Development of the new 10 N·m deadweight torque standard machine in Czech metrology institute

L Vavrečka, M Chlumský, P Kašpar
Czech metrology institute, Okružní 31, Brno, Czech Republic
lvavrecka@cmi.cz

Abstract. In order to expand the range of the torque standards in Czech metrology institute (CMI) and fulfill requirements from the industry, a new deadweight torque standard machine (DWTSM) is being designed and manufactured. This paper describes the development and construction of a new torque standard machine at CMI. It is focused on design, engineering and assembly of the main parts of the machine such as the lever arm, weights, air bearing, counter torque device, weights operating units and pedestal.

1. Introduction
In order to expand the range of the torque standards, a deadweight torque standard machine with rated capacity 10 N·m is being developed in CMI during last few years. It makes the list of the torque standards complete. Currently two bigger torque standards are operated at CMI, 100 N·m and 1000 N·m, both are DWTSM. Capacity selection of 10 N·m was based on requirements from industry during last few years. Such a device also maintain connectivity between all DWTSM and allow comparative measurement with 100 N·m DWTSM.

The torque standard machine (Figure1) consist of the following main mechanical parts: Pedestal, lever arm, weights and weights units, counter torque unit and aerostatic bearing.

Counter torque unit
Aerostatic bearing
Lever arm
Torque transducer
Weights
Weights operating unit
Pedestal

Figure 1. CMI 10 N·m deadweight torque standard
2. Lever arm and bearing
Three types of fulcrum design were considered. Edge fulcrum was rejected even though it would be the easiest solution with a cheap build and maintenance, but it is out of date. Ball bearings were considered, but rejected as they have big resistance for such a small torque rate. Air bearing was chosen for the final design. Selected bearing with operating pressure 5 bar was delivered by Calibration Engineering Hohmann e.K. It is the only bigger part completely manufactured outside CMI.

Lever arm was designed in CMI. Invar 36 Material was selected because of its excellent thermal expansivity of 1.3 ppm/°C. To optimize weight and stiffness of the lever arm, free FEM tool Calculix (Figure 2) was used. Overall arm length was designed to be 440 mm. Weights are suspended on thin metal bands at \(L_{AL} \) = 200 mm from the fulcrum. This length was calibrated in the CMI technical length laboratory on the SIP CMM5 device (Figure 3) at the temperature of 20 °C. The results of the length calibration are listed in Table 1. First, the center of the fulcrum was located, then the farthest line on the cylindrical surface was found. Data from this line were then averaged.

![Figure 2. FEM results – total displacement for torque 10 N·m](image)

![Figure 3. Lever arm length calibration](image)

| Side  | Measurement 1 (mm) | Measurement 2 (mm) | Measurement 3 (mm) | Uncertainty |
|-------|--------------------|--------------------|--------------------|-------------|
| Left  | 200.0106           | 199.9872           | 200.0033           | 0.0020      |
| Right | 200.0659           | 200.0883           | 200.0727           | 0.0020      |

3. Weight sets
Weight sets are suspended on metal bands 50 mm wide and only \(t_w = 0.02\) mm thick (Figure 4). Metal bands start their path on top of the lever arm clamped with two bolts and steel plate. Then the band goes down through the labyrinth made of steel cylinders, to be protected from possible destruction by sharp edges. And then bands lean on the cylinder at the calibrated length \(L_{AL}\) from the fulcrum (Figure 5).

Weight sets are designed as one-inner type with chain a structure and disc shape (Figure 7). They are made from austenitic stainless steel. There are 12 pieces of them on both sides of the lever arm, one piece to produce torque \(0.2\) N·m, one piece to produce torque \(0.3\) N·m, one piece to produce torque \(0.5\) N·m, and nine pieces to produce torque \(1\) N·m each, to cover calibration range 2 to 100% of torque 10
N·m (Figure 6). Nominal weight was calibrated using the results of the local gravity measurement 9810207.83 μm·s⁻² with uncertainty 0.08 μm·s⁻² and with active arm length \( L_0 \), where: \( L_0 = L_{AL} + t_w/2 \).

Weights are moved vertically by the weights operating unit, controlled by the ball screw and step motor.

4. **Counter torque unit**

The step motor with ratio of 25600 step/rev. driving the gear components, worm gearbox and pulley with belt transfer (Figure 8) with combined ratio 1:300, generates the counter torque. Thus, the resolution of counter torque unit is 7.680.000 step/rev. Counter torque unit is adjustable in all 6 degrees of freedom.

To adjust alignment of the counter torque unit and the fulcrum of the lever arm (Figure 9), and to avoid possible loading of the transducer with bending moments, a special jig with two perpendicularly installed dial gauges was used. This jig moves on the rails on the pedestal. First, axis of the air bearing was set parallel to the rails on pedestal. Then the fulcrum and counter torque unit were connected with one meter long rod. Two points were chosen. Measurements were made at these two points and counter torque unit was adjusted until the same results for both points were obtained.
5. Control and operation

Electronic control system was designed in CMI. Microcon steppers were used for all drives, inductive sensors were used as end sensors. The system is controlled with Fatek PLC devices and programmed using WinProladder software. Nowadays DWTSM is operated manually. Automatic operation is to be considered.

The position of the lever arm is controlled by laser length sensor with range of 10 mm and linearity of 12 µm. To increase the sensibility, the laser sensor is placed 500 mm from the fulcrum (Figure 10). To fix lever arm in stable position for the maintenance or during calibrated transducer installation, two support units (Figure 11) are used.

Rod with diameter of 20 mm was chosen for the fulcrum. To insert calibrated transducer (Figure 12) into the TSM, two flexible couplings were used.

6. Conclusion

The machine is already assembled and the first sets of measurements have been performed. However there are still many tasks to be completed.

The next step is to provide machine with the housing, and to make first comparative measurements.

The effort put in the design and construction of the new torque standard machine, should turn out in the new national standard with international qualities.

References

[1] Guidelines on the Calibration of Static Torque Measuring Devices » - EURAMET/cg14/v.02 – March 2011 (Previously EA-10/14)