

ENLARGEMENT OF THE TORQUE MEASUREMENT CAPABILITIES AT CEM: DEVELOPMENT OF A 10 kN·m DEADWEIGHT TORQUE STANDARD MACHINE

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Abstract: Centro Español de Metrología (CEM) is developing a completely new torque 10 kN·m deadweight standard machine. This new torque standard machine operates in a working range up to 10 kN·m, clockwise and anti-clockwise. The designed machine, actually under construction, consists of a torque arm, an air bearing, two concentric sets of weight stacks, a main body and a control system that will be able to operate it almost fully automatically.

This paper explains the main technical achievements in its design.

Keywords: Deadweight torque machine, torque measurement, standard torque machine.

1. INTRODUCTION

Since 2001 CEM has developed three torque standard machines, a 1 kN·m deadweight machine, a 20 N·m comparison machine and a 5 kN·m comparison machine.[1] [2]

The main goals in the development of this new standard machine are the improvement of measurement capabilities in torque up to 10 kN·m and the provision of traceability at the highest level to calibration and testing laboratories as well as the industry.

As a first step in the development of the machine, a detailed study of the needs of the Spanish industry as well as a careful research of the state of the art in torque measurements was performed, based on the previous experience of our first torque primary standard.

Once the construction of the machine was decided, the main stages of the project were:

- Study, design of the machine and evaluation of influencing and uncertainty factors. To achieve this, we consulted diverse existing bibliography and we contacted and visited NMIs laboratories, such as PTB (Germany) and NPL (UK). [3] [4] [5]
- Development of the mechanical and electronic design as well as of the control system, including the operational software.
- Construction, assembly, commissioning and characterization of the machine.
- Bilateral comparison and consolidation as a primary standard.

As of the date of this publication, a large part of the mechanical design has been completed and the construction and assembly of the machine structure have been started, as shown in Figure 9.

2. DESCRIPTION

The design of the machine is based on a virtual development, using the modelling tools CAD/CAM (Catia, Pro-Engineer and Ansys), which enables a numerical analysis and calculation. A structural model was developed for the main elements of the machine, such as the arm, frames, transmissions, etc. This model has been developed from two different perspectives. The first one is based on the classical theory for calculating structures, which employs the principles and equations of Euler, Navier, Lagrange, Mohr's Circle, Castigliano, etc. The second method is based on the states theory, the energy transition theory, the finite elements theory, Markov transitions and Von Mises.

Figure 1 gives an overview of the structural parts of the machine, which are described below.

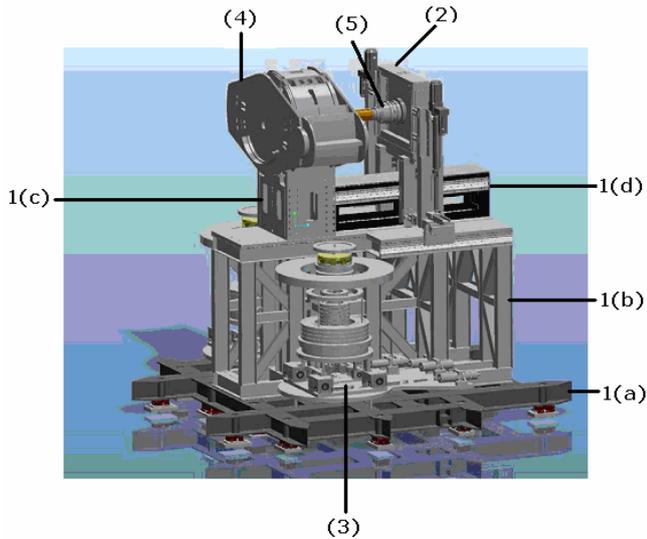


Fig 1: Overview of the machine design

Machine frame (1):

The machine frame constitutes the main structure and is used for supporting and ensuring the stability of the torque measurement mechanism placed above. That is why they have several auto compensating supports that generate a highly stable flat level. The loading centres of the machine have been identified in this machine frame. The configuration has been orientated to the residual stress redirection, which generates a better isolation from natural vibrations and any efforts applied to the structure by the mechanism during the torque application.

It is made up of four structures:

Base frame (1a): its main function is to provide stability and isolation to the system, with a structural configuration orientated to the residual stress redirection, with prior identification of the loading centres, based on energy models. At the same time, the numerous auto-compensating supports and settings contribute to the development of a highly stable flat level. The whole torque standard machine rests on this element.

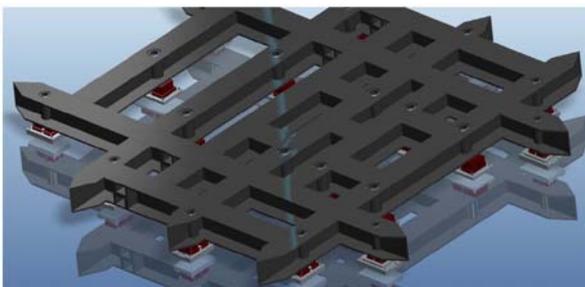


Fig 2: Design of base frame:structure

Supporting frame (1b): This is a key element of the standard machine. It works as a structural element of the machine as well as an auto-compensating element within the whole machine. It enables to minimize flecion reactions and their derivatives. This self-regulated balance is obtained through its hemodynamic architecture.

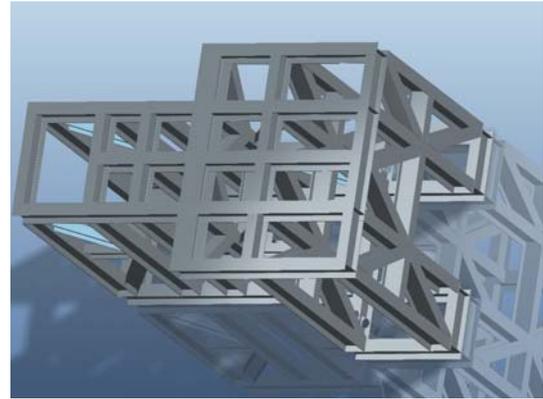


Fig 3: Design of the supporting frame

Air-bearing/ arm level support (1c): The air bearing will be enclosed in a cylindrical ring, as shown in Figure 4. This cylindrical structure will enable the bearing to rotate 360° in its interior to determine its centroid more accurately. Once the position is determined, using discs and pneumatic clamps, it will be fixed, allowing a better accuracy in determining the symmetry and the dimensions of the arm. This structure will be placed on a base, which will be able to support it and transmit the loads to the next frame.



Fig 4: Design of air-bearing/ arm level structure support

Transmission frame (1d): it enables to set the symmetry axis of the machine, and it is used as a support and a guide for the reaction system to the torque generated (counter bearing). This structure is characterized by the rigidity and toughness in its coupling with the transmission bridge (moving part).

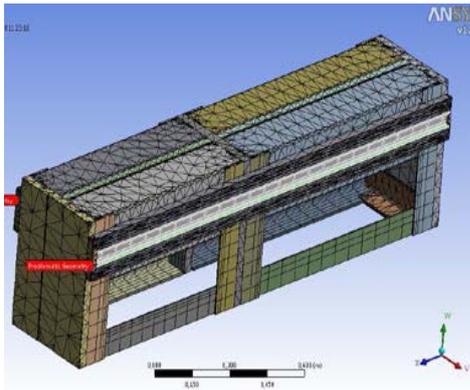


Fig 5: Design of transmission frame structure

Transmission bridge (2)

It serves as a support to the harmonic-drive, which works as a reaction element and moves through rails situated in structures 1(b) and 1(d), providing high rigidity to the whole machine. It has a self-centering and self-balancing system over the main line of the bridge, which allows for a maximum load deflection smaller than $6\mu\text{m}$.

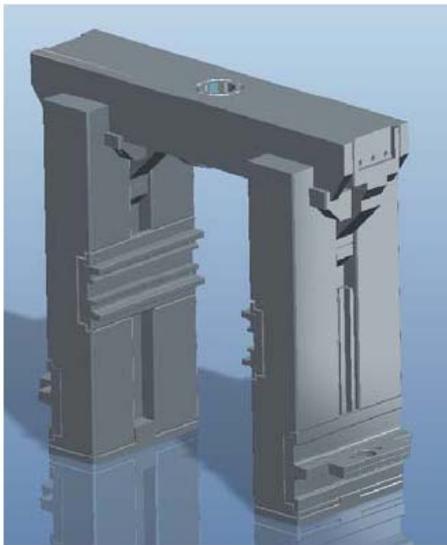


Fig 6: Design of the transmission bridge structure

Torque generation system (3):

The machine will have two sets of masses; each of them rests on a platform with security systems to absorb the system's traction impact. Each platform is composed by three independent lifting systems with a set of masses each. Each set of masses will be a telescopic system and will include 30 masses of three different types, 1 000 N, 500 N and 100 N, which have been manufactured in 1.3952 stainless steel (X4 Cr Ni Mo N 18.14). These masses will be calibrated in CEM with a relative expanded uncertainty better than 2×10^{-6} .



Fig 7: Design of the platform with the set of masses

Set of arm level and air bearing (4)

The arm length is 1m (symmetric) and it is manufactured in INVAR alloy with a robust and light design, which is able to support torques up to 10 kN·m.

The horizontal position of the lever is controlled by non-contact sensors and adjusted to less than $10\mu\text{m}$ using the main drive of the counter bearing.

The arm includes a length checking device, composed by a block gauge and contact sensor in order to verify the position of the arm at any moment. [1]

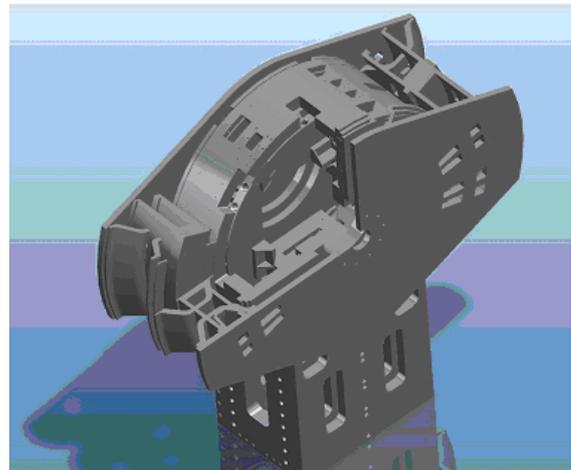


Fig 8: Detail of the arm

In order to minimise friction the lever is suspended by an air bearing, which is enclosed inside a housing cylinder. This development allows rotating the air bearing and obtaining a map to know the symmetry and the centre for the ensemble arm-air bearing. This feature will allow a better accuracy in arm length determination.

The force generated by load elements is transmitted to the arm via thin metal belts.

The foil will be attached in its ends to connect the masses with the arm. This arm will be traced in the CEM Length Laboratory.

Transducer coupling (5)

The installation of the torque transducers in the machine is made via several attachment devices that allow calibrating torque transducers of various sizes and shaft diameters between 50 mm and 110 mm.

Flexible couplings and hydraulic clamps are used in order to reduce possible misalignments during the mounting of torque transducers that could produce parasitic bending inside the transducer and increase the measurement uncertainty.

3. CONTROL SYSTEM

A PLC device is used to control the movements of the machine via a PC that acts as man machine-interface. The machine can operate almost fully automatically with the exception that, the tightening and freeing of the hydraulic clamp to rotate the torque transducer is required to be performed manually during the measurement process.

The main actions of the torque machine are described as follows:

- Moving up and down the weight stacks to increase/decrease the torque sequentially.
- Maintaining the torque arm in a horizontal position by a servomotor and a harmonic drive counteracting the applied torque.

The machine requires seven motors to perform the above actions. One is the counterbearing motor, and the other six are used to move the weight stacks up or down.

4. CONCLUSIONS

When this paper was finished the machine was in the final design stage but some parts have already been manufactured, as it can be seen in figure 9.

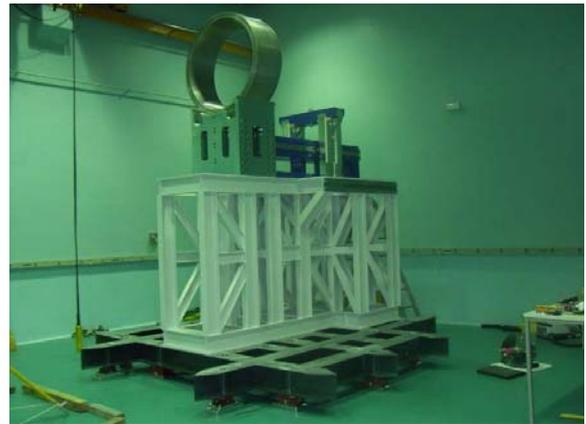


Fig 9: View of the current state

An important advantage of this design is the fact that the main parts of the machine, which include the machine frame and the air bearing, have been designed for torques up to 20 kN·m. As a result, it would be relatively easy to increase the capacity of this machine.

Once the installation is finished, we will compare the new torque standard machine to confirm the expected metrological characteristics. We will inform about the completion of the assembly and the results of such comparison in future technical articles.

Thanks to this new development, CEM will contribute to the current state of the art in torque and will increase, in the near future, the National Standard measurement capabilities up to 10 kN·m, with an expected 2×10^{-5} relative expanded uncertainty.

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