A COMPARISON BETWEEN THE NBR 12240:00 AND OTHER STANDARDS FOR TORQUE CALIBRATION - IT IS TIME FOR A CHANGE

Rafael Soares de Oliveira[1], *Luis Carlos Cabral de Freitas*[2], *Cláudio Afonso Koch*[3]

[1] Inmetro, Rio de Janeiro, Brasil, rsoliveira@inmetro.gov.br
[2] Inmetro, Rio de Janeiro, Brasil, lccabral@inmetro.gov.br
[3] Inmetro, Rio de Janeiro, Brasil, cakoch@inmetro.gov.br

Abstract: The main purpose of this paper is to show how the NBR 12240 standard is attending the demands for torque transducer calibration. By comparison with the other international standards DIN 51309 and BS 7882, it is possible to observe how the national standard is far from the current characterization needs of a torque transducer and clarify what proposes can change this figure.

Keywords: torque calibration, standardization, NBR 12240, BS 7882, DIN 51309.

1. INTRODUCTION

Nowadays in Brazil, the standard guide used for torque transducer calibration is the same as ten years ago (NBR 12240:2000 [1]), it means, for example all calibration series, load and unload sequences, coupling instructions and classification proceedings are the same.

But, it is clear that torque measurement instruments had developed, from their functional principles to the quality of the product, and every year the industry interprets torque measurements in a more refined point of view. So, a better traceability in the quantity becomes an important actor in this process.

Traceability can be understood by the existence of two main conditions: (a) there must be standard equipment capable of generating torque values with a well known reliability level, (b) there must exist updated standard guides with the most coherent proceeding to disseminate these generated torque values to other equipment and instruments.

To satisfy the first condition, the Brazilian National Metrology Institute - INMETRO - installed a primary standard for torque transducer calibration in the ranges of 20 Nm to 3000 Nm, with a characterized Best Measurement Capability of 100 ppm [2].

But there is still a gap in the second condition about the proceeding guide because the calibration standard presently used in Brazil, NBR 12240, was published about ten years ago as a translation of the BS 7882:1997.

So the next topics will present some results of a comparison between the NBR standard and the actual international standards in use for static calibration of torque transducers, the British standard (BS 7882:2008) [3] and the German standard (DIN 51309:2005) [4, 5].

The comparison approach will cover the main fields of a torque standard guide, with the main purpose of defining what will be the next revision steps for adapting the Brazilian torque traceability to the actual and current metrological requirements of the quantity.

2. METHODOLOGY

The comparison methodology will contemplate the most important points of a torque transducer calibration proceeding.

First, a look in the pre-requisites of the instruments is very important to see if there are significant differences between the pre-proceedings.

After the analysis of the pre-requisites, it is time to look for the main differences in the loading sequences, what brings the mainframe of the study. The newer standards make a relation between the types of transducer and the sequence of loading applied.

The last comparison item is about the calculation of the calibration results, classification and uncertainty of measurement. For this purpose, three calibrations will be done, using the different standards, to one high quality torque transducer.

The measurements were made using two different types of transducers, one with square connector and range of 200 Nm and other with better quality, round shaft and range of 100 Nm.

Measurements are done for each transducer, and data are analyzed according to each standard. The measured values are the same for both standards so, some parameters can be calculated according to each standard but using the same database.

3. PRE-CALIBRATION ITEMS

This item will highlight the two more different items on the pre-calibration proceeding, being the load sequences and the torque calibration points to be measured.

All other items as resolution definition, identification and pre-conditions of equipments to be used, substitution of the digital display amplifier, pre-load sequences, alignment warnings and temperature working range are pretty much the same within the three standards.

3.1. Definition of load sequences

Both international standards have a specific annex bringing the load sequence to be applied according to the class expected for the transducer, while the NBR standard has only one minimum required load sequence. The figure 1 shows an example of these pictures for a class 0.1 transducer with round shaft.

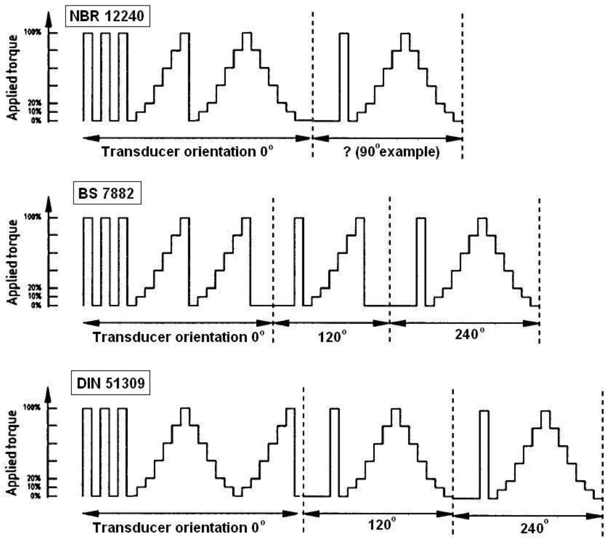

Fig. 1. Load sequences for a class 0.1 transducer, round shafts and hysteresis series.

As it can be seen, there are some differences that will result in different results, as it is shown in section 4.

The NBR standard does not make distinction between different types of transducers and determines that at minimum one change must be done to the position of the transducer. For hysteresis evaluation, two decreasing series are done.

The BS standard determines that three different mounting positions should be done and test hysteresis only in the last mounting position.

The DIN standard also determines three different positions and hysteresis is done in all of them. This is really significant because, as it will be shown forward, the decreasing values are used to calculate the reference of the point under calibration.

These same differences happen to other types of transducers, which will depend on the principle of coupling and the class to be achieved. For example, the square drive connector transducer, with expected class 0.5 or 1, will have the same NBR shape of load sequence of the figure 1 but different for BS and DIN, where appears four mounting positions but BS maintain only decreasing measurement in the last position.

3.2. Selection of Calibration Torques

Both standards, NBR and BS do not specify the number of points to be measured in the range, only a minimum of five points is required, independent of the transducer type or class.

The DIN standard determines some ranges depending on the class of the transducer, as shown below:

- *classes 0.05 and 0.1:* 8 pts (10, 20, 30, 40, 50, 60, 80 and 100 %) or (2, 5, 10, 20, 40, 60, 80 and 100 %)
- *classes 0.2 and 0.5:* 5 pts (20, 40, 60, 80 and 100 %)
- *classes 1, 2 and 5:* 3 pts (20, 60 and 100 %).

The load sequences and the steps defined have a strong influence in the time spent for doing a calibration. For example, if comparing the time spent for doing a square connection transducer calibration, it will take two times more to calibrate with DIN (four mounting positions with decreasing torque) than with NBR (two mounting positions).

4. CALIBRATION RESULTS

Measurements were done for both transducers:

a) TT1 : 200 Nm, square connection, developed in Lafor, amplifier HBM DK 38

b) TT2 : 100 Nm, round shaft connection, Raute Precision, amplifier HBM DMP 40

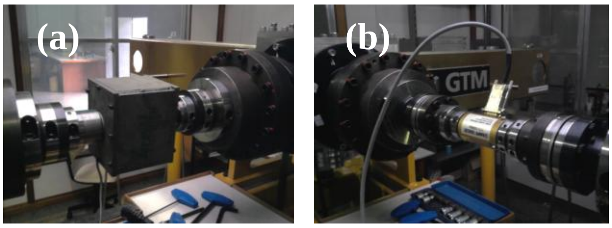

Fig. 2. Transducers TT1 (a) and TT2 (b) mounted on the primary torque standard of Lafor/Inmetro

The parameters for calibration results, calculated according to each standard, were:

- Repeatability
- Reproducibility
- Residual deflection (zero)
- Interpolation values for linear and 3rd degree curves
- Reversibility
- Classification
- Uncertainty of measurement

From these parameters, some had severe modification depending on the standard and others remain very close. As there are too many data, the most important differences will be shown here and other analysis will appear as a general comment.

To make easier to the reader, analysis and comparison will be divided for each parameter.

Repeatability and residual deflection remained very close for all standards, what is not critical for analysis.

One first point to highlight is the reference value calculated in the DIN, where the increasing and decreasing torque are considered for each step of calibration. The DIN standard makes a difference for the reference values without hysteresis and with hysteresis, named Y and Y_h respectively (Eq. 1). This reference will be used for all following calculations and classification. NBR and BS standards use the average values of increasing torque for no-changed and changed mounting positions.

$$Y_h = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{I_j + I'_j}{2} - I_{0,j}\right) \quad (1)$$

where;

I_j = increasing values I_0 = inicial zero values

I'_j = decreasing values n = number of mounting position

The DIN standard divides the condition to calibrate in three different cases, according to the purpose of the calibration (see table 1)

Table 1. Cases for calibration acc. DIN standard

Case I-A	3rd deg. fitting curve	No hysteresis
Case I-B	Linear fitting curve	No hysteresis
Case II	Linear fitting curve	With hysteresis

Although this is a very important point, which will influence some results, including the uncertainty of measurement, in order to have data for comparison, this study ill not consider this conditions and the calibrations are done with both fitting curves and also hysteresis for both transducers.

4.1. Calibration points in the transducers

For the TT1 transducer's range points, five steps were chosen (40, 80, 120, 160 e 200 Nm). For NBR two mounting positions were considered and for DIN and BS, four positions, including decreasing torque. For TT2, BS and NBR used five point of the range, while DIN used eight points, but for the purpose of the comparison, only the coinicident points of the range are shown.

4.2. Reproducibility

For the TT1, the most critical parameter in this type of transducer is the reproducibility, because the connector is subject to gaps, misalignments and non uniform loads on their edges and faces. To estimate this influence and make a better analysis of the reproducibility, BS and DIN adopted a four mounting position calibration where it is possible to map even difficulties to fix the transducer to the connection parts.

Table 2 shows the results for reproducibility in the three standards. It is clear that the four mounting position proceeding can show the bad performance of the transducer while a two mounting position proceeding does not.

Table 2. Relative reproducibility of TT1 (values in %)

(Nm)	*BS*	*DIN*	*NBR*
40	0,99	0,99	0,38
80	0,57	0,57	0,23
120	0,48	0,48	0,17
160	0,35	0,35	0,13
200	0,29	0,29	0,12

For TT2, although reproducibility values are lower because the round shaft connection propitiates a better distribution of torque load to the measuring body, there is still a huge difference between NBR and the other standards (see Table 3).

Table 3. Relative reproducibility of TT2 (values in %)

(Nm)	*BS*	*DIN*	*NBR*
20	0,0049	0,0045	0,0019
40	0,0032	0,0043	0,0026
60	0,0043	0,0043	0,0021
80	0,0087	0,010	0,0039
100	0,0043	0,0044	0,0033

4.3. Interpolation

The different reference values calculated from each standard with different mounting positions will influence other parameters. Tables 4 and 5 show respectively the calculated values for transducers TT1 and TT2.

Table 4. Interpolation values of TT1 (values in mV/V)

(Nm)	*BS*	*DIN*	*NBR*	*BS*	*DIN*	*NBR*
	linear			*3rd degree*		
40	0,23660	0,23708	0,23605	0,23640	0,23703	0,23567
80	0,47359	0,47405	0,47283	0,47330	0,47413	0,47229
120	0,71057	0,71102	0,70962	0,71046	0,71120	0,70939
160	0,94756	0,94799	0,94640	0,94766	0,94811	0,94659
200	1,18455	1,18495	1,18318	1,18469	1,18471	1,18346

Table 5. Interpolation values of TT2 (values in mV/V)

(Nm)	*BS*	*DIN*	*NBR*	*BS*	*DIN*	*NBR*
	linear			*3rd degree*		
20	0,266192	0,266210	0,266188	0,266181	0,266206	0,266182
40	0,532412	0,532429	0,532402	0,532388	0,532421	0,532381
60	0,798632	0,798648	0,798616	0,798615	0,798645	0,798596
80	1,064851	1,064867	1,064830	1,064853	1,064871	1,064826
100	1,331071	1,331086	1,331044	1,331092	1,331093	1,331071

Interpolation errors are calculated also with different equations and proceedings, Tables 6 and 7 show these results for the transducers.

Table 6. Interpolation error of TT1 (values in %)

(Nm)	*BS*	*DIN*	*NBR*	*BS*	*DIN*	*NBR*
	linear			*3rd degree*		
40	-0,13	-0,003	-0,46	-0,043	0,021	-0,071
80	-0,041	0,009	-0,16	0,020	-0,008	0,031
120	-0,013	0,022	-0,045	0,0027	-0,0035	0,0056
160	0,0039	0,018	0,015	-0,0069	0,0047	-0,012
200	0,014	-0,020	0,050	0,0020	0,0001	0,0035

Table 7. Interpolation error of TT2 (values in %)

(Nm)	*BS*	*DIN*	*NBR*	*BS*	*DIN*	*NBR*
	linear			*3rd degree*		
20	-0,0018	0,0016	-0,0012	0,0025	0,0032	0,0009
40	-0,0049	-0,0060	-0,0045	-0,0004	-0,0045	-0,0005
60	-0,0031	-0,0003	-0,0026	-0,0011	0,0001	0,0
80	0,0010	0,0010	-0,0003	0,0009	0,0006	0,0001
100	0,0013	0,0003	0,0019	-0,0002	-0,0002	0,0000

From these tables we can also see, as expected, that third-degree curves had better performance than linear fit for all standards. Due to the reference values adopted, DIN and BS standards show different values for interpolation.

It is important to remind that DIN used a range with eight steps against five from BS, what should give, at least in theory, a better fit.

4.4. Reversibility

Next comparison is about the reversibility analysis. Once again, the reference value makes the difference and the DIN standard is more comprehensive as it considers the maximum error between increasing and decreasing torque for the torque step within the four mounting position (Tables 8 and 9). As the BS standard applies decreasing torque only in the last mounting position, it might have a not real value for reversibility.

Table 8. Relative reversibility error of TT1 (values in %)

(Nm)	*BS*	*DIN*	*NBR*
40	0,025	1,72	0,30
80	0,021	0,76	0,12
120	0,017	0,59	0,080
160	0,0084	0,36	0,041
200	---	---	---

Table 9. Relative reversibility error of TT2 (values in %)

(Nm)	*BS*	*DIN*	*NBR*
20	0,018	0,023	0,020
40	0,016	0,016	0,013
60	0,010	0,010	0,0093
80	-0,0001	0,0045	0,0040
100	---	---	---

Reversibility or the hysteresis will not be applied to all types of transducer. What the DIN standard classified as ‘cases’, can be understood as the proposal for the use of the transducer. If a transducer has a nice quality, what means long term stability, and will be used as a transfer standard in a key-comparison for example, that will apply only increasing torque [5]. If another transducer is used as a standard for torque wrench calibration or reaction torque measurement, it can be from a not so qualified level and must be calibrated with decreasing torque for those applications in clockwise and counter-clockwise.

4.5. Classification

Next comparison is about the classification of the transducer. The NBR standard does not have the 0.05 class, which is applied to high performance transducers. This is a very important point to change in the standard once this kind of instrument, if calibrated with the current NBR standard, will have its performance automatically degraded.

All other parameter limits are the same for the three standards. The Tables 10 and 11 show the classification for the transducers, with the different interpolation curves making difference only in the NBR.

Table 10. Classification of TT1

(Nm)	*BS*	*DIN*	*NBR linear*	*NBR 3rd deg.*
40	1	2	0.5	0.5
80	1	1	0.2	0.1
120	0.5	0.5	0.1	0.1
160	0.5	0.5	0.1	0.1
200	0.5	0.5	0.1	0.1

The step of 40 Nm had class 2 because of the relative reversibility error above the limit of 1,25 % for class 1.

Table 11. Classification of TT2

(Nm)	*BS*	*DIN*	*NBR*
20	0.05	0.05	0.1
40	0.05	0.05	0.1
60	0.05	0.05	0.1
80	0.05	0.05	0.1
100	0.05	0.05	0.1

4.6. Uncertainty of measurement

About the uncertainty of measurement, NBR does not present a proceeding and only makes reference to the uncertainty of the reference standard in use for the case of classification. Uncertainty budget is currently based on some particular proceedings, what brings with no common directions between calibration labs.

Both DIN and BS methods are based on the propagation law of uncertainties considering all parameters calculated and presume a coverage factor *k=2* to expanded uncertainty (acc. to Eq. 2).

$$W = 2 \cdot \sqrt{w_{KE}^2 + 2 \cdot w_r^2 + w_b^2 + w_{b'}^2 + w_0^2 + w_{f_a}^2} \qquad (2)$$

But, as already mentioned, DIN presents a different approach for linear fitting curve and hysteresis when these parameters are calculated according to the chosen *case*. Equation 3 shows the case I uncertainty calculation for linear fitting curve.

$$W = 2 \cdot \sqrt{w_{KE}^2 + 2 \cdot w_r^2 + w_b^2 + w_{b'}^2 + w_0^2 + \left(\frac{f_a}{Y} \cdot 100\%\right)} \qquad (3)$$

Equation 4 shows that, for case II, linear fitting curve and hysteresis are considered systematic errors and uncertainty is expressed as an uncertainty interval (Eq. 4). In this case the reference value will be Y_h, not Y.

$$W' = \left|\frac{f_a}{Y_h}\right| \cdot 100\% + \left|\frac{h}{2.Y_h}\right| \cdot 100\% + k \cdot w \qquad (4)$$

Table 12 shows the uncertainty of measurement calculated for TT1, using linear and third-degree fitting curves. For the DIN standard, equation 4 was used for the linear fitting curve.

We can see there is no significant difference between linear and third-degree results for the BS but, when DIN considers the linear and hysteresis as systematic errors, there is a significant difference between the curves.

Table 12. Uncertainty of measurement of TT1 (values in %)

(Nm)	*BS*	*DIN*	*BS*	*DIN*
	linear		*3rd deg.*	
40	0,71	1,44	0,71	0,58
80	0,40	0,76	0,40	0,33
120	0,34	0,73	0,34	0,28
160	0,25	0,53	0,25	0,20
200	0,20	0,35	0,20	0,17

For transducer TT2, once again the interval of uncertainty is calculated for the linear fitting curve and sensible differences are noted for DIN results. Once again, differences are not significant for BS standard.

Table 13. Uncertainty of measurement of TT2 (values in %)

(Nm)	*BS*	*DIN*	*BS*	*DIN*
	linear		*3rd deg.*	
20	0,015	0,093	0,015	0,013
40	0,014	0,17	0,014	0,010
60	0,012	0,041	0,012	0,011
80	0,012	0,069	0,012	0,011
100	0,010	0,038	0,010	0,011

5. CONCLUSION

After some experience of Lafor/Inmetro using the Brazilian standard NBR 12240 for calibrating many types of torque transducer, some points highlighted the necessity to update the national proceeding according to natural new demands coming from instruments and equipment developed by industry to attend also new applications for torque measurements.

A comparison was made between the standards NBR 12240, BS 7882 and DIN 51309. An analysis of each one was done in order to detach the main differences between them and quantify, by evaluated results of measurements, misalignments of the national standard with the international proceeding currently practiced.

Two types of transducer, with different qualities, were used for the tests and each parameter evaluated for them according to the different standards.

Although the results are shown and differences can be noted very clear, it is early to point what standard or procedure should be adopted. With this study, the national technical committees can have some initial fundamental data for proposing the revision of the national standard, in the same way that happened with the choice of ISO 6789 as torque wrench calibration proceeding [6].

Maybe, in a near future, these discussions, based on more results, can be taken to the ISO technical committees level and, joining other countries, begin some studies with the purpose of creating an international standard for torque transducer calibration, as more and more countries are developing torque metrology in their National Institutes of Metrology and measurements should be homogenized, similarly to what occurs with ISO 376 for calibrating force transducers.

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