

# INVESTIGATION OF THE CALIBRATION AND MEASUREMENT CAPABILITIES OF THE NEW 5 kN·m TORQUE CALIBRATION MACHINE AT GUM

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**Abstract** – A new torque calibration machine with a torque capacity of 5 kN·m has been installed in Force and Pressure Laboratory of GUM. This reference type machine generates torques in vertical axis in a range from 10 N·m to 5 kN·m with an expanded relative measurement uncertainty of 0,04 % ( $k = 2$ ). Performance of the machine has been evaluated via comparison between GUM and PTB. Results of comparison measurement are presented.

**Keywords:** torque, torque calibration machine, comparison

## 1. INTRODUCTION

For calibration of torque measuring devices different types of torque standard machines can be used. Direct loading machines generate torque usually in horizontal axis with masses on a lever arm. This type is generally used as national standard with traceability directly derived from units of mass, length and time. Direct application of dead weights enables generation of torques with high accuracy but requires considerable building space and a lot of maintenance of main machine components such as air bearing or damper. Due to high cost of materials and components such as dead weight and lever, dead weight torque standard machines are also quite expensive.

On the other hand reference type machines can be found as much cheaper solutions. Most of them generate torques in vertical axes which allows to reduce parasitic components derived from the weight of the test transducer, adapters and couplings. Reference torque machines can work for many years without maintenance and repair. For providing the traceability it is required to recalibrate reference transducers, mostly in every two years. Reference type machines enable also continuous calibration while direct application machines can realize only step loading.

In December 2014 a new torque calibration machine (TCM) with a torque capacity of 5 kN·m has been installed in Force and Pressure Laboratory of GUM. This machine was developed and constructed by Calibration Engineering Hohmann (CEH, Germany) in co-operation with Drehmomentservice Dr. Peschel (DmS, Germany). The TCM is a reference (comparison) type machine and uses a set of three torque transducers as references (working standards).

After the installation of the machine calibration of three torque transfer transducers have been done as a part of a

comparison between results obtained in the GUM's TCM and torque standard machines at PTB

## 2. DESCRIPTION OF THE TCM AND ITS COMPONENTS

The TCM is a manually controlled machine which consists of three columns framework with a side boom, DC motor for torque generation with a gearbox, flexible couplings, clamping elements, adaptation parts, amplifiers, three reference transducers and laptop with special software. The detailed description of main components of the TCM is given in Table 1.

Table 1. Detailed description of main components of the TCM.

Component	Detailed description	
Framework	Ø1000 mm, vertical height ~3600 mm, torsional stiffness about 3°, pneumatic lifting block for 3 kN, one side boom frame length ~3000 mm fixed to the base frame and the floor	
Reference transducers	TB2 flange type, manufacturer: HBM - Darmstadt, Germany, with cylindrical shaft pieces, equipped with inner square drives	
	Capacity	Calibration range
	100 N·m	10 N·m to 200 N·m
	500 N·m	50 N·m to 1000 N·m
3000 N·m	200 N·m to 5000 N·m	
Amplifiers	Type DMP 40 S2 and MGCplus/ML38B, manufacturer: HBM - Darmstadt, Germany	
DC motor and gearbox	0,75 kW, 180 VDC, speed operated manually operated, combination of planetary and worm gearbox for self-locking	
Flexible couplings	Radex NN, highly flexible for bending and very stiff for torsion	
Special software	For multichannel reading, correction of nonlinearity and hysteresis, calibration in accordance to DIN 51309 [1] and DKD R 3-7 [2], measurement of creep and remanence value	

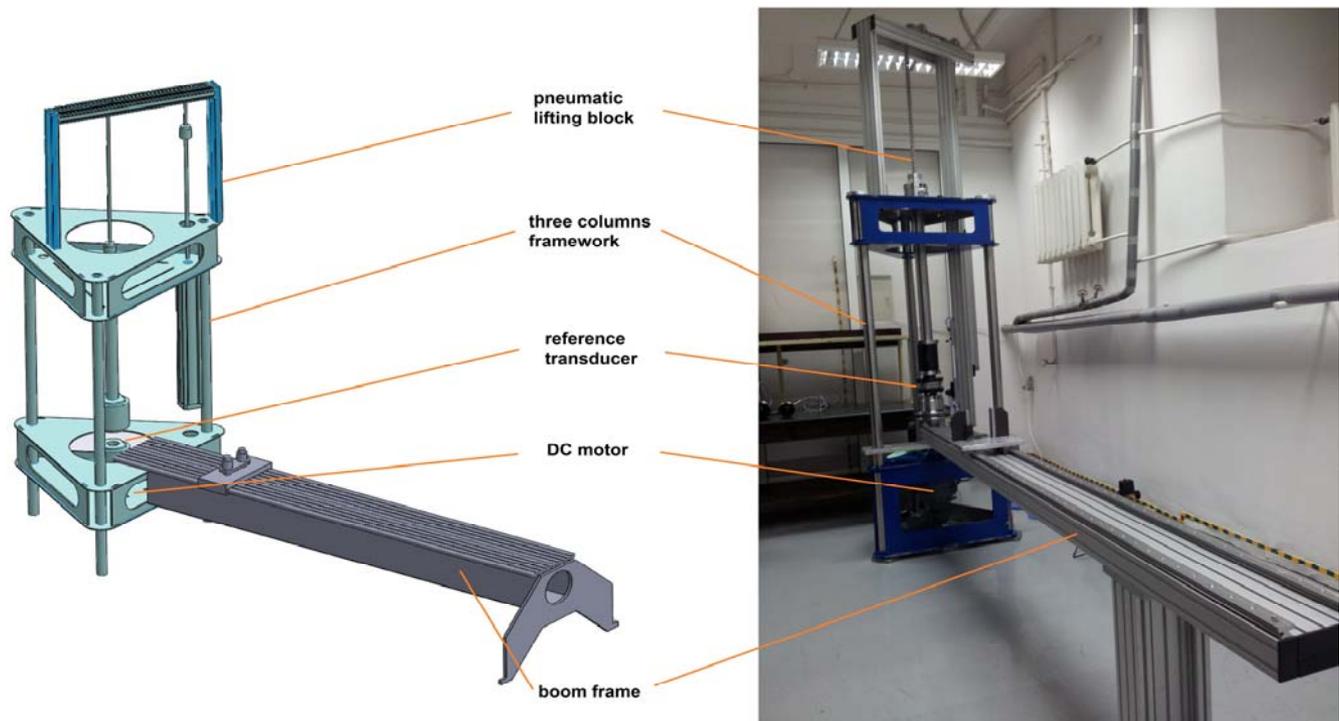


Fig. 1. General overview of the TCM installed in GUM as a scheme (left) and at the photo (right).

All reference transducers are being used in a range exceeding their nominal capacity in agreement with the manufacturer. The calibrations of reference transducers were carried out by PTB according to DIN 51309 (for both clockwise and anticlockwise torques). Measurements of short-term creep have been performed. The calibrated reference transducers and their calibration results are used for the control of the machine. Operating system of the machine allows the operator to generate any value of the torque within the reference transducer's measuring range, apply it to the calibrated device and interpolate results to full values of the torque (eg. 100 N·m). The TCM is used to calibrate torque transducers and, by using the specially designed side boom frame, torque transfer wrenches. The general overview of the TCM is shown in Fig. 1.

### 3. UNCERTAINTY EVALUATION

The standard measurement uncertainty of the torque generation of the TCM can be estimated from (1):

$$u_{\text{TCM}}^2 = \sum_{i=1}^7 u_i^2 \quad (1)$$

where:

$u_1$  – relative standard uncertainty of calibration results of reference transducers, less than  $3 \cdot 10^{-5}$  when cubic fitting functions are used;

$u_2$  – relative standard uncertainty due to short-term creep of reference transducers; maximum relative creep:  $1 \cdot 10^{-4}$ ;

$u_3$  – relative standard uncertainty associated with long-term drift of reference transducers; relative drift between calibrations is expected to be not greater than  $2 \cdot 10^{-4}$ ; the exact value of the long-term drift will be calculated using results of the next calibrations performed on the same torque standard machines at PTB;

$u_4$  – relative standard uncertainty due to misalignment of the device under calibration; when using two flexible couplings the influence of radial displacement is very small; in this case the relative change of sensitivity is only  $1 \cdot 10^{-5}$  [3];

$u_5$  – relative standard uncertainty associated with the resolution and stability of the indicating device (amplifier); it was found to be smaller than  $6,612 \cdot 10^{-5}$ ;

$u_6$  – relative standard uncertainty associated with using reference transducers in partial ranges; implementation of the scaling transformation of polynomial interpolation equations (3<sup>rd</sup> degree, for both increasing and decreasing torque) allows this uncertainty to be smaller than  $1 \cdot 10^{-4}$  [4];

$u_7$  – relative standard uncertainty due to stability of torque transmission on shafts; related with performance of the DC motor and the gearbox; smaller than  $1 \cdot 10^{-5}$  [5];

$u_8$  – relative standard uncertainty due to influence of the variation of temperature on reference transducers; not greater than  $1,155 \cdot 10^{-5}$ ;

The uncertainty budget for torque generation of the TCM is presented in Table 2.

Table 2. Uncertainty budget of the TCM.

Parameter	Probability distribution	Relative uncertainty
calibration uncertainty of reference transducers	normal	$u_1 = 3 \cdot 10^{-5}$
creep	rectangular	$u_2 = \frac{1 \cdot 10^{-4}}{\sqrt{3}} = 5,77 \cdot 10^{-5}$

long-term drift	rectangular	$u_3 = \frac{2 \cdot 10^{-4}}{\sqrt{3}} = 1,15 \cdot 10^{-4}$
misalignment	rectangular	$u_4 = \frac{1 \cdot 10^{-5}}{\sqrt{3}} = 5,77 \cdot 10^{-6}$
indicator	normal	$u_5 = 6,61 \cdot 10^{-5}$
partial range	normal	$u_6 = 1 \cdot 10^{-4}$
transmission	normal	$u_7 = 1 \cdot 10^{-5}$
temperature	rectangular	$u_8 = \frac{2 \cdot 10^{-5}}{\sqrt{3}} = 1,15 \cdot 10^{-5}$
combined uncertainty	normal	$u_{TCM} = 1,794 \cdot 10^{-4}$
expanded uncertainty	normal ( $k = 2$ )	$U_{TCM} = 3,588 \cdot 10^{-4}$

Therefore, the TCM is able to reach a calibration and measurement capability of  $U_{TCM} = 0,04\%$  (expanded uncertainty with  $k = 2$ ).

### 3. COMPARISON RESULTS

In order to investigate the measurement performance of the TCM three transfer transducers have been calibrated in PTB as well as on-site in GUM under stable laboratory conditions. Transfer transducers are the same type and capacity as reference transducers. Table 3 shows measuring ranges realized with the set of transducers.

Table 3. Measuring ranges realized during the comparison.

Reference transducer	Transfer transducer	Measuring range
TB2 / 100 N·m	TB2 / 100 N·m	10 N·m to 200 N·m
TB2 / 500 N·m	TB2 / 500 N·m	50 N·m to 1000 N·m
TB2 / 3000 N·m	TB2 / 3000 N·m	200 N·m to 5000 N·m

Calibration results of transfer transducers has been fitted by using cubic functions to reach small uncertainties of 0.04 % in the TCM. In this case, the results of the 100 N·m and the 3000 N·m transducers are very close to that obtained during the calibrations in the PTB, see Table 4. Due to significant sensitivity drift of the 500 N·m transfer transducer its results are worse by about one order of magnitude [6].

Table 4. Relative deviations between the results of the transfer transducer calibrations obtained in the TCM in GUM and the initial calibration results in PTB.

Reference transducer	Maximum relative deviations between two calibration results in GUM and PTB for all torque steps	
	Clockwise	Anti-clockwise
TB2 / 100 N·m	0.002 %	0.003 %
TB2 / 500 N·m	0.036 %	0.042 %
TB2 / 3000 N·m	-0.005 %	-0.006 %

For the calculation of comparison results, it is important to realize that the calibration results are not uncorrelated. The reference transducers used in the TCM were calibrated on the same torque standard machines like the transfer transducers. Therefore the correlations must be taken into account

For the evaluation of comparison results, the  $E_n$  value given by (2) is used in most cases. Values  $X_{P1}$  and  $X_{P2}$  with corresponding standard measurement uncertainties  $u_{P1}$  and  $u_{P2}$  are results of the participants 1 and 2, respectively.

$$E_n = \frac{X_{P1} - X_{P2}}{2 \cdot \sqrt{u_{P1}^2 + u_{P2}^2}} \quad (2)$$

When the quantities are correlated  $E_n$  can be expressed as follows in (3), where  $u_{1,2}$  is the covariance.

$$E_n = \frac{X_{P1} - X_{P2}}{2 \cdot \sqrt{u_{P1}^2 + u_{P2}^2 - 2 \cdot u_{1,2}}} \quad (3)$$

In the case of perfect correlation the correlation coefficient is 1 [7] and the covariance can be found from (4). The assumption that correlation coefficient of 1 is a strong criterion. For values less than 1 the  $u_{1,2}$  will be lower than  $u_1 \cdot u_2$  and the denominator in (3) will be higher which will result in lower  $E_n$  values.

$$u_{1,2} = u_1 \cdot u_2 \quad (4)$$

For the analysis of this comparison the  $E_n$  value is then given by (5).

$$E_n = \frac{X_{TCM} - X_{PTB}}{2 \cdot |u_{TCM} - u_{PTB}|} = \frac{X_{TCM} - X_{PTB}}{|U_{TCM} - U_{PTB}|} \quad (5)$$

The condition for a successful result of comparison is given by (6).

$$|E_n| \leq 1 \quad (6)$$

Fig. 2, Fig 3 and Fig 4 show results of the calculated values of  $E_n$  for all three transfer transducers.

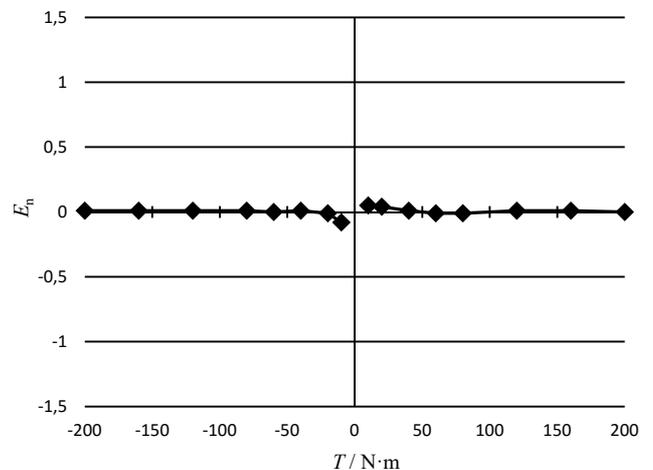


Fig. 2. Calculated values of  $E_n$  for 100 N·m transfer transducer.

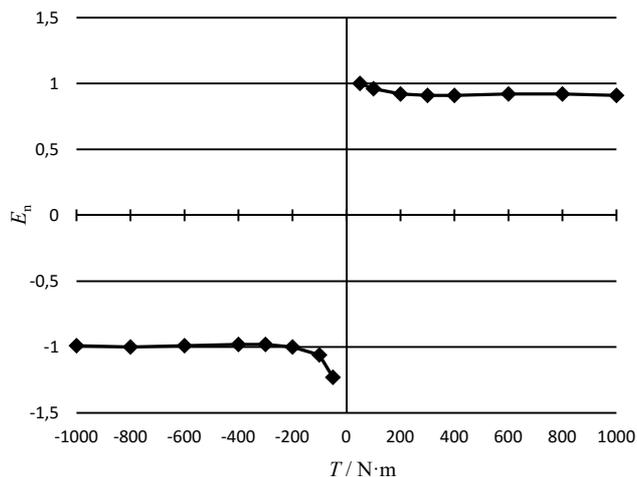


Fig. 3. Calculated values of  $E_n$  for 500 N·m transfer transducer.

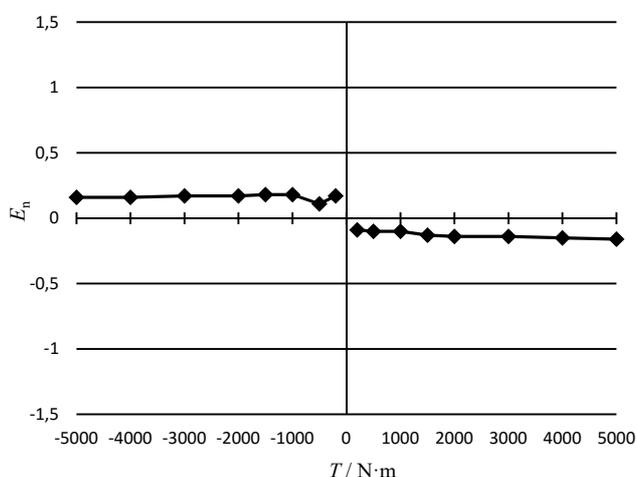


Fig. 4. Calculated values of  $E_n$  for 3000 N·m transfer transducer.

#### 4. CONCLUSIONS

It can be seen that the results shown in Fig. 2, Fig 3 and Fig 4 demonstrate that the TCM installed in GUM was able to generate clockwise and anticlockwise torques in a range from 10 N·m to 5 kN·m with an expanded relative measurement uncertainty of 0,04 % ( $k = 2$ ). Due to its instability, the results of the 500 N·m torque transfer transducer cannot be taken as a proof of reaching the calibration and measurement capability of the TCM. However, the overall result of the comparison is successful because for two other transfer transducers, 100 N·m and 3000 N·m which cover the whole measuring range of the TCM, absolute values of  $E_n$  do not exceed 0,19.

#### ACKNOWLEDGMENTS

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