IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference
11 – 13 October 2022, Cavtat-Dubrovnik, Croatia

1 kN·m UNIVERSAL TORQUE CALIBRATION MACHINE WITH REFERENCE TORQUE TRANSDUCER AT SASO / NMCC

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Abstract:

1 kN·m universal torque calibration machine with reference torque transducer was established at National Measurement and Calibration Center (SASO / NMCC) in 2019. Torque values are generated over reference torque transducers by means of a servo motor. The machine is equipped with an air bearing and a torque arm mounting component. It is possible to calibrate torque transducer, torque wrench with high accuracy and also hand torque tools with this machine. In this paper, the mechanical structure of the machine and the result of the performances test and uncertainty assessment are described. The relative expanded measurement uncertainty is smaller than 2×10^{-4}.

Keywords: torque calibration machine; torque calibration with reference torque transducer; static torque calibration; air bearing; uncertainty

1. INTRODUCTION

The variety in torque measurement devices has also led to the variation of torque calibration devices. In addition to that, the demand for high precision, the expectation of compliance to changing standards, increasing workload of calibration laboratories and data security led to the emergence of more flexible and inclusive calibration devices.

The 1 kN·m universal torque calibration device introduced in this article is the result of an effort to reduce the static (or quasi-static) calibrations in the torque field to a single device.

The machine is designed for almost all types of static calibration of torque measuring devices. Calibration facilities of the machine are as follows:

- Static calibration of torque transducers (according to EURAMET/cg-14:2011, DIN 51309:2005, and BS 7882:2017 or equal standards [1], [2], [3])
- Static calibration of indicating torque wrenches with high accuracy (calibration of reference torque wrenches according to DKD-R 3-7:2015 or equal standards [4])
- Calibration of hand torque tools (according to ISO 6789 -2 or equal standards [5])

2. PRINCIPLE OF THE TORQUE CALIBRATION MACHINE

2.1. Mechanical Structure of the Machine

1 kN·m Torque Calibration Machine is universal torque calibration machine (Figure 1) and provides torque with the help of reference torque transducers. The working direction of the machine is vertical. It is used for static or continuous (quasi-static) calibration of torque measuring devices according to the national and international torque calibration standards.

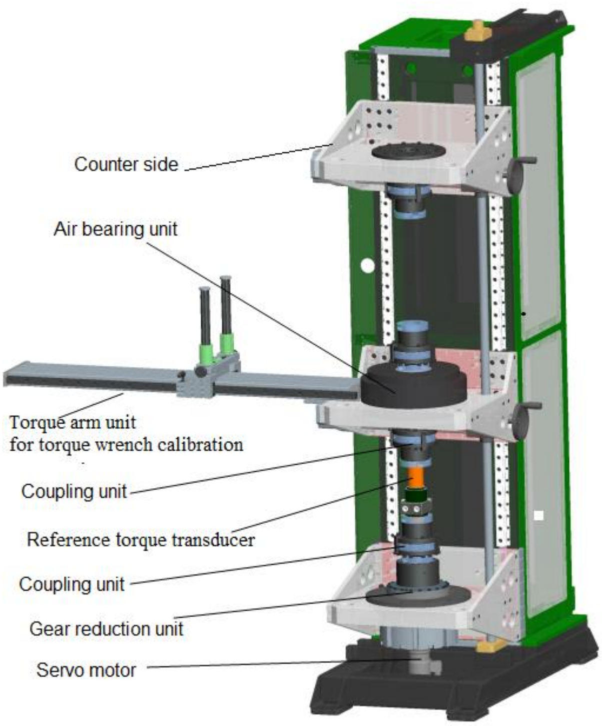

Figure 1: Schematic view of 1 kN·m universal torque calibration machine

Torque values are generated over reference torque transducers by means of a servo motor and harmonic gear box. The reduction ratio of the gear box is 1:5 000 and a 13-bit absolute encoder is used with the servomotor.

To be able to eliminate the parasitic effect on the reference torque transducer, an H-type air bearing (Intop, GmbH) is used in between testing and the reference transducer, Figure 1 and Figure 2. The use of the air bearing makes it possible to maintain the calibrated conditions of the reference torque transducer which is calibrated by a pure torque calibration machine, by preventing the formation of shear force and bending moments on the reference torque transducer. In addition to that, the air bearing also prevents the axial forces being transmitted directly to the reference transducer. Axial forces mainly come from the weight of couplings or connection equipment and the weights of the tested transducer.

For the calibration of torque wrenches, a torque arm mounting component is integrated with the air bearing unit. In order to hold the torque wrench to be tested, there is a movable torque wrench holder unit on the torque arm for adjusting the torque arm mounting component height and length. In the holder unit a linear bushing is used for minimising the friction between tested torque wrench and torque arm of the machine. This avoids an additional influence on the zero signal value at no load condition during the calibration of high-precision torque wrenches. The effective torque arm length of the machine is approximately up to 1.1 m.

Figure 2: General view of 1 kN·m universal torque calibration machine with control table

Hydraulic coupling elements (ETP50) are mainly used for the connection of both the reference torque transducer and test transducer. Depending on the test and reference transducer used, the use of additional elastic couplings and hydraulic couplings depends on the operator choose. In Figure 2 and Figure 3, an example of calibration set up with four elastic couplings and eight hydraulic couplings (ETP 50) is shown.

By changing the reference torque transducer on the machine working ranges can be changed. Reference transducer is used with a digital precision measuring amplifier (DMP41-T2, HBM GmbH) for high accuracy.

The servo motor is controlled by a computer-based PLC. PLC algorithm controls the motor according to the reference torque signal received from the digital precision measuring amplifier to provide the desired torque value.

There is a temperature and humidity sensor on the machine pedestal in order to record the ambient conditions together with the torque measurement data simultaneously.

Figure 3: Torque transducer calibration with 1 kN·m universal torque calibration machine

2.2. Operational System of the Machine

The control of the machine is through a user friendly interface software. By using this interface, the desired torque value is realised through the PLC control algorithm and servo motor. There are four different torque application modes given in the interface depending on the device to be calibrated:

- mode-1 for torque transducer and indicating torque wrenches with high accuracy.
- mode-2 for indicating hand torque tools (type I according to ISO 6789-1:2017)
- mode-3 for setting hand torque tools which returned to the starting position by backward motion. All of the torque wrenches and screwdrivers can be calibrated with this mode (Type II according to ISO 6789-1:2017)
- mode-4 for setting hand torque tools to return to the starting position by forward motion. This is

especially convenient for some of the screwdrivers. (Type II, Class D, E, F according to ISO 6789-1:2017)

In mode-1, there are two options as a continuous or non-continuous torque application. In continuous torque, applying desired torque value and holding this value within the desired limit. If the limit is exceeded, the servomotor will be activated and brings the torque value back into the desired limits. In non-continuous torque application, the servomotor will be activated for the desired torque value and then deactivated.

The working principle of mode-2 is almost similar to mode-1 except a little bit faster than mode-1. This mode is special for indicating hand torque tools.

In mode-3 and mode-4, for setting type torque tools, the machine detects the peak value and then returns to zero torque by forward or backward motion. For setting type torque tools, torque application should be realised within the given time limits. For this purpose, when the machine applies the torque value also gives the information about torque applied time. When the application time does not meet the limits given in ISO 6789-1, the speed of the motor can be changed. Torque application time is calculated at over 80 % of the target torque value, Figure 4.

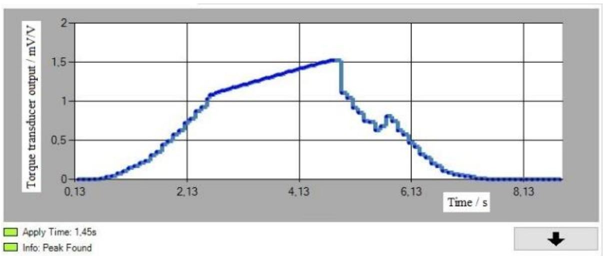

Figure 4: Torque application graph for setting type torque tools

If the test device is able to communicate with the calibration machine, the test and reference signal can be stored automatically via the interface. If the test device does not have communication capability, the test device measurement data must be entered by the operator via a pop-up menu. During the taking of torque measurement data, the ambient conditions related to each calibration point are also stored.

For setting torque tools, each test and reference signal is stored also with ambient condition and torque application time.

3. PERFORMANCE OF THE TORQUE CALIBRATION MACHINE

3.1. Uncertainty of the Machine

The measurement uncertainty of the machine is substantially depends on performance of reference torque transducer, the friction losses in the air bearing, stability and data acquisition of control system and parasitic effect coming from alignment and coupling. The mathematical model of torque generated by torque calibration machine can be taken as in equation (1). The measurements uncertainty parameters of the machine can be summarised as follows [1], [2], [5].

$$T = T_{\mathrm{ref\_trans}} \prod_{i=1}^{n} (1 - \partial T_i) \qquad (1)$$

- ∂T_1: influence of calibrations uncertainty of the reference torque transducer ($\partial T_{\mathrm{cal}}$)
- ∂T_2: influence of temperature on reference torque transducer ($\partial T_{\mathrm{temp}}$)
- ∂T_3: influence of long-term stability of reference torque transducer ($\partial T_{\mathrm{drift}}$)
- ∂T_4 : influence of creep of reference torque transducer ($\partial T_{\mathrm{creep}}$)
- ∂T_5 : influence of alignment of reference transducer ($\partial T_{\mathrm{alig}}$)
- ∂T_6: influence of the air bearing ($\partial T_{\mathrm{air}}$)
- ∂T_7: stability of control system ($\partial T_{\mathrm{sys}}$)
- ∂T_8: influence of torque apply time ($\partial T_{\mathrm{a\_time}}$)
- ∂T_9: influence of coupling ($\partial T_{\mathrm{coupling}}$)
- ∂T_{10}: influence of square drives ($\partial T_{\mathrm{s\_drive}}$)
- ∂T_{11}: influence of torque arm (bending force) on torque wrench calibration ($\partial T_{\mathrm{arm}}$)
- ∂T_{12}: other effects ($\partial T_{\mathrm{other}}$)

Some of uncertainty components are relatively small and non-dominant for the level of 10^{-4}. For example, stability of control systems, friction of air bearing (≤ 40 µN·m), total alignment of the machine (≤ 20 µm), bending forces (compensated by air bearing), and torque apply time for nearly static application (Figure 5).

For simplicity of uncertainty evaluation, all of those parameters can be taken as uncorrelated and combined relative expanded measurement uncertainty can be calculated according to equation (2) and equation (3) [6].

$$w(T) = \sqrt{w^2(\partial T_1) + w^2(\partial T_2) + \cdots + w^2(\partial T_n)} \qquad (2)$$

$$W(T) = k \times w(T)\,. \qquad (3)$$

3.2. Verification of the Machine

For verification, torque transfer standards (GTM GmbH, Class 0,05 according to DIN 51309:2005) were used. During the tests, the transfer standards were mounted on the machine as a test device. In order to understand the total performance of the machine, the results obtained from the transfer standards by using the machine and the results from the certificate of the transfer standards were compared.

Table 1: Uncertainty evaluation of the torque calibration machine for torque transducer calibration

Uncertainty component	**Relative uncertainty**
Calibrations uncertainty of the reference torque transducer for k = 2	$\leq 1 \times 10^{-4}$
Uncertainty due to temperature effect on reference torque transducer for k = 1	$\leq 2 \times 10^{-5}$
Uncertainty due to long term stability of reference torque transducer for k = 1	$\leq 3 \times 10^{-5}$
Uncertainty due to creep of reference torque transducer for k = 1	$\leq 3 \times 10^{-5}$
Combined relative standard measurement uncertainty k = 1	$\leq 7 \times 10^{-5}$
Combined relative expanded measurement uncertainty for k = 2	$\leq 1.4 \times 10^{-4}$
Declaration value of relative expanded measurement uncertainty	$\leq 2 \times 10^{-4}$

Deviation graphs obtained as a result of performance tests are given in Figure 5, Figure 6, and Figure 7. During the verification, measurement sequence was performed according to DIN 51309 and results were calculated as in the case I-A. Evaluation of these results was conducted by E_n value and all the E_n values are less than 1.

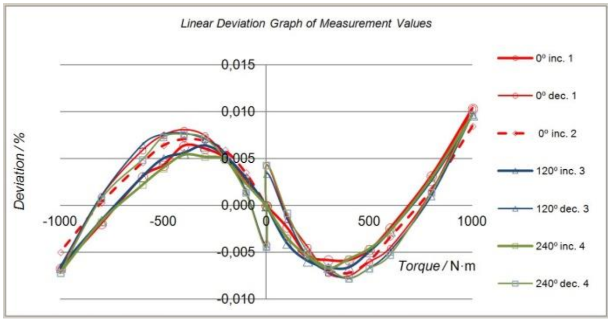

Figure 5: Test I; 1 kN·m reference transducer and transfer standard (both GTM GmbH, Class 0,05)

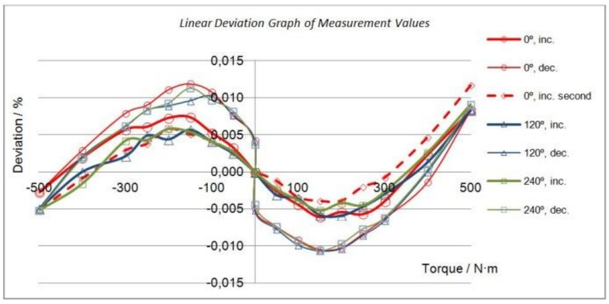

Figure 6: Test II; 1 kN·m reference transducer, 500 N·m transfer standard (both GTM GmbH, Class 0,05)

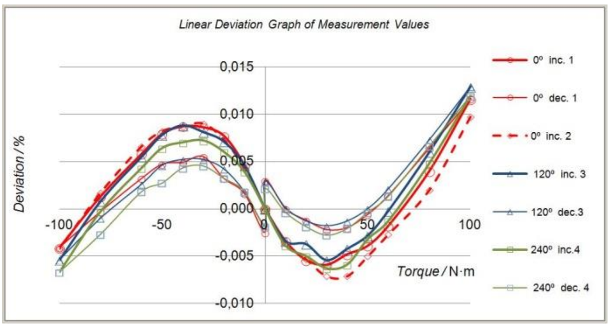

Figure 7: Test III; 100 N·m reference transducer and transfer standard (both GTM GmbH, Class 0,05)

4. SUMMARY

It is generally known that the torque measurement chain reaches the end user from the primary level in two ways. The first way is to transfer the pure torque without bending moments and shearing forces, while the second way is to transmit the torque value with the bending moments and shearing forces. In the universal torque calibration machine of 1 kN·m uses a torque transducer which is calibrated by taking traceability in the first way. The calibration realised by this machine ensures the process in two ways without any problem with the help of air bearing. This ability gives a chance to make almost all the static calibration of the torque measuring devices in the same machine.

5. REFERENCES

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