

TORQUE STANDARD MACHINES AT CEM

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Abstract: Centro Español de Metrología has established a torque laboratory according to the State of the Art as a result of a cooperation project with PTB. This paper introduces the torque standards machines developed and installed at CEM, describes their main technical and metrological characteristics and shows some results of the performance studies and comparisons carried out.

Keywords: Torque standard machine, comparison, relative uncertainty.

1. INTRODUCTION

Centro Español de Metrología (CEM), as the Spanish organism in charge of obtaining, maintenance, development and dissemination of the national measurement standards has established a torque laboratory according to the State of the Art as a result of a cooperation project with PTB started in 1998 and ended in 2004. (Fig 1)



Fig 1: Torque laboratory

These new facilities consists of one deadweight torque standard machine with nominal value of 1000 N·m, that allows to generate reference torque values, in clockwise and anti-clockwise from 1 N·m up to 1000 N·m, with an estimated relative uncertainty of $2 \times 10^{-5} T$ ($k=2$), and two torque comparator machines of 5 kN·m and 20 N·m that enable the generation of a torque range from 0.2 N·m up to 5 kN·m in clockwise and anti-clockwise, with an estimated relative uncertainty of $2 \times 10^{-4} T$ ($k=2$). The torque generation is directly traceable to the base units of mass and length of CEM.

2. DESCRIPTION

The torque standard machines are located in a laboratory room with 323.3 m², acclimatized at 20 °C ± 1°C. The local gravity value measured in this room is 9.79950659 m/s².

The three torque standard machines include air bearings as quasi-static radial bearings for absorbing transverse forces and bending moments.

Their main technical characteristics are described in the following items.

2.1. 1 kN·m deadweight torque standard machine

The torque magnitude is generated by dead-weights suspended by a two arm lever in the gravitational field of the earth. The measurement axis of this machine is horizontal.

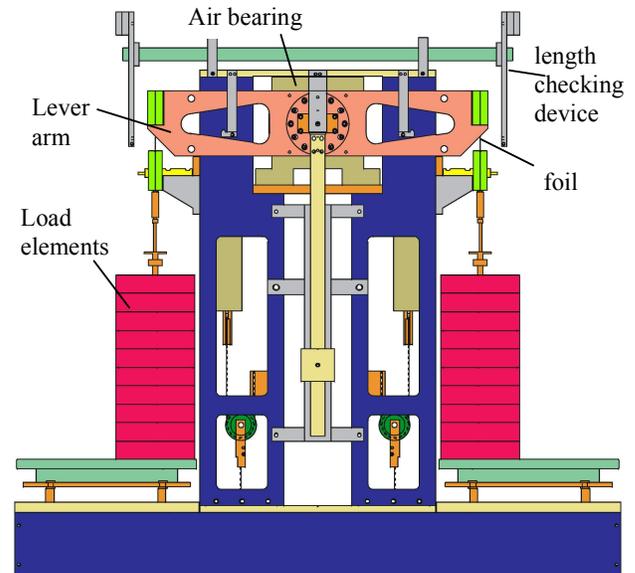


Fig 2: 1 kN·m deadweight torque standard machine

The torque standard machine (Fig.2 and Fig.3) consists of the following main parts:

Main frame

The frame is of welded and bolted steel construction, floor mounted. It has a high stiffness and support torque producing with deadweight and the lever.

Arm lever

The lever composed of two symmetric arms is made of Super Invar (special steel with a thermal expansion coefficient of less than $2 \times 10^{-7} \text{ K}^{-1}$) with a nominal value of 500 mm (symmetrical). It was machined avoiding heating in order to maintain their physical properties.

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 force generated by load elements is introduced into the arm lever via thin metal belts of $25 \mu\text{m}$ thickness.

A length checking device composes by 1050 mm block-gauge and contact sensors, is mounted in the frame in order to check the stability of the arm length.

Air bearing as fulcrum

The lever is suspended by a radial air bearing and for axial fixation small additional axial air bearing are mounted to the machine frame. The frictional moment evaluated by tests is $10 \mu\text{N}\cdot\text{m}$. The bearing operates at a constant pressure from 400 kPa to 600 kPa.

Weight loading parts

The load elements are 120 disk shaped austenitic non-magnetic stainless steel (X2CrNiMoN 18.14-3) and surface roughness of $R_a \leq 5 \mu\text{m}$ and $R_z \leq 10.5 \mu\text{m}$, grouped in 12 sets positioned at each side of the lever for right and left hand torque values:

10 disks x 200 N x 2 sets

10 disks x 100 N x 2 sets

10 disks x 40 N x 2 sets

10 disks x 20 N x 2 sets

10 disks x 10 N x 2 sets

10 disks x 4 N x 2 sets

The stacks of load elements are placed on a manual turntable for changing the six sets of load elements. In this turntable is included an elevator device for loading and unloading the load elements.

The mass values of all load elements are traceable to the national mass standards and their relative uncertainties are less than $1.5 \times 10^{-6} M$. ($k=2$)

Counter bearing

A servomotor and a harmonic drive are used as counter torque application. The adjustment tolerance for the horizontal lever position is better than $10 \mu\text{m}$ ($2 \times 10^{-5} \text{ rad}$).

Transducer coupling

The installation of the torque transducers in the machine is made via some attachment devices that allow calibrating torque transducers of various sizes and shapes with dimensions up to 300 mm of radius and of 830 mm of length and shaft diameter between 8 mm and 50 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.

Control system

A PLC device is used to control the movements of the machine via a PC that acts as man machine-interface. The measurement software has been developed at CEM using visual basic tools that allows to carry out automatic calibration procedures.



Fig 3: 1 kN·m deadweight torque standard machine

Specifications

- Torque range:
1 N·m up to 1000 N·m
- Relative uncertainty of the torque:
 $2 \times 10^{-5} T$ ($k=2$)
- Testing space:
Maximum space allowable:
Diameter: 600 mm
Length: 830 mm
- Approximate overall height of the machine:
1800 mm
- Base area:
1870 mm x 1895 mm
- Approximate weight of the machine:
2380 kg

2.2. 5 kN·m comparator torque machine

The torque magnitude is generated by an electric motor and gear boxes. The measurement axis of this machine is horizontal. (Fig 4)

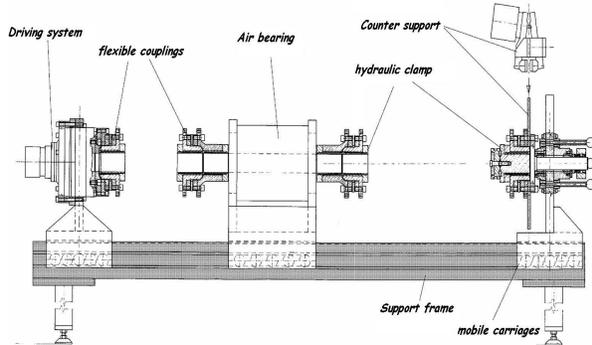


Fig 4: 5 kN·m Comparator machine scheme

The torque standard machine consists of the following main parts:

Support frame

The frame is of welded and bolted steel construction with a high stiffness and, floor mounted.

On this frame, three mobile carriages are mounted that support the driving unit, air bearing and counter support system respectively, in order to adapt the machine to different transducer dimensions.

Driving system:

An AC servomotor combining with a precision harmonic drive gearing allow to generate a very wide range of angular speed and provide smooth torque in the measurement range of the machine.

Air bearing

The connection between the reference transducer and the test transducer is made via an air bearing in order to reduce parasitic loads resulting from the handling of the test transducers.

The frictional moment evaluated by tests is $12 \mu\text{N}\cdot\text{m}$. The bearing operates at a constant pressure from 400 kPa to 600 kPa.

Coupling

The installation of the torque reference transducers and calibration objects in the machine is made via hydraulic clamp and flexible couplings that compensate possible misalignments and angle errors and provide low stiffness for bending moment a high stiffness for torque.

Counter support

It comprises a steel disk with four air clamp brake units. It is located at the output drive end of the calibration object. This device allows to avoid possible overloads by regulating the air pressure of the brake clamps.

Control system

The machine operation is carried out by a programmable logic controller (PLC) together with a personal computer.

The measurement software has been developed at CEM using visual basic tools that allows to carry out automatic customized calibration procedures clockwise and anticlockwise. The reference set torque point values are got dynamically and without necessity of interpolation tools with a maximum deviation of 2×10^{-5} of reading.



Fig 5: 5 kN·m Comparator machine scheme

Specifications

- Torque range:
from 2 N·m up to 5000 N·m
- Relative uncertainty of the torque:
 $2 \times 10^{-4} T (k=2)$
- Testing space:
Maximum space allowable:
Diameter: 640 mm
Length: 740 mm
- Approximate overall height of the machine:
1440 mm
- Base area:
2500 mm x 800 mm
- Approximate weight of the machine:
1450 kg

2.3. 20 N·m comparator torque machine

This machine has a similar design that 5 kN·m but with vertical measurement axis. This vertical design allows to reduce all side forces generated by the weight of all components (reference transducers and calibration objects). (Fig 6)

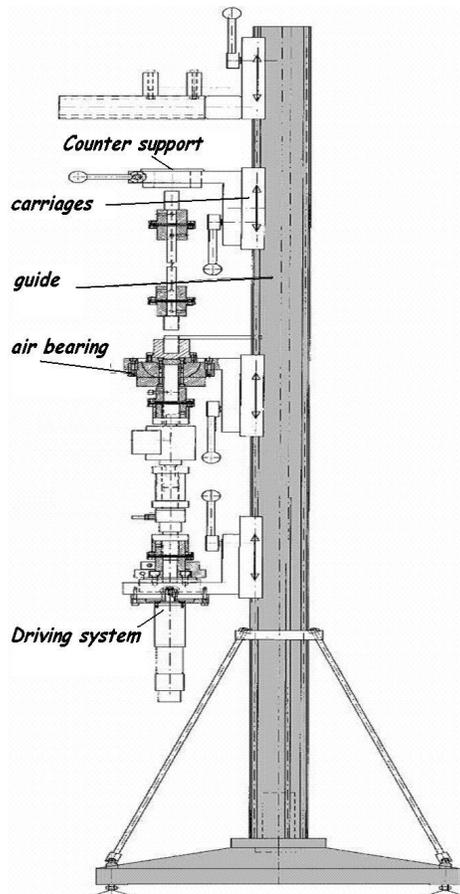


Fig 6: 20 N·m Comparator machine scheme

Specifications

- Torque range:
from 0.2 N·m up to 20 N·m
- Relative uncertainty of the torque:
 $5 \times 10^{-4} T (k=2)$
- Testing space:
Maximum space allowable:
Diameter: 220 mm
Length: 820 mm
- Approximate overall height of the machine:
1900 mm
- Base area:
500 mm x 500 mm
- Approximate weight of the machine:
45 kg

3. PERFORMANCE STUDIES

Some studies about performances of the machines have been carried out in order to evaluate some possible influences such as stability of the frame, misalignment, and others. Results of these studies are given in short in the following lines.

3.1 Stability of the frames

The stability of the frames has been tested loading the machines with different torque values and measuring possible deformation of the frames by precision gauge levels and dial indicators. Negligible deformations have been found.

3.2 Balance test in 1 kN·m deadweight machine

The torque standard machine is tested as a balance with equal load elements mounted on both side of the lever arm. The test consists in:

- take the value of zero indication without any loads in the arm lever
- apply a load on one side of the lever arm
- balance the arm lever with a load equal to the above step on the other side of the lever arm and take the measurement value. This value gives the possible unbalanced state of the arm
- repeat 4 times more the above steps

This test has been carried out with different standard torque transducers (10 N·m, 20 N·m, 100 N·m, 1000 N·m).

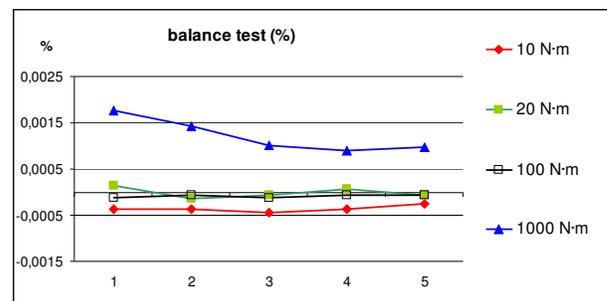


Fig 7: Balance test results

The results of this test represented in Fig 7 have shown a very good balance behaviour.

3.3. Sensibility of the 1 kN·m torque standard machine

It was tested by small weights and one small capacity torque transducer (1 N·m) and was evaluated by 0.01 mN·m.

3.4 Bending evaluation of the arm (1 kN·m torque standard machine)

It was evaluated at maximum load on both side of the arm. The maximum displacement at the end of the arm is 85 μm (relative variation of the arm length of 1.5×10^{-8}). There are no torsions in the two plate of arm.

3.5 Misalignment test

The axial alignment of the machines is checked periodically by an accuracy steel shaft H7 tolerance and the results have shown a good adjustment and stability.

4. COMPARISONS

Internal comparison among the three torque machines and in addition a bilateral comparison with PTB has been carried out.

The transfer standards used in these comparisons were high precision torque transducers, type TT1 (Raute) and TN (HBM), associated with a carrier frequency measuring amplifiers, type DMP 40 S2 and a PC, working with data acquisition software developed at PTB for CEM-PTB comparison and data acquisition software developed at CEM for internal comparison, which facilitates data transfer and analysis by excel spreadsheets.

The scheme of the test procedure applied in both comparisons is shown in Fig. 8. The load steps were 20%, 40%, 60%, 80% and 100 % of the nominal torque value.

In the case of CEM-PTB comparison, the preloads were carried out by loading sequences (loading-unloading step by step) and not for one maximum value as traditional in calibration procedures.

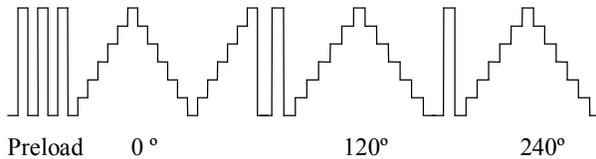


Fig 8: Comparison test procedure

4.5.1 Internal comparison (coherence test)

The coherence of the measurement results of the three machines is assessed by comparing the results of some torque transducers subjected to the same torque values realized in the three torque machines following the procedure mentioned above. The results obtained are shown in figures 9 to 12.

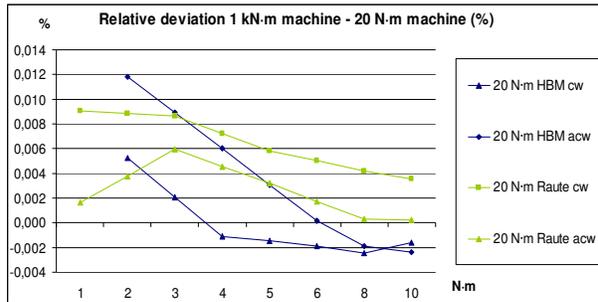


Fig 9: Internal comparison results (1 kN-m machine/10 N-m as reference transducer in 20 N-m machine)

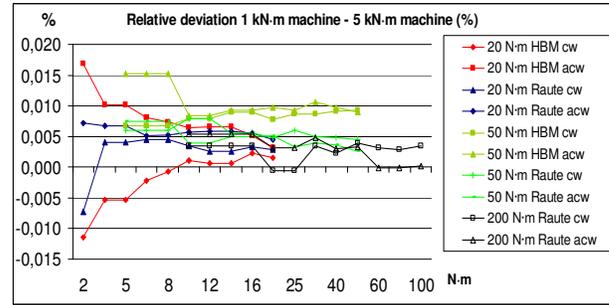


Fig 10: Internal comparison results (1 kN-m machine/100 N-m as reference transducer in 5 kN-m machine)

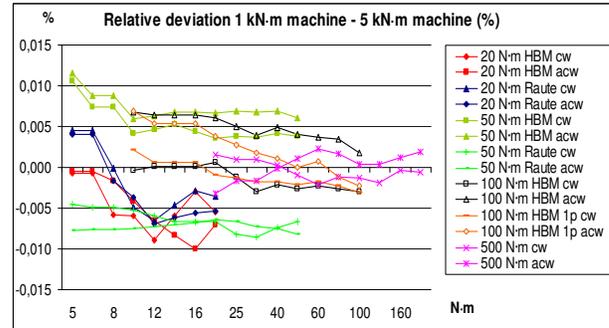


Fig 11: Internal comparison results (1 kN-m machine/200 N-m as reference transducer in 5 kN-m machine)

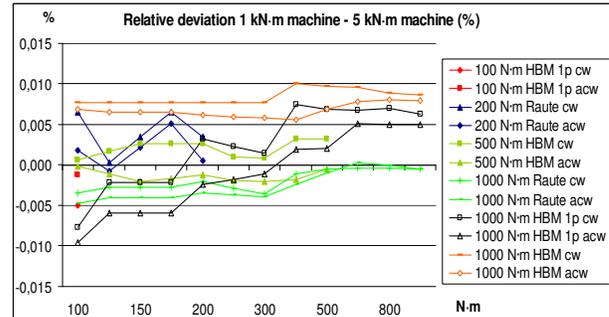


Fig 12: Internal comparison results (1 kN-m machine/1000 N-m as reference transducer in 5 kN-m machine)

The results have shown a coherence better than 2×10^{-4} between the three machines.

4.5.2 CEM-PTB Comparisons

4.5.2.1 Comparison of deadweight torque standard machine 1 kN-m

The relative deviations of the results between CEM and PTB for the transducers used in the comparison exercise (1 kN-m, 100 N-m, and 10 N-m) are presented in Fig 13. The results show a maximum relative deviation better than 5×10^{-5} .

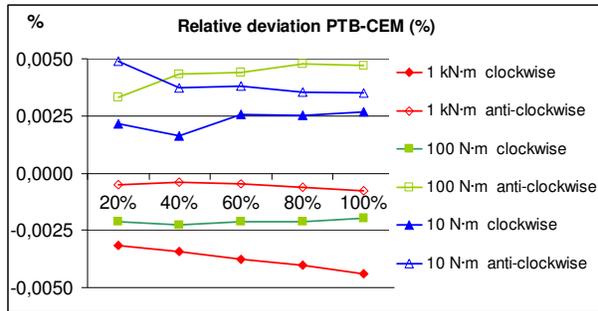


Fig 13: CEM-PTB comparison results

4.5.2.1.1 Calibration comparison 5 kN·m

To check the comparability of the calibration results according to EA-10/14, a 5 kN·m torque transducer was calibrated clockwise and anticlockwise at 5 kN·m torque comparison machine of CEM and 20 kN·m deadweight torque standard machine of PTB. The results are shown in Fig 14.

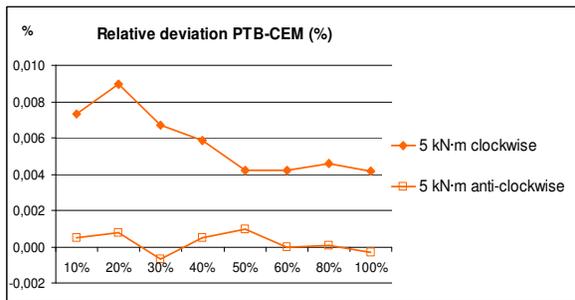


Fig 14: CEM-PTB calibration result comparison

The results show a maximum relative deviation better than 9×10^{-5} .

5. CONCLUSION

A set of torque standard machines has been developed taken into account the State of the Art in torque measurement and has been installed at CEM laboratory. The results of the studies and comparisons carried out prove that the best measurement capabilities of these torque standards machines are in line with other similar machines of National Institutes.

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