New Approach to Overcome the Limitations in Small Torque Realization

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Abstract

Current investigations into small torque realization and measurement are driven by the growing need for improvement in the metrological characterization of upcoming applications in science and industry with nominal torques in a range of 1 Nm to 10 mNm with torque steps down to 1 mNm and a relative uncertainty of 1×10^{-5} (k=2). This paper includes a comparison of variants of the dead weight principle based on feasibility analysis and uncertainty calculations. As one of the results, a clear definition of the limitations of known variants based on the dead weight principles will be given. Furthermore, a new approach to overcome these limitations will be shown, which gives the basics for the development of a new primary torque standard machine for small torques with an unachieved low level of relative uncertainty.

1 Dead weight principle - variants, characteristics and limitations

The dead weight principle is the most common principle to realize the torque calibration. It realizes a force by using masses in the field of gravity. The required torque in a Torque Standard Machine (TSM) is realized by inducing this force into a pivoted lever. So, the physical quantity torque can be represented by the two SI base quantities mass and length and the local gravity. Considering the influence of buoyancy in air, the system follows formula (1).

$$\vec{M} = m \cdot l \cdot \vec{g} \cdot \left(1 - \frac{\rho_{air}}{\rho_{mass}}\right) \tag{1}$$

There are different variants of the dead weight principle, as shown in [1]. To have a base to compare the different variants regarding to the reachable relative uncertainty, the following assumptions were fixed. All principles use standard weights of class E1 [2] as loading masses. The torque steps 1, 10, 100 and 1000 mNm were investigated.

1.1 Principle of mass differences

The most important variant of the dead weight principle is called principle of mass differences. It is basically consisting of a symmetrical pivoted lever and a stack of masses at each of the lever ends. As the name already suggests, this principle realizes different torques by mass differences between the both mass stacks. A simplified sketch of this principle is shown in Figure 1.

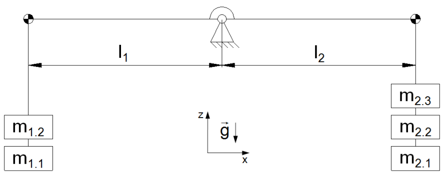

Figure 1: Principle of mass differences

This principle is mainly used in primary TSM's because until now an extended relative uncertainty of $U_r = 2\times10^{-5}$ (k=2) is reachable, admittedly not for small torques [3]. The error analysis shows three main influence factors: mass, length and density of air. The uncertainty index of each influence factor is shown in Figure 2 for a lever length of 500 mm and in Figure 3 for a lever length of 50 mm.

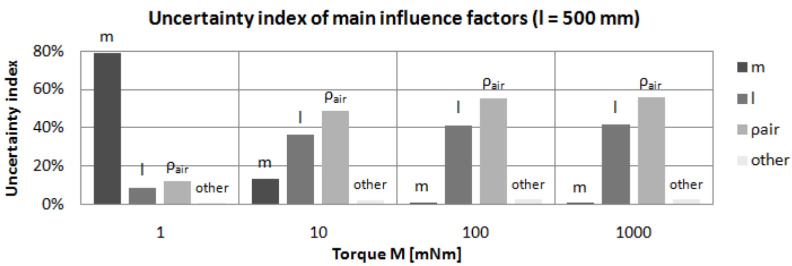

Figure 2: Uncertainty index of the main influence factors with lever length of 500mm

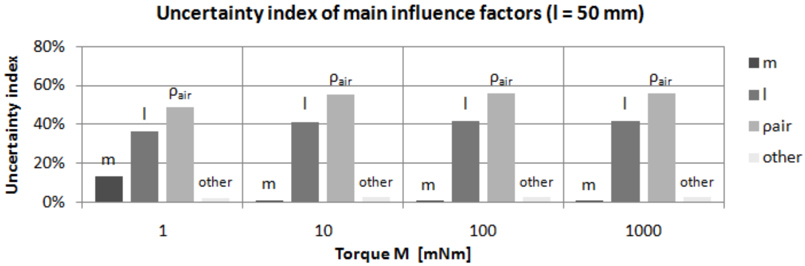

Figure 3: Uncertainty index of the main influence factors with lever length of 50mm

It can be seen, that the uncertainty of small torques is mainly influenced by the mass, while using a large lever. This influence can strongly be reduced by using a shorter lever. Then, the uncertainty is mainly influenced by the lever length and density of air. This creates new opportunities to reduce the uncertainty, discussed in chapter 2.

1.2 Jockey-weight principle

The so called jockey-weight principle consists of a symmetrical pivoted lever, where a mass can be moved on it [4]. Contrary to the principle of mass differences, the jockey-weight principle realizes torques by moving a constant mass in different positions on the lever, so by length differences. A simplified sketch of this principle is shown in Figure 4. This principle is mainly used in secondary TSM's because of its actual higher uncertainty $U_r = 1 \times 10^{-4}$ (k=2). Nevertheless, this principle is in the ongoing investigation.

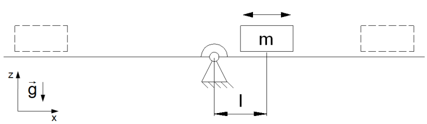

Figure 4: Jockey-weight principle

The main sources of uncertainties in this principle, especially for small torques, are parasitic influences caused by co-moving mass while moving the mass in a discrete position or holding the mass in a discrete position on the lever. These problems could be solved by a skilful design.

2 New approach to overcome the limitations

There are three main approaches to overcome the limitations of the dead weight principle to realize small torques with reduced uncertainty. With a shorter lever length higher masses can be applied beneficially. As a collateral disadvantage, the influences of length and air density deviations are growing. To handle this, a good control on both quantities is required. A permanent absolute length measurement seems to be a good method to solve the first part of the task. Further on, a reduction of the air density deviation can be reached e.g. by operating in a pressure chamber. Ongoing investigations in the mentioned directions show good potential to reach the goal of an extended relative uncertainty $U_r \leq 1 \times 10^{-5}$ (k=2) even for very small torques.

3 Conclusions

The growing number of small torque applications is requesting a reduced uncertainty. This needs to be answered by a new approach for a torque standard machine. Actually, the dead weight principle gives the best metrological characteristics, but there are technological limitations if it comes to small torques. The requirements to the precise definition of length and density of air are growing, but this opens up new approaches and good opportunities to overcome the existing limitations and reach an extended relative uncertainty lower than 1×10^{-5} (k=2) for small torques.

Acknowledgements

These results were achieved in the research project DEBRATOR, a sub-project of the BRAGECRIM Research Initiative, funded by DFG and CAPES.

References:

[1] Wagner, A.; Bitencourt, A.C.P.; Theska, R.: *Solution principles for the metrology of very small torques with minimized relative uncertainty.* EUSPEN's 10th International Conference, Delft, Netherlands, 2010

[2] OIML R 111-1, International Organization of Legal Metrology, 2004

[3] Peschel, D.; Roeske, D.: *Messunsicherheiten bei der Drehmomentmessung.* tm-Technisches Messen, Vol. 72, pp. 308-324, 2005

[4] Allgeier, T.; Kolwinski, U.; Schwind, D.: *Jockey-weight lever machines for force and torque.* 18th Conference on Force, Mass and Torque, Celle, Germany, 2005