Metrological characterisation of the 5 kN·m torque standard machine of LNE

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Abstract. After the development of the new 5 kN·m torque standard machine, LNE realized its metrological characterisation. This paper describes the determination of the uncertainties of this torque standard machine, including the uncertainty due to the mobility and the sensitivity of the arm lever. It describes also the comparison carried out with the national metrology laboratory of Germany PTB. The results show that the estimated uncertainties are satisfactory because divided by a factor of at least four compared to the old standard machines.

1. Introduction
The torque standard machine of 5 kN·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; 50; 500 and 5000 N.m. The latter will make the link with the LNE high capacity 200 kN·m torque standard machine.

So as to gain sufficient experience in designing the new machines, we first developed the 5 and 50 N·m machines [1] [2]. This enabled us to validate the selected concepts to be used for the other machines. The development of the 5 kN·m (see figure 1) was launched afterwards.

Figure 1. LNE 5 kN·m torque standard machine.
Information on the design, development, and commissioning of this standard are given in [3], in particular, the double arm lever, one for deadweight force transmission and the other for localization of this force. Also, the air bearing based on used of porous material. The attention given to these elements enables to consider uncertainties four times less than uncertainties of the old standard machines.

The next chapter describes the determination of the uncertainties of this 5 kN·m torque standard machine, including the uncertainty due to the mobility and the sensitivity of the arm lever. Mobility is link to air bearing friction. Sensitivity is link to the lever weight and to the position of its gravity center. The other chapter describes the comparison carried out with the national metrology laboratory of Germany (PTB) and deviations obtained.

2. Evaluation of uncertainty
The uncertainty of the torque (T) applied by the 5 kN·m machine has been estimated as usual, including the uncertainty contribution of the deadweight force, of the length and due to sensitivity-mobility of the lever (see Table 1). An additional uncertainty contribution is taking into account due to the torque transmission. This component is estimated using the result of the comparison with PTB presented in next chapter, taking into account a normal probability distribution.

### Table 1. Uncertainty budget of the LNE 5 kN·m torque standard machine

| Uncertainty component                        | Standard uncertainty in N·m |
|----------------------------------------------|----------------------------|
| **FORCE**                                    |                            |
| Mass                                         | $2.5 \times 10^{-6} \times T$|
| Calibration                                  | $8.0 \times 10^{-7} \times T$|
| Measurement trueness$^a$                     | $1.5 \times 10^{-6} \times T$|
| Drift (based on calibration uncertainty)     | $8.0 \times 10^{-7} \times T$|
| Earth's gravitational field                   | $3.1 \times 10^{-7} \times T$|
| Air buoyancy                                 | $1.6 \times 10^{-6} \times T$|
| **LENGTH**                                   | $2.0 \times 10^{-8} \times T$|
| Calibration                                  | $1.2 \times 10^{-8} \times T$|
| Measurement trueness$^a$                     | $6.1 \times 10^{-6} \times T$|
| 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                  | $2.9 \times 10^{-7} \times T$|
| **SENSITIVITY and MOBILITY**                 | $2.4 \times 10^{-3} + 9.4 \times 10^{-7} \times T$|
| **TORQUE TRANSMISSION (CIL)**                | $6.7 \times 10^{-3} + 1.1 \times 10^{-5} \times T$|

$a$ Due to the use of nominal value instead of measured value

The expanded (k=2) uncertainty $U_t$ of the torque (T) applied by the LNE 5 kN·m machine is obtained by combination of those components: $U_t = 10 \text{ mN·m} + 5.0 \times 10^{-5} \times T$.

3. Interlaboratories comparison
The comparison has been made with the national metrology laboratory of Germany, PTB. They used their 1 kN·m and 20 kN·m torque standards machines. The expanded uncertainty (k=2) on the applied torque T is equal to $2.0 \times 10^{-5} \times T$. 

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The comparison measuring range was the measuring range of the LNE 5 kN·m torque standard machine i.e. from 100 N·m up to 5000 N·m.

For this comparison we used four transfer torquemeters (figure 2). Table 2 shows the measuring bridges used and the measuring steps realized with the set of torquemeters.

| Transfer torquemeter | Measuring bridges | Steps (N·m)               |
|----------------------|-------------------|--------------------------|
| Raute TT1 200 N·m    | HBM ML38          | 100 and 200              |
| Raute TT1 1000 N·m   | HBM DK38          | 300, 400, 600, 700, 800 and 1000 |
| Raute TT1 2000 N·m   | HBM DK38          | 600, 800, 1000, 1200, 1600 and 2000 |
| Raute TT1 5000 N·m   | HBM DK38          | 1500, 2000, 2500, 3000, 4000 and 5000 |

Each torquemeter has been calibrated on LNE 5 kN·m torque standard machine two times. The first calibration was before sending to the PTB and the second after receiving it from the PTB. Thereby the drift has been established.

The calibrations have been realised in clockwise and in anticlockwise. The calibration of each torquemeter has been realised by performing, in order, the following operations:

- Application of three preload at the nominal value of the torquemeter held for thirty seconds and with a rest period of thirty seconds between each preload.
- Application of at least four series of increasing charges and one 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 (at least 3 different angles). Preload at the maximum load of the sensor after each rotation

For each torquemeter the differences between the LNE values and those of the PTB were calculated. If one step has been measured by two transducers, the mean is taking into account. The LNE values are the average of the results of the calibration before and after the calibration at PTB.
The ‘figure 3’ shows, for each steps of torque, the differences between LNE and PTB. The verticals bars represent the combination of the uncertainty (k=2) of the LNE and PTB torque standard machines.

\[ \text{Figure 3. Difference} = (\text{results LNE 5 kN\cdot m} - \text{results PTB}) \pm U_{\text{standards machines}} \]

For each step, difference is less than uncertainty, it is not significant. Those differences are less than \((2.0 \times 10^{-4} + 3.4 \times 10^{-5} \times T)\) N-m. This limit is taking into account in the budget uncertainty as torque transmission component.

4. Conclusion
The metrological characterisation of the LNE torque standard machine of 5 kN\cdot m give an expanded (k=2) uncertainty equal to \(10 \text{ mN\cdot m} + 5.0 \times 10^{-5} \times T\).

The comparison performed with PTB show that this uncertainty is quite justified.

This metrological characterisation validates technological choices and qualification process which will be applied for the next LNE torque standard machine of 500 N\cdot m under development.

5. References
[1] Averlant P and Gosset A 2007 Development of the new LNE 50 N.m deadweight torque standard machine 20th IMEKO TC3 International Conference, 27 to 30 November, 2007, Merida, Mexico
[2] Dufon C and Averlant P 2014 Qualification métrologique des nouveaux bancs de référence de couple de 5 N.m et de 50 N.m du LNE Revue française de métrologie Volume 2014-2 n°34
[3] Averlant P, Lacipiere P and Davis J-M 2014 Development of the new LNE 5 kN.m deadweight torque standard machine Joint IMEKO 22nd TC3, 12th TC5 and 3rd TC 22 International Conference, 5 to 5 February, 2014, Cape Town, Republic of South Africa