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Development of the new LNE 50 N·m deadweight torque standard machine

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Abstract

This paper describes the new LNE 50 N.m deadweight torque standard machine. Informations on the design, development, and commissioning of this standard are given. Its design is described focusing on mechanical and metrological characteristics in particular of the structure, the deadweight, the air bearing and the lever arm.

Keywords : Torque standard machine.

1. Introduction

The development of the Torque standard machine of 50 N.m is part of a wider scheme which aims at updating French metrological references in Torque metrology. Indeed, the design of the current calibration machines is outdated and these do not meet calibration needs. The *Laboratoire national de métrologie et d'essais* 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 50 N.m one (fig. 1). This allowed us to validate the selected concepts to be used for the development of the other machines.

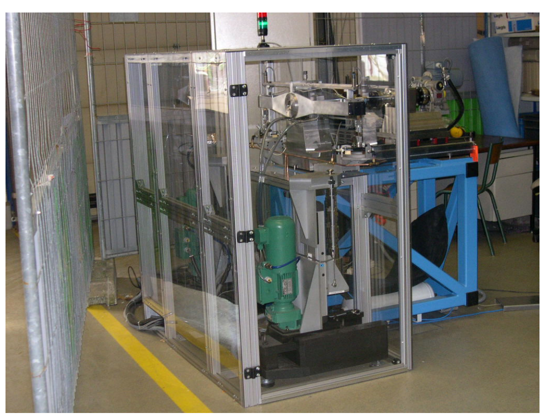

Figure 1. The new LNE 50 Nm deadweight torque standard machine

The next chapters introduce the different steps taken to develop this 50 N.m machine: the principles considered and those selected, a description of the different parts, and the mechanical and metrological features.

2. Principle

Our first target during the development process was to ensure a better definition of the torque applied by the machine on the instrument to calibrate. This applies to the magnitude of he torque applied as well as its geometrical alignment and to the reduction of other applied efforts as far as possible.

The other major aspect was to facilitate the implementation of calibration procedures for torque transducers in accordance with current practices in this field [1] while automating the calibration cycle and optimizing the operation duration. Besides, the system should allow an adjustment to future evolutions in these processes and the application of specific protocols, for the CIPM key comparisons for example.

To reach these objectives, the LNE designed the machine, namely the mechanical elements which play a role in the realization of the Torque quantity. Several specialized subcontractors were entrusted with its realization. The user interfacing software for the machine was designed and built by LNE.

The principle opted for is a classic solution that is adopted for most standard machines recently manufactured in Europe or worldwide, namely a machine with a horizontal transducer orientation, generating torque using a lever-deadweight system. The lever beam is mobile in rotation and is supported in the middle by an air bearing.

The machine (fig.2) is thus mainly made up of :

- the masses generating the forces,
- the platform associated with the weightstack,
- the lever beam and its air bearing,
- the loading device by rotation of the Torque transducer,
- the structure,
- the controlling devices.

The torque measuring device to be calibrate is located between the arm supported by the air bearing and the reduction gear used to compensate the torsion angle of the torque transducer and activate loading.

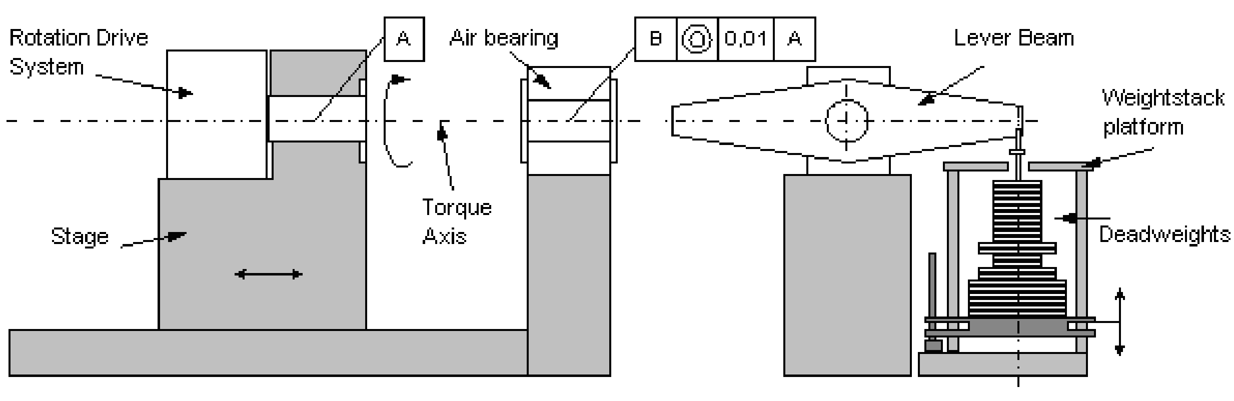

Figure 2. Principal components of the LNE 50 Nm deadweight torque standard machine

3. Structure

The structure was built in a such a way as to allow the forces applied on the sensor to be in the best conditions for definition (direction, magnitude, stability) and by reducing parasitical efforts as far as possible. In order to do so, we focused on the hardness, the isostatism of structures and the thinness of geometrical features.

Thus, mechanical flaws were reduced as far as possible and deformation of the structure during load transfer was minimised thanks to the large size of each mechanical component.

The structure (fig.3) is mainly made up of: :

- a supporting base,
- a straight guidance system,
- a movable stage,
- the support of the air bearing.

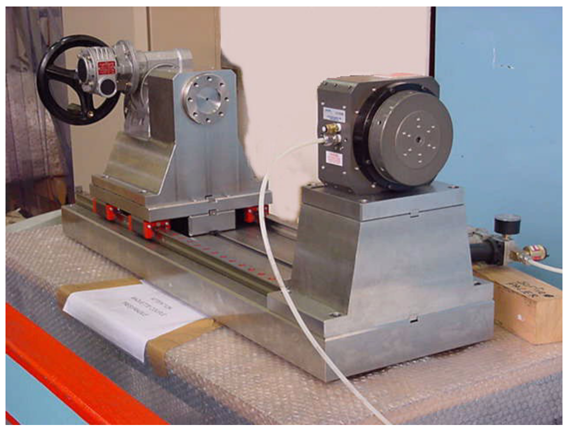

Figure 3. Structure of the machine

. The Supporting Base

It is one meter long and has a reference groove materializing the machine axis. This reference is used to position the support of the air bearing on one hand and the movable stage on the other hand.

. The Straight Guidance System

It is made up of two rails fitted with linear ball bearings of the machine tool type. It allows the adjustment of the machine workspace length by translation of the stage, while staying aligned with the lever beam axis.

. The Stage

The mobile stage in translation on the rails integrates the axis materialisation and hosts the rotation drive system.

. The Support of the Air Bearing

The support of the air bearing has an intermediary plate the height of which is set by rectification to respect the concentricity tolerance with the drive shaft.

This structure ensures at any time the coaxiality between the rotation axis of the lever beam and the rotation axis of the drive system as close as 0.01 mm.

The workspace of the structure can host a cylinder 550 mm long and with a 490 mm diameter. This structure sits on a mechanically welded mount (fig.4).

Figure 4. Mechanically welded mount

4. The Rotation Drive System

To ensure gradual loading on the sensor to calibrate, we selected a reduction gear with a reduction of 6000 (fig.5 rep.1). This extremely high ration is necessary because of the stiffness frequently associated with torque transducers. The reduction device is made up of two worm gear reducers mounted one after the other. This technology ensures static and dynamic irreversibility.

A flexible coupling (fig.5 rep.2) between the reducing gear and the drive shaft optimizes the angular stiffness and thus prevents a significant angular swing while keeping the loading speed gradual. In order to minimize parasite dynamic torques, two levels of angular speeds are used. Speed changes are achieved through slow acceleration and deceleration in order to gradually transfer the torque without shocks and by avoiding causing the lever beam to swing.

The drive shaft (fig.5 rep.3) is positioned in the stage using two hybrid antifriction bearings with ceramic balls. This technological option is good as it reduces friction, which facilitates very low rotational speeds and even loading.

A torque sensor (fig.5 rep.4) permanently fitted on the exit of the reduction gear allows the regulation of loading and monitors the safety thresholds. A friction torque limiter, integrated into the reduction system, protects the equipment from accidental overloading.

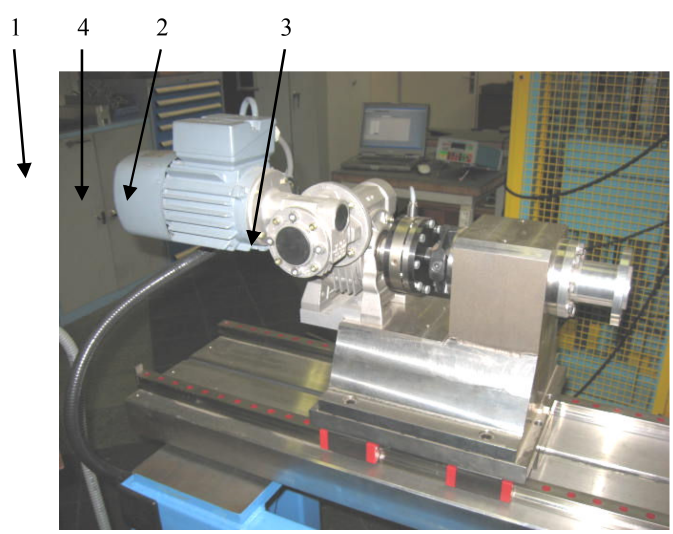

Figure 5. Rotation drive system

5. The Weightstacks

We relied on the principle behind the weightstacks of the LNE torque standard machines of 2 kN (1977) and 5 kN (2000). This principle consists in realizing a weight in two main parts: a “valve” (fig.6 rep.1) and a “bell” (fig.6 rep.3 and 4). The bell of one given weight covers the valve of the next weight. This principle allows the weights to be attached to one another by a single vertical movement (fig.7).

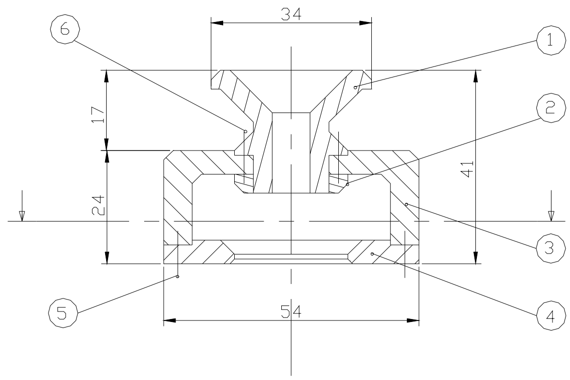

Figure 6. Structure of the machine weights.

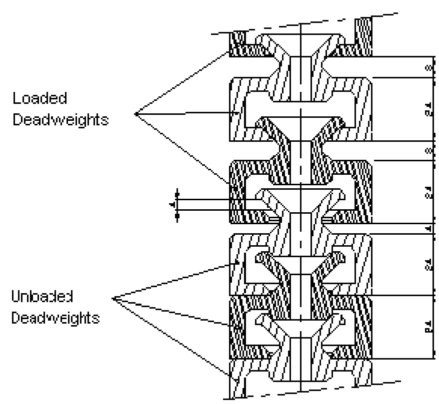

Figure 7. Diagram of the machine weightstack.

The shapes and the manufacturing limits were chosen so as to ensure the gravity centres are aligned and to reduce swing movements. The discs are positioned with a centering cone at 45° with supporting surfaces strictly parallel to each other. These features ensure the disks are stacked very neatly.

The weight steps were chosen in such a way as to allow the calibration of torque transducers of a measuring range of 10 N.m; 20 N.m or 50 N.m; in ten points distributed evenly.

Thus, the proportions of the break down selected for the 5 kN machine are adopted. The length of the torque standard machine lever beam is 0.5 m. This gives the following nominal values, for each weight and in the sequential order of attachment :

- 10 weights generating 2 N (≈ 204 g)
- 2 weights generating 4 N (≈ 408 g)
- 2 weights generating 2 N (≈ 204 g)

- 2 weights generating 4 N (≈ 408 g)
- 6 weights generating 10 N (≈ 1020 g) (fig. 8)

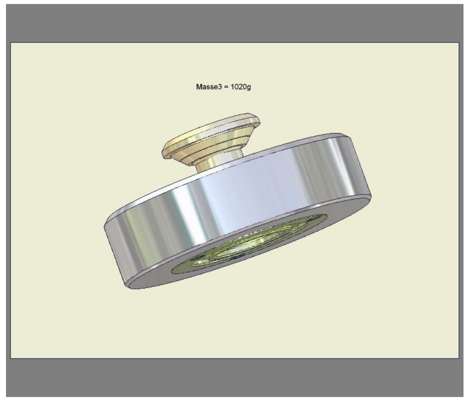

Figure 8. Weight « 10 N ».

This weightstack (fig.9) attached to the end of the lever beam allows the realisation of the following 22 torque steps: 1;2;…;9;10;12;14;15;16;18;20;25;…;45 and 50 N.m

Figure 9 The machine weightstack

The weights are adjusted so as to generate these torque values. The adjustment takes into account the local gravity and an average value for the air buoyancy. The adjustment was made in different steps. The final adjustment was carried out on a mechanical element of low weight, facilitating a high accuracy adjustment up to 2 10^{-6} in relative value.

All mechanical parts within weights are identified by individual and specific labeling. This enables us to monitor subgroups and to modify the parts if need be.

So as to ensure a good preservation of the weights with regard to oxidation issues, weights are made of anti magnetic stainless steel (permeability < 1.01) with improved mechanical features of the same type as the steal of the 5 kN torque machine: NiCu 30 A1 3 Ti (MONEL k500) with a density somewhere around 8460 $kg.m^{-3}$.

6. The Weightstack Plataforms

The weightstacks are integrated to two platforms set at each end of the lever beam. This makes possible calibrations in the two possible directions: clockwise and anti-clockwize modes.

Each platform contains a baseplate supporting the weightstack. By moving vertically, this baseplate allows the suspension of the weights, the first one being attached to the lever beam connector.

During a load modification, lock stops limit the angular range motion of the lever beam which is later set to horizontal by rotation of the torque transducer to be calibrated. This solution with end stops is very beneficial as it ensures that loading is done gradually and evenly through rotation of the torque transducer, and this reduces swinging movements.

Two solutions were considered as to how to position the lock stops. The first of them is a classic one which consists in positioning the lock stops between the lever beam and the mount. However, to load from zero torque to the maximum calibration torque (and inversely), it is necessary to wait until the weightstack suspension is completed. Loading time becomes too long to study the drift under load or the torque sensors relaxation. Therefore, we did not keep this solution.

The other solution has never been put to the test before and was specially implemented for this machine. It consists in shifting the lock stops towards the weightstack and making them retractable (fig.10).

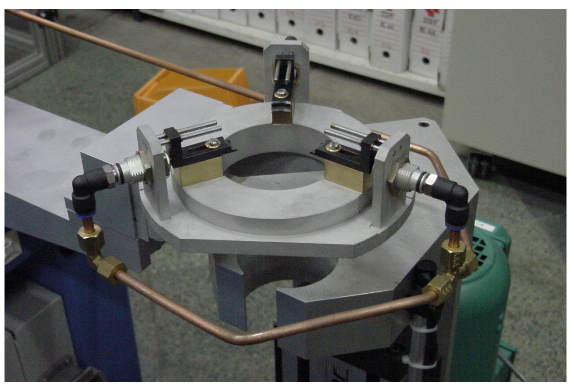

Figure 10. Weightstack platform retractable stops

The first weight is hanged either on the lever beam connector or on the end stop depending on their relative positions. It is possible to prepare a load of several weights by hanging them on the end stop (fig.11 rep.1).

Then, the transfer of this load on to the lever beam only requires one sequence (fig.11 rep.2).

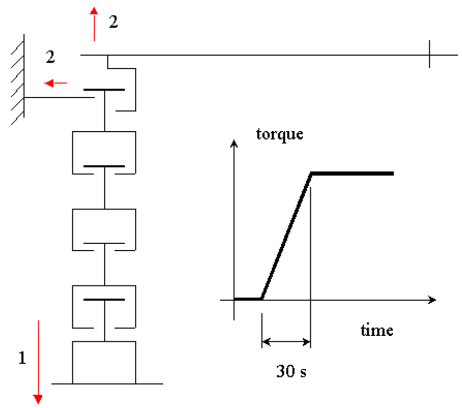

Figure 11. Principle of weightstack platform retractable end stops

This solution has the advantage of keeping loading time optimised when loading from zero torque to the maximum calibration torque when for example realising preloading or when analysing the drift under load and the sensors relaxation.

7. The Arm and its Bearing

The first option we considered was the old LNE 2 kN.m machine, namely, an arm with circular ends and winding tape. But we finally opted for an arm to switch back to horizontal position after each load modification by rotation of the torque transducer. This principle offers advantages compared to the old bench :

- it makes the initial torque offset, caused by the asymmetry of mechanical elements (adjustment parts), constant and acknowledged by the torque transducer initial indications,
- it cancels the variable unbalance caused by the tape winding,
- It allows the calibration of torque transducers of strong angular deformation.

The arm must fulfil two essential roles with regard to the vertical forces generated by the weights: transfer them to the torque transducer and position them at a controlled distance of the rotation axis. Four solutions were considered.

The first of them is to uncouple these two functions by doubling the arm : one being used for transferring the effort and the other being used for keeping the distance. This solution is particularly relevant for substantial efforts. It was not selected for the 50 N.m machine and will be considered for the design of the 5 kN.m machine.

The second solution which was considered had the particularity of keeping weights on one side of the arm only, the other side being fitted with a counterweight. This distinctive feature is interesting in terms of automation, as a single level of weights requires only one actuation. The downside was a noticeable increase of the lever arm weight, namely caused by the counterweight, which resulted in deteriorating the arm mobility and sensitivity essential properties. This solution was rejected.

Another solution was to make an arm with a material of high thermal stability, such as invar. This solution, frequently adopted on recent machines in other countries, present the disadvantage of increasing the weight and the inertia of the arm as well as deteriorating the arm mobility ad sensitiveness.

For optimal mobility and sensitiveness qualities, the arm must be as light as possible with a gravity centre close to the rotation axis. The solution adopted is the realisation of an arm using an aluminium-base alloy with improved mechanical features. The centre of gravity is adjusted by vertical and horizontal displacement of extra weights. The arm includes a device which controls the stability of its length by comparison against an invar ruler fixed on the frame. The comparison is carried out using capacitative sensors. Besides, laser sensors allow the detection of the arm angular position.

The arm is one meter long in total and it is supported in its middle by an air bearing allowing the reduction of friction as far as possible. The air bearing is made by Dover (USA), which is a specialist provider of high precision bearings. The internal clearance between the rotor and the stator is situated somewhere around 10 µm. The rotor has axial thrusts, which allow the bearing to support both axial (up to 755 N) and radial loads (maximum 530 N). Tests made it possible to estimate mobility as being lower than 150 µN.m. An anti-vibration viscous fluid chamber system allowed the reduction of the remaining oscillations.

Fig. 12 Arm in the integration stage

A tape is fixed at both ends of the arm to facilitate the positioning of the force and its uncoupling. An alloy of copper and beryllium was selected for its elastic qualities. The initial width is 0.2 mm but it will be possible to carry out test with different widths and materials if necessary.

This tape is pressed between two plates the shape of which is particularly neat, with gradual and symmetrical radiuses of curvature so as to reduce stress concentration phenomena in the gripping area which can disturb the position of their resultant.

8. Operating the Torque Standard Machine

The operation mode is that of the LNE force standard machines (500, 50, and 5 kN).

For all basic functions, the machine is operated by a programmable automatic control. The latter is operated by a computer which acts as an interface with the user. A specially designed software makes the programming adjustable according to the type of calibration to perform.

Moreover, the automation of calibrations goes as far as allowing the recording of values for the sensor being calibrated through the use of a camera and a character recognition system.

9. Conclusion

The machine is in the final assembly phase (fig.13). It still has to undergo metrological qualification including interlaboratory comparisons.

The effort put in the definition and realisation of the new torque standard machine, in particular in terms of its geometrical properties, should make it a reference at the international level.

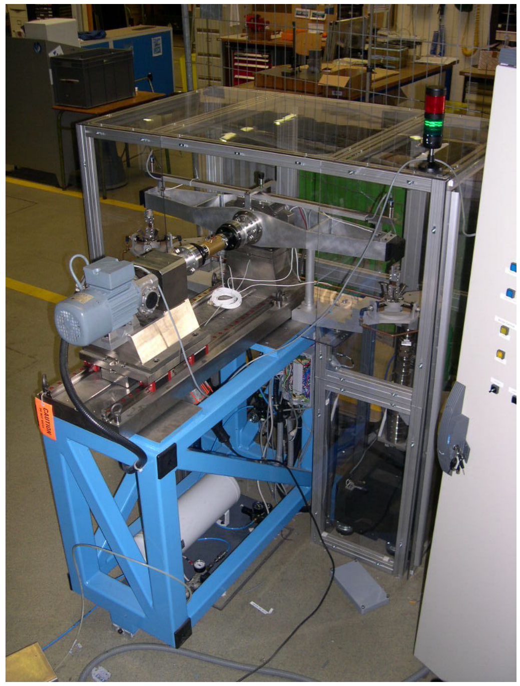

Figure 13. Banc 50 N.m au cours de sa qualification

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