

# DEVELOPMENT AND METROLOGICAL CHARACTERISATION OF THE NEW LNE 500 N·m DEADWEIGHT TORQUE STANDARD MACHINE

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## Abstract:

This paper describes the development and metrological characterisation of the new LNE 500 N·m deadweight torque standard machine. This machine is integrated into the LNE 5 kN·m deadweight torque standard machine. New masses and a mass change platform have been developed and added to the 5 kN·m machine. After this, LNE realised the metrological characterisation of the 500 N·m machine. The determination of the uncertainties of this torque standard machine and the comparison measurements with the LNE 50 N·m deadweight torque standard machine and with CEM, the National Metrology Institute of Spain, are described in this paper. The results show that the estimated uncertainties are satisfactory because they are a factor of about four times smaller than those of the old standard machines.

**Keywords:** torque standard machine

## 1 INTRODUCTION

The development of the torque standard machine of 500 N·m is part of a wider scheme which aims at

updating French metrological references in torque metrology. The Laboratoire national de métrologie et d'essais (LNE) is conducting this project which involves the development of several machines: 5 N·m; 50 N·m; 500 N·m; and 5000 N·m. The development and the metrological characterisation of the 5 N·m, 50 N·m and 5000 N·m torque deadweight standard machine have already been made and presented in articles [1][2][3][4].

The next sections introduce, for the 500 N·m torque standard machine, the development of the deadweights, the principle of the mass change platform (see Figure 1), the determination of the uncertainties and the comparison measurements carried out with the LNE 50 N·m deadweight torque standard machine and with the National Metrology Institute of Spain (CEM) 1 kN·m deadweight torque standard machine. After this comparison a Euramet comparison will be done. This Euramet comparison will be used to support our BIPM Calibration and Measurement Capabilities change.

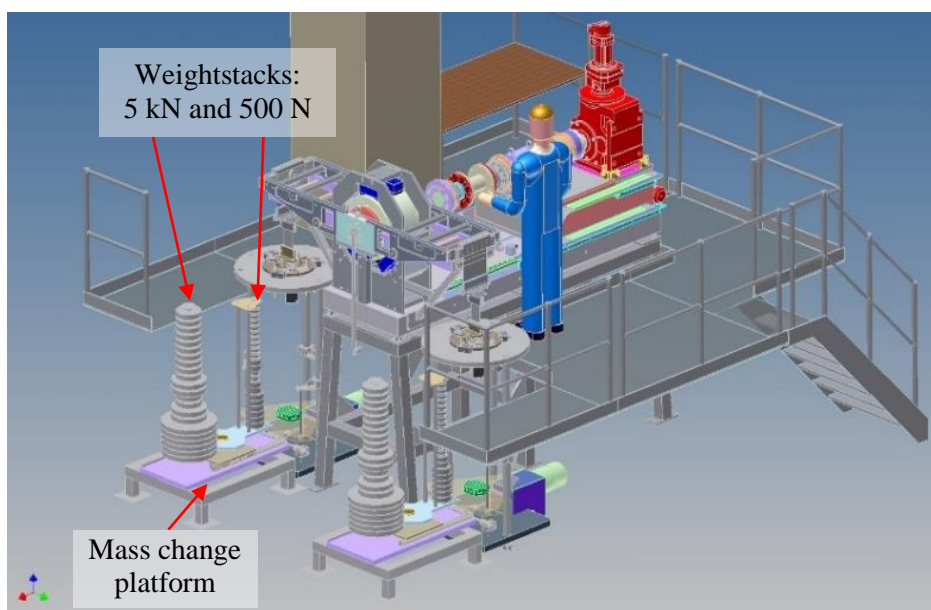


Figure 1: 500 N·m and 5 kN·m machines

## 2 DEVELOPMENT OF THE 500 N·m MACHINE

The 500 N·m deadweight torque standard machine is integrated into the LNE 5 kN·m deadweight torque standard machine. New masses and a mass change platform have been developed and added to the 5 kN·m machine (see Figure 1). The next sections describe these new parts. The lever arm and the air bearing are described in detail in the article [2].

### 2.1 The weightstack

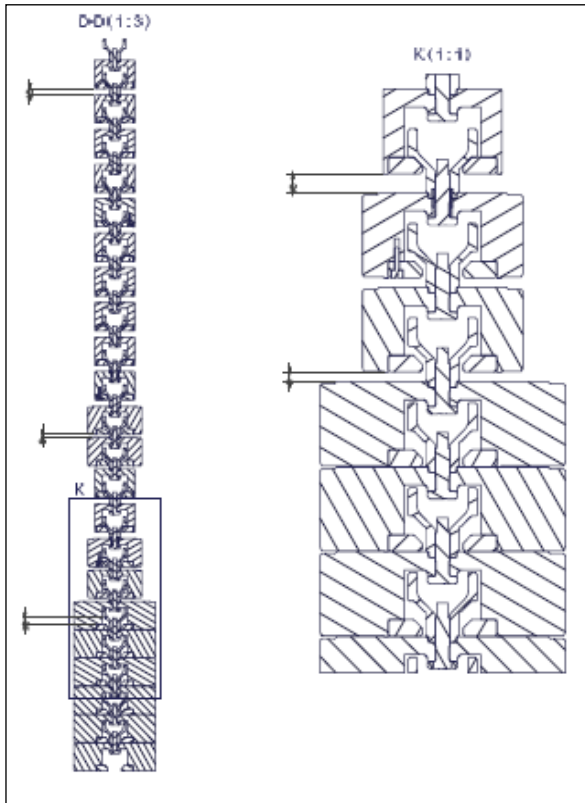


Figure 2: 500 N·m weightstack

Two weightstacks (see Figure 2) were manufactured to be placed on both extremities of the lever arm to apply torques either on the left or the right side.

These stacks have a height and an arm interface identical to the weightstack of the 5 kN·m machine so that the machine can operate in the same way.

They are made of a series of non-magnetic stainless steel disks that are sequentially hung from each other depending on the height of the weight carrier. Each stack is composed of the same series of the following 22 discs:

- 10 discs each creating 10 N;
- 2 discs each creating 20 N;
- 2 discs each creating 10 N;
- 2 discs each creating 20 N;
- 6 discs each creating 50 N.

This particular layout enables loadings to be conducted with intervals of 10 N·m, 20 N·m or 50 N·m, by increasing or decreasing load values over ten steps with only one motorisation. This allows us to respect the international practices regarding calibration of torque transducers with a capacity of 100 N·m, 200 N·m and 500 N·m.

### 2.2 The mass change platform

The mechanism for carrying out the mass change consists of a change platform (see Figure 3), on each side of the arm, placed on the rear of the machine

The mass change platform is equipped with a slide and a pivot for translation and rotation. Movements are motorised.

The translational plate, allowing the approach of the masses in position 5 kN or 500 N, is comb-shaped and must be inserted in the basket support plate. Then the existing basket motors are used to lift the masses.

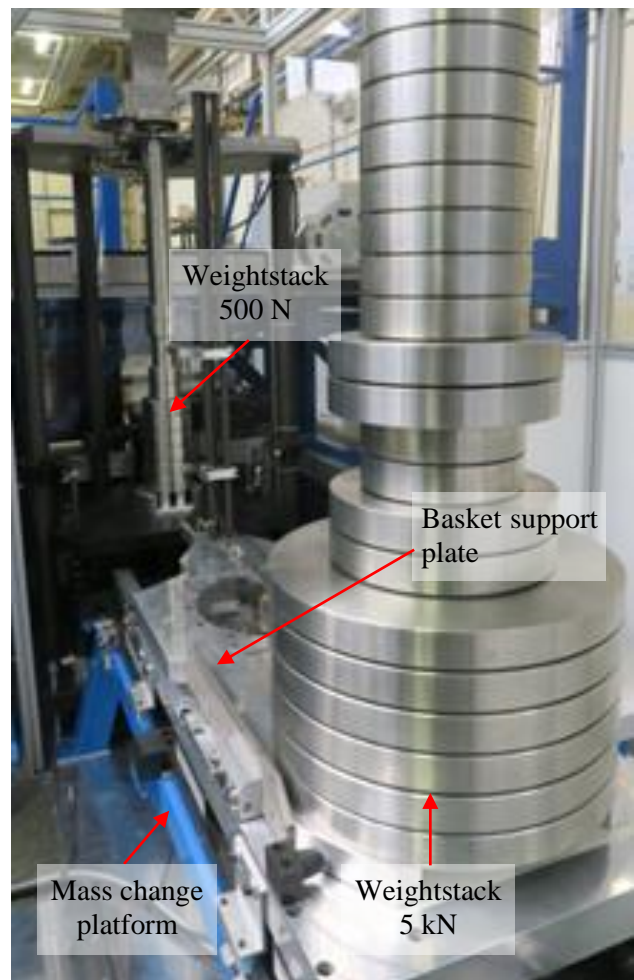


Figure 3: Mass change platform and weightstacks

### 3 EVALUATION OF UNCERTAINTY

The uncertainty of the torque  $T$  applied by the 500 N·m machine has been estimated including the uncertainty contribution of the deadweight force, of the length and due to sensitivity mobility of the lever (see Table 1).

Concerning the deadweight force, the uncertainties have been estimated as usual and same components than for the 5 kN·m range of the machine (see [4]) have been taken into account.

As there is only one lever used for both the 5 kN·m and 500 N·m ranges, we use the same calibration results obtained on a three-dimensional measuring machine. So components link to length are exactly the same as for 5 kN·m range (see [4]).

The sensitivity and mobility of the lever arm associated with the air bearing have been estimated in the same way as for the 5 kN·m range: lever imbalances have been measured using a small capacity torque transducer with a very small resolution.

Additional to all those components, a last uncertainty contribution is taken into account. Doing interlaboratory comparison, deviations could be observed between two torque calibration machines. In force and torque field, sometimes,

Table 1: Uncertainty budget of the LNE 500 N·m torque standard machine

Uncertainty component	Standard uncertainty / N·m
<b>FORCE</b>	$2.7 \times 10^{-6} \times T$
<b>MASS</b>	
Calibration	$1.0 \times 10^{-6} \times T$
Measurement trueness <sup>a</sup>	$1.5 \times 10^{-6} \times T$
Drift (based on calibration uncertainty)	$1.0 \times 10^{-6} \times T$
<b>EARTH'S GRAVITATIONAL FIELD</b>	$3.1 \times 10^{-7} \times T$
<b>AIR BUOYANCY</b>	$1.7 \times 10^{-6} \times T$
<b>LENGTH</b>	$2.0 \times 10^{-5} \times T$
Calibration	$1.2 \times 10^{-5} \times T$
Measurement trueness <sup>a</sup>	$6.1 \times 10^{-6} \times T$
Temperature	$4.9 \times 10^{-6} \times T$
Drift (based on calibration uncertainty)	$1.2 \times 10^{-5} \times T$
Force position	$6.7 \times 10^{-6} \times T$
Deformation and inclination	$2.9 \times 10^{-7} \times T$
<b>SENSITIVITY and MOBILITY</b>	$7.1 \times 10^{-4} + 9.4 \times 10^{-7} \times T$
<b>TORQUE TRANSMISSION</b>	$1.6 \times 10^{-3} + 1.9 \times 10^{-5} \times T$

<sup>a</sup> Due to the use of nominal value instead of measured value those deviations are bigger than the combined uncertainty, means that there are significant, or that

the uncertainties have been underestimated. To avoid this, we enlarge the uncertainty, adding a component based on comparison results. We call this component “torque transmission” because the mechanical way to apply the torque to the device could explain the deviation results. For the 500 N·m range, this component is estimated using the deviation between the measurements obtained by transducers calibrated by the LNE 500 N·m, LNE 50 N·m and CEM machines. The comparison of measurements is presented in the next chapter.

The expanded ( $k = 2$ ) uncertainty  $U_T$  of the torque ( $T$ , in N·m) applied by the LNE 500 N·m machine is obtained by combining these components:

$$U_T = 3 \text{ mN}\cdot\text{m} + (5.0 \times 10^{-5} \times T) \text{ N}\cdot\text{m} \quad (1)$$

### 4 COMPARISON MEASUREMENTS

The comparison has been made with transducers calibrated by LNE and CEM. CEM used their 1 kN·m torque standard machine. The expanded uncertainty ( $k = 2$ ) on the applied torque  $T$  (in N·m) is equal to  $(2.0 \times 10^{-5} \times T) \text{ N}\cdot\text{m}$ .

Each torquemeter was calibrated twice in LNE's 500 N·m torque standard machine, firstly before sending it to CEM and secondly after receiving it back, thereby establishing the drift.

For torque from 10 N·m to 50 N·m an internal LNE comparison with the 50 N·m torque standard machine has been made. The expanded uncertainty ( $k = 2$ ) on the applied torque  $T$  (in N·m) is equal to  $0.5 \text{ mN}\cdot\text{m} + (5.0 \times 10^{-5} \times T) \text{ N}\cdot\text{m}$ .

The comparison took place over a few days so only one calibration was made on the 500 N·m machine. For these comparisons we used five transfer torquemeters. Table 2 shows the measuring bridges used and the measuring steps realised with the set of torquemeters.

Table 2: Measuring ranges realised during the comparisons

Transfer torquemeter	Measuring bridges	Steps (N·m)
Raute TT1 50 N·m	HBM DK38	10, 20, 30, 40, 50
GTM Dm-TN 50 N·m	HBM DK38	10, 20, 30, 40, 50
Raute TT1 100 N·m	HBM ML38	10, 20, 30, 40, 50, 100
Raute TT1 500 N·m	HBM ML38	50, 100, 150, 200, 250, 300, 400, 500
GTM Dm-TN 500 N·m	HBM ML38	50, 100, 150, 200, 250, 300, 400, 500

The calibrations were performed in both clockwise and anticlockwise modes.

The calibration of each torquemeter has been realised by performing, in order, the following operations:

- Application of three preloads at the nominal value of the torquemeter held for thirty seconds and with a rest period of thirty seconds between each preload.
- Application of four series of increasing charges and three series of decreasing charges without return at zero charge

between each step. The measurements are taken after about thirty seconds.

- Rotation of the torquemeter around its axis (3 different angles). Preload at the maximum load of the sensor after each rotation

Figure 4 shows, for each torque step, the weighted average of differences between the CEM and LNE 50 N·m and the LNE 500 N·m machines. The vertical bars represent the uncertainty ( $k = 2$ ) of the LNE 500 N·m torque standard machine.

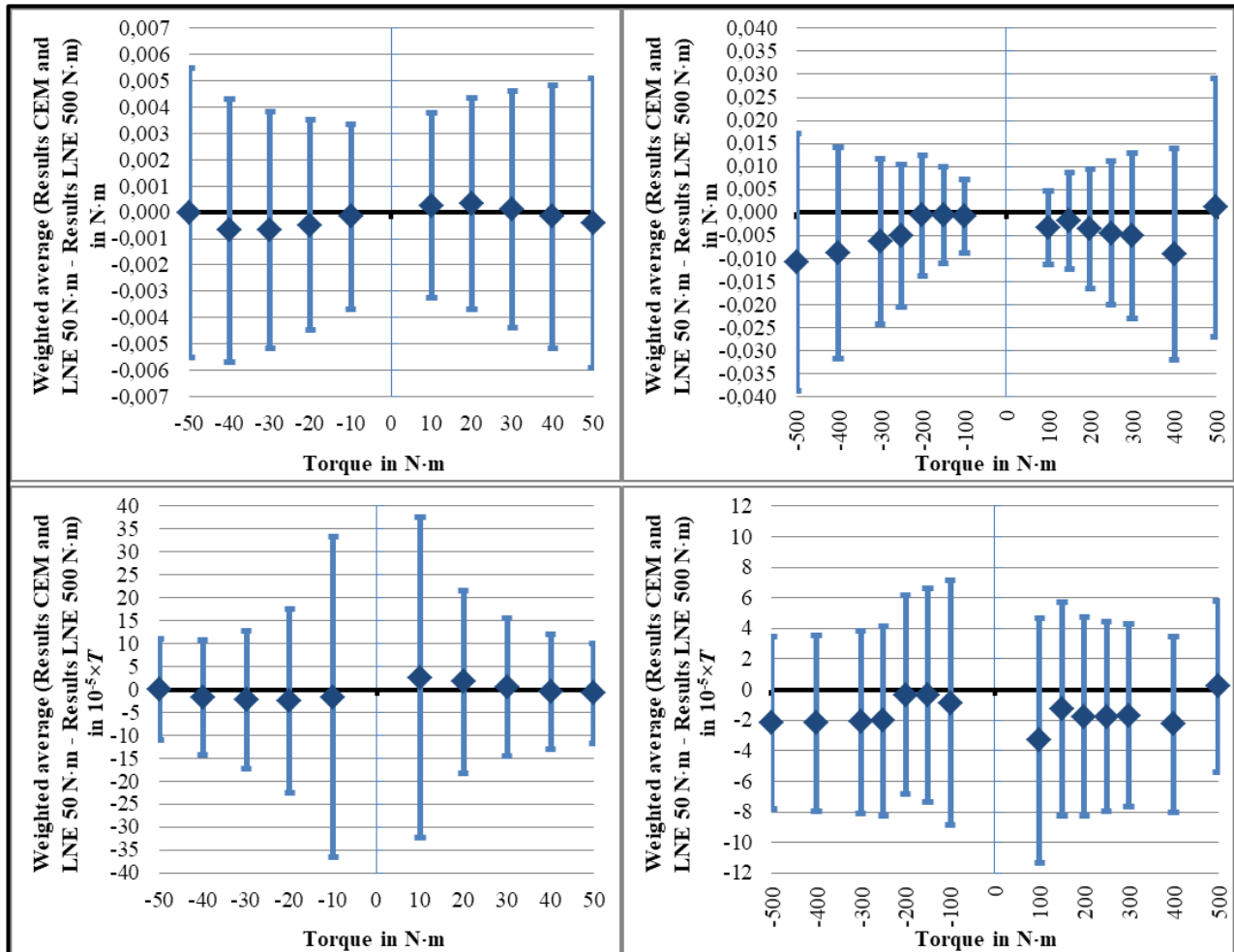


Figure 4: Weighted average of difference = (results CEM and LNE 50 N·m - results LNE 500 N·m)  $\pm U_{LNE500}$

For each step, the difference is less than the uncertainty, so it is not significant. Maximum differences are taken into account in the uncertainty budget as the torque transmission component.

## 5 CONCLUSION

The metrological characterisation of the LNE torque standard machine of 500 N·m gave an expanded ( $k = 2$ ) uncertainty equal to  $3 \text{ mN}\cdot\text{m} + (5.0 \times 10^{-5} \times T) \text{ N}\cdot\text{m}$ .

The comparison performed with the LNE 50 N·m machine and the CEM 1 kN·m machine showed that this uncertainty is quite justified.

The results show that the estimated uncertainties are satisfactory because they are a factor of about

four times smaller than those of the old standard machines. A Euramet comparison will be done to support our BIPM Calibration and Measurement Capabilities change.

## 6 REFERENCES

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