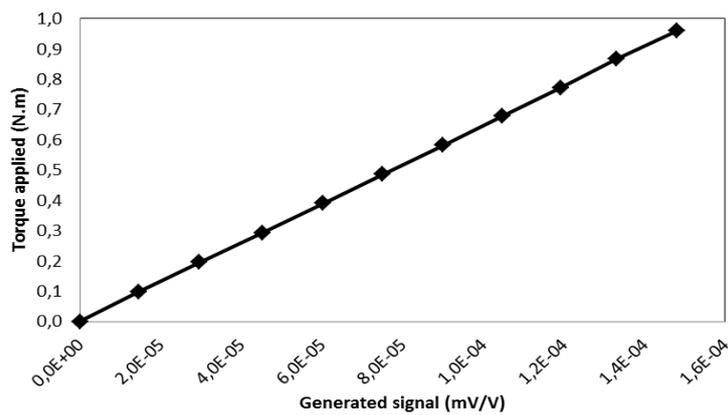


Figure 3. Calibration curve

From the results obtained in the calibration it was possible to quantify the percentages of deviations due to non-linearity, repeatability and hysteresis of the measurements, reaching the following results, Tab. 2:

Table 2 - Characterization results

Non-linearity deviation	1,6%
Repeatability deviation	0,05%
Hysteresis deviation	0,14%

The calibration exhibits a linear behavior for both increment and decrement torque loads. This is a unique behavior, due to the method how the prototype equipment was designed and built. Some constructive parameters were not fully evaluated (for example, bar fixation, the weight of the measuring device and strain concentration profiles), which are non linearities in the measurement system.

Due to the way the prototype equipment was built, it was not possible to carry out further tests, which quantified the characteristics of the equipment with more detail, such as reproducibility and bending effect.

4. CONCLUSIONS

In the literature, it was identified other tests that could be performed in order to complete characterize a torque bar, however performing those tests would not be possible due to the design of the prototype equipment. The consequence of

the above is that the complete evaluation of the measurement system was not predicted, due to the mechanical and construction characteristics of the prototype characteristic. Otherwise, the results of this work are consistent with the capabilities of the current prototype project. It was not possible to perform the reproducibility test, bending effect, torque alternation and bending rigidity.

To overcome the geometrical obstacle to characterize and operate the equipment, a fully new design is being developed that will allow the complete metrological characterization and thus, perform a calibrated and reliable micro-torque measurement. For this the new equipment will allow to perform afore mentioned tests: reproducibility test, bending effect, torque alternation and bending rigidity. With the development of the new micro-torque meter, its construction and measurement characteristics will be studied in order to improve its performance thus meeting all test requirements in BS 7882 and Euramet Guidelines for a complete characterization of the measurement system

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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