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## INFLUENCE OF SPECIFIC PARAMETERS ON A HAND-OPERATED TORQUE STANDARD MACHINE

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**Abstract** – In a hand-operated torque primary standard machine, many parameters are very peculiar and can really influence the final results of a calibration. The paper presents studies to quantify how those parameters act and be able to influence on the main operations of this type of machine. As a conclusion, it is demonstrated that only an initial characterisation of the system is not enough to guarantee good results but, the day-by-day use of the machine demands for practice and better knowledge of the cited parameters.

**Keywords:** Torque standards, Hand-operated machines, Torque calibration.

### 1. INTRODUCTION

In metrological systems in the field of torque, mainly primary standards, machine projects with fully automated functions are always preferred to more simple projects, as hand-operated machines with functions done directly by the operator, as manipulation of parts, items and data acquisition, because of their low values for the uncertainty budget.

However, automated systems can cost, in the same nominal range, three times more than manual or semi-automated machines. Hence, the option for that more simple equipment becomes feasible from the moment that one National Metrology Institute fits it to the degree of accuracy of its demand on the dissemination of the quantity in the national traceability chain [1].

This paper has the purpose to identify and quantify some parameters which defers, in the nature of its operation, the projects for hand-operated torque machines from those automated ones. Then, actions and solutions are presented with the aim of minimizing possible interference of those parameters in the results and proceedings of calibration.

It is not enough, to the crew, only to accept the uncertainty budget achieved in an initial qualification or characterisation of the system. But to determine its variable parameters and try to use, or change them, in the way to adequate them to the day-by-day of the machine operation, even as a practice for continuous improvement and reliability.

### 2. THE PRIMARY STANDARD

The system used for the tests is the Torque Primary Standard in the Force Laboratory of the National Metrology Institute of Brazil (LAFOR/INMETRO), which main functions are realised manually by the operators [2]. Fig. 1 shows an assembly of a transducer to be calibrated and the parts of the system where the operator acts directly.



Fig. 1. Torque Primary Standard (LAFOR/INMETRO) with indication of main parts operated manually.

The calibration main proceeding with the operation of the machine is described as follow:

- One operator puts masses, according to the calibration point, in one of the plates ( $B_R$  or  $B_L$ ), depending on the direction of the calibration.
- The other operator applies the counter-torque ( $CT$ ), trough the handle ( $Mn$ ), using the residual torque shown in  $I_{CT}$  as a reference for horizontal position, it means, residual torque null.
- When the torque value in  $I_{CT}$  is approaching zero, the operator of the  $CT$  starts the countdown stabilization and maintain the  $I_{CT}$  around zero till it is time to read the torque value from the transducer ( $Tr$ ) using a digital amplifier indication.
- This proceeding is repeated for the next points and also for unloading measurement, but removing the masses.

Fig. 2 shows a diagram with a load application curve and respective examples of readings from  $I_{CT}$ .

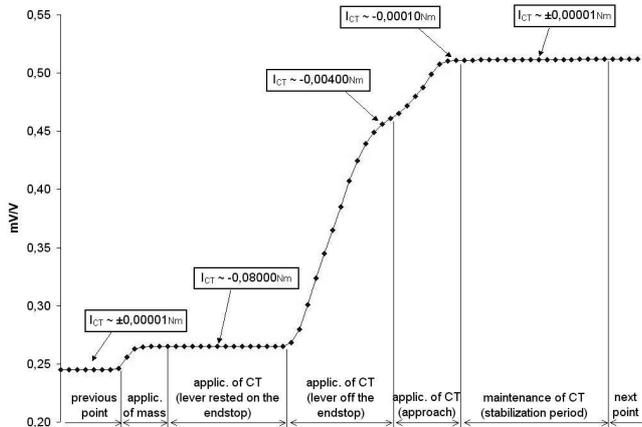


Fig. 2. Characteristic load curve (mV/V reading from digital amplifier).

### 3. METHODOLOGY

The specific parameters will be analysed through calibrations and measurements done with torque transducers in the primary standard. There are related below the parameters and the tests to quantify them. Some tests used three different operators which will be identified as *OpL* (low experience), *OpM* (medium experience) and *OpH* (high experience).

#### 3.1. End-stop adjustment

The end-stop is a part for security and stabilization during the placement and removal of the masses (see Fig. 2), what can avoid some overloading and oscillation of the lever arm.

It is important to detach that this was a part improved in the machine replacing the original support under the base of the balance plate. The end-stop distance must be adjusted according to the angular displacement of the elastic mechanical element of the transducer and before the calibration begins. The adjustment is done regarding to the  $I_{CT}$  value shown after all masses of a measuring point are put or removed.

As an example of the functionality of these parts, in Fig. 3 there is a load curve for a 0-50 Nm step with the moment of putting a 5 kg mass on the balance. The overshoot happened because there was no end-stop supporting the lever. Although the oscillation can be minimized by an oil damper system, during the place or removal of masses, the operator exerts some extra force on the balance, what can cause higher oscillation and be critical depending on factors as:

- weight and design of each mass piece
- practice for holding and centralizing
- fatigue of the operator

degrees of freedom of the balance sustain sensitivity of the transducer (stiffness)

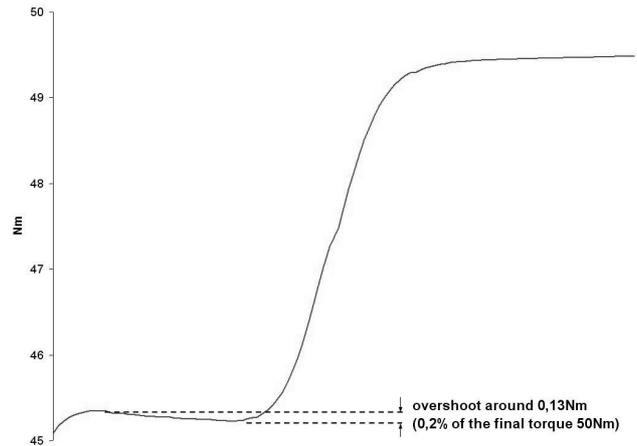


Fig. 3. Mass load (0-50 Nm) without end-stop in a 1000 Nm transducer

Once it is desirable to have only increasing torque for up series, to have this decreasing of 0,13 Nm is not a good behaviour for the transducer during calibration (small hysteresis). After putting mass, the torque reached 90 % of the target value, what is critical also for being too close from an overloading. On the other hand, if the end stop is used, the torque after putting masses reaches about 10-14 % of the final target without overshooting, what is more trustful for both operators.

#### 3.2. Placement and removal of masses

As it was explained in 3.1, the ability of the operator to work with the mass pieces is important to have a more constant behaviour of the calibration proceeding. Fig. 4 and 5 show the transducer response to different operations on putting and removing mass respectively. For that, a 100 Nm mass piece (~10 kg) was manipulated five times in a 1000 Nm transducer and the characteristic shape was defined for each operator. The time taken refers from the first moment of touching the balance till the lever rest stabilized on the end-stop.

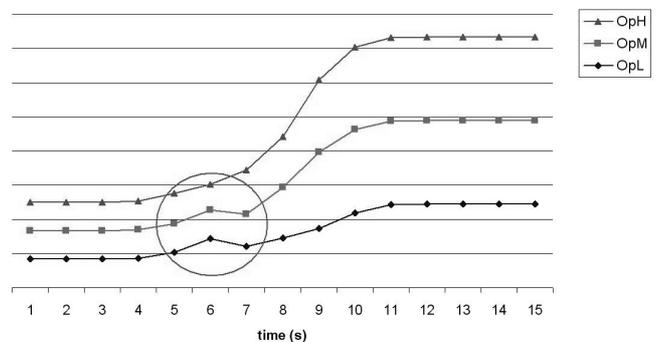


Fig. 4. Mass load curve shape for each operator

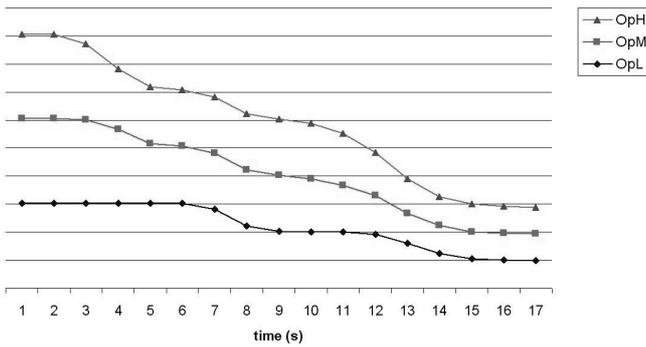


Fig. 5. Mass unload curve shape for each operator

In the load shape, the circle identifies the critical area and there is a different between operators. As we can also see, it is more critical for loading mass than removing it.

**3.3. Counter-torque application**

The counter-torque (CT) system is one of the most important parts of a primary torque standard and some factors must have special attention during project of the machine and elaboration of calibration proceedings:

- reference quantity (residual torque, lever position, counter-torque angle)
- indication of the counter-torque values and references
- actuator to generate the counter-torque (handles)
- period and speed of application

In the case of Lafor’s primary standard, it is an electric instrumentation (strain-gages) in some parts of the lever which signals, from not horizontal position and balances’ misalignment, are concatenated into one *residual torque value* intended to be zero at the point of calibration. So to bring this value to zero, an operator uses a handle while observes a digital indicator with the  $I_{CT}$  values and also the values from the transducer to confirm his action (direction and speed of application).

To study this part, two main parameters were varied: the rate of the handle and the start-up  $I_{CT}$  value.

To apply the counter-torque it is possible to choose one of two handles, one with high reduction rate and other with smaller rate, *MnH* and *MnL* respectively. The original project of the machine had only one type, with low rate, but that was difficult to work when applying small values of torque (< 50 Nm). Table 1 shows some results for the tests done with the three operators measuring in the 50 Nm transducer and the two types of handles.

Table 1. Different handles for each operator

Operator	Total time		$I_{CT} > \pm 0,0001Nm$	
	<i>MnL</i>	<i>MnH</i>	<i>MnL</i>	<i>MnH</i>
<i>OpL</i>	1910 s	2500 s	8 pts	4 pts
<i>OpM</i>	2340 s	2480 s	6 pts	2 pts
<i>OpH</i>	1180 s	1360 s	1 pt	0 pt

The test consisted of an up and down series (0-50-0 Nm) with 10 Nm steps, totalizing 10 measures. It was checked the total time to do this series and the number of points where the operator could not stabilize the  $I_{CT}$  value within the range  $\pm 0,00010$  Nm, considered ideal to calibration

From the results it is clear, and the operators confirmed, that is easier to stabilize the system using the *MnH*, on the other hand, that took some more time to measure. Using *MnL* the operator *OpL* had a reduction of about 24 % in the total time of the series, while *OpH* had 13 % time reduced. Operator *OpM* had little time reduction and only improved in the  $I_{CT}$  stabilization range period.

Another important parameter is the start-up value for the  $I_{CT}$  reference, what is set according to the distance from the end-stops to the lever. This corresponds to the value shown at  $I_{CT}$  box in the *Applic. of CT (lever rested on the end stop) period* in Fig. 2.

If the value set for  $I_{CT}$  is small, speed applied will be mainly based on the transducer reading, what is more difficult for the operator, creating a risk of too fast approach to stabilization range and also overloading. Then, the high is the  $I_{CT}$  set, the better for the operator, because he can first work with transducer reading and then, after the lever is off the end-stop, he still has some large range of  $I_{CT}$  to work on quietly. All three operators confirmed that during their operation.

To do this test, two different values were used for start-up,  $\pm 0,08$  Nm and  $\pm 0,15$  Nm. Both *OpL* and *OpM* reported difficulties to work with start-up at 0,08 Nm because they were insecure about the control being based on the transducer value indication, what forced them to check measures done in previous calibration of that instrument. That improvement was then suggested to be implemented in the proceedings and sheets of calibration.

**3.4. Intralaboratorial comparison**

To complete the analysis of these different behaviours, two final tests were, which intend to concatenate all parameters directly related to the staff operation and the level of capacitation and expertise of the operators.

First, a repeatability and reproducibility (r&R) study was done using the simple method of range and average, with three operators, four loadings each and a tolerance of 0,025%, as that is the maximum admissible for transducers class 00 [5]. Table 2 can show some results for points in the beginning and near the end of the range for both 50 Nm and 1000 Nm transducers.

Table 2. ‘r&R’ results for “Range and Average Method” with 99%, three operators, four loadings each and tolerance of 0,025%

Transducer	Point (Nm)	‘r&R’ (%)
50 Nm	10	2,52
	40	0,24
1000 Nm	100	4,31
	800	0,68

From these results, we can check all values are within the acceptable range of under 10% [4], but here we can also

already check the differences between the readings from the beginning of the range and from the end of that, when the relation 'r&R' decreases significantly. To have a more detailed study of these and also to consider more parameters from the measurement proceedings, an intralaboratorial comparison was done and supplied some more data.

Two transducers, 50 Nm and 1000 Nm, were measured and calibrated under special conditions, it means, the proceeding adopted was a little different from a real calibration in the way to isolate the parameters influenced by the operator from those mainly originated by the system and/or by the transducer behaviour. Then one pre-load and two series of load and unload points, without any rotation or re-coupling, were applied to the transducers.

Once the international standards and guides are not very specific about intervals and total time for calibration, it is suggested to the laboratories to work with intervals more equally distributed as possible. Fig. 6 and 7 show the time taken by each operator for each measuring point in the range. There is also the total time taken for calibration. As we can see, operator *OpH* had faster calibrations and more homogeneous time for the intervals.

Once again, the diagram shows the better stability to work with the 1000 Nm than the 50 Nm transducer, as time intervals are more equally spaced.

In the calibration of the 50 Nm transducer, the 20 Nm point presented some gap, what made the operators to work more carefully.

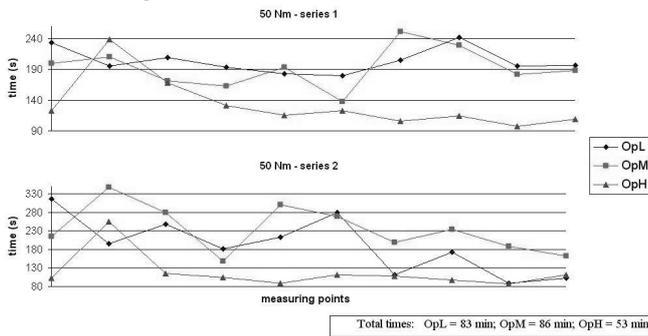


Fig. 6. Intervals between measuring points and total time for calibration of the 50 Nm transducer

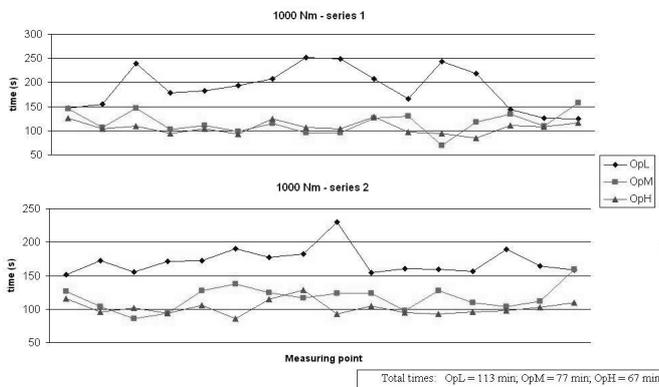


Fig. 7. Intervals between measuring points and total time for calibration of the 1000 Nm transducer

Tables 3 and 4 present the average values acquired from the transducers measurements and the expanded relative uncertainty for each point.

Table 3. Average values from the 50 Nm transducer (mV/V) and relative expanded uncertainties *U* (%)

(Nm)	<i>OpL</i>		<i>OpM</i>		<i>OpH</i>	
10	0,266935	0,013	0,266918	0,008	0,266920	0,006
20	0,533851	0,010	0,533846	0,007	0,533841	0,006
30	0,800797	0,007	0,800784	0,005	0,800790	0,004
40	1,067761	0,004	1,067755	0,004	1,067755	0,002
50	1,334732	0,004	1,334724	0,005	1,334730	0,003

Table 4. Average values from the 1000 Nm transducer (mV/V) and relative expanded uncertainties *U* (%)

(Nm)	<i>OpL</i>		<i>OpM</i>		<i>OpH</i>	
100	0,134507	0,012	0,134508	0,011	0,134506	0,012
200	0,269029	0,007	0,269032	0,006	0,269028	0,007
300	0,403544	0,005	0,403547	0,004	0,403544	0,005
400	0,538073	0,004	0,538077	0,004	0,538072	0,004
500	0,672597	0,003	0,672600	0,002	0,672596	0,002
600	0,807136	0,002	0,807138	0,001	0,807133	0,001
800	1,076213	0,003	1,076218	0,003	1,076211	0,003
1000	1,345309	0,001	1,345311	0,001	1,345303	0,001

To evaluate the results from the calibration, and have uncertainty values, the following parameters were adopted: repeatability, zero deviation, interpolation and *I<sub>CT</sub>* values. The hysteresis error was also calculated but not inserted in the uncertainty budget. The contribution of the uncertainty related to the standard machine was not used to make this comparison. The *I<sub>CT</sub>* contributions are referred by the higher variation of *I<sub>CT</sub>* during the stabilisation time was counting down at each point in the range and interpolated with the reading values from the transducer. This result was then concatenated with the interpolation done without *I<sub>CT</sub>* correction.

Analysing the data from Table 3, it is clear the tendency of reducing the uncertainty according to the experience of the operator. Operator *OpL* had some bad results in repeatability, what was predominant to final uncertainty values. Results from *OpM* and *OpH* were very similar, but still differentiating in the *I<sub>CT</sub>* stabilization, where the first had 13 readings greater than ±0,00010 Nm while *OpH* had only 04 reading out of this pre-determined acceptable range.

On the other hand, analysing Table 4, results of the three operators are very similar, even when considered the *I<sub>CT</sub>* stabilization variance, because the 1000 Nm transducer is less sensitive to variations in the order of 10<sup>-4</sup> Nm in the standard machine torque application.

The Normalized Error (1) was used to compare the results, where the values obtained from the operator *OpH* were considered as reference for the comparison. Fig. 8 and 9 show the diagram for *E<sub>N</sub>* in both transducers calibrations.

$$E_N = \frac{x - X_{ref}}{\sqrt{U_x^2 + U_{ref}^2}} \quad (1)$$

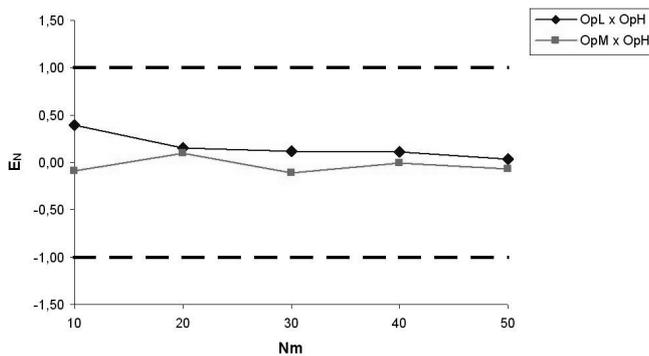


Fig. 8. Normalized errors calculated for the 50 Nm calibration

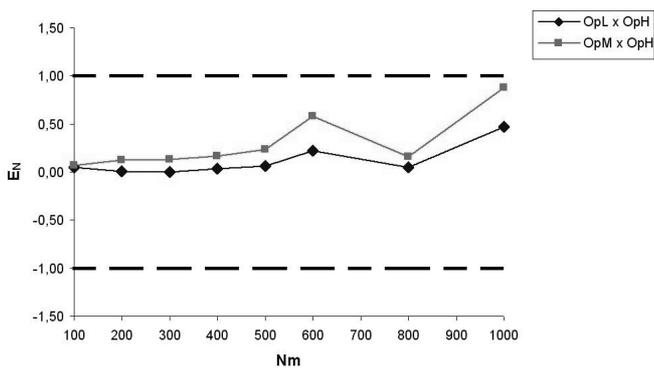


Fig. 9. Normalized errors calculated for the 1000 Nm calibration

Analysing the graphics of  $E_N$ , all points are inside the range of  $\pm 1$ , what indicates a reliability of the system (machine + transducer) even if operated under many different influences.

#### 4. ADDITIONAL INFORMATION AND IMPROVEMENTS

After and during the tests with the different operators and conditions, some extra information could be collected and changed here into some improvement to the system and the proceedings:

- Some points of ergonomics must be observed as: the weight to be carried, the design of the mass stacks, the position and height of the balances, the height and force done at the counter-torque handle.
- A software, created at Lafor, was used to help the operator during application of  $CT$ , generating a sound signal to advise the final 10 seconds countdown to make the automatic reading and writing in the calibration sheet.
- At some points, operators were confused about the references, so this was implemented: a previous loading series must be done in the transducer for knowledge of the  $mV/V$  values related to torque values; these values are written and well visual identified in the calibration sheet.
- To avoid overload risk, as the machine does not have an automatic feedback, it will be implemented, via software, an alarm identification for each point together

with a real time acquisition of the reading values of the transducers.

#### 5. CONCLUSION

The main purpose of the paper was to identify and isolate the parameters which could be vulnerable to different actions and behaviour of the operators. So, some parts as couplings and structure materials, known for having great influence in the machine behaviour, were not considered here.

Although some different and no desirable behaviours could be noticed during the different operators measurement proceedings, the primary standard system considered here (Inmetro's Torque Primary Standard) have a huge convergence assembly of instrumentation, instrumental control and operational parts, what brings to the final results a very smooth deviation between operators, what shows that simple changes and cautions, when taken, can really make easier, help in day-by-day hand-operated torque machines and promote continuous improvement to the system and future projects.

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