Solution Principles for the Metrology of very Small Torques with Minimized Relative Uncertainty

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Abstract

The realization of the physical quantity torque as a primary standard is a precondition for the setup of a traceability chain [1]. However, the existing primary standard devices are already reaching their limits, mainly for small torque realization. The best realization of small torques is currently given by a 1 Nm torque standard machine (TSM) at PTB (Physikalisch-Technische Bundesanstalt). It realizes a nominal torque of 1 Nm with steps up to 1 mNm ($1 \cdot 10^{-3}$ Nm) and an expanded relative uncertainty of $U_r = 1 \cdot 10^{-4}$ (k=2) [2]. Demands for torque realization and measurement in ranges of mNm to even µNm ($1 \cdot 10^{-6}$ Nm) with further reduced relative uncertainty are growing, driven by the need for metrological characterization of upcoming miniaturized actuators, gears and sensors [3]. There is a shortfall in knowledge which means that research is needed for torque realization and measurement.

This paper deals with the determination of new solution principles based on the 1 Nm TSM. Solution principles are idealized representations of the system structure. Elements and relations, which are not important for the function, are neglect. Solution principles, especially new solutions, can be found by using a methodical approach. It describes the first step of the design process of a new TSM with reduced relative uncertainty.

1 Abstraction of the 1 Nm TSM

Until now primary torque standard machines use the dead-weight principle. This principle consists of a beam balance with standard weights, leveled by a counter-torque device. This is also the case for the 1 Nm TSM of the PTB.

At the beginning of the study an abstraction of the existing machine is needed. Therefore the machine is roughly divided into three main functional groups, as it is shown in Figure 1.

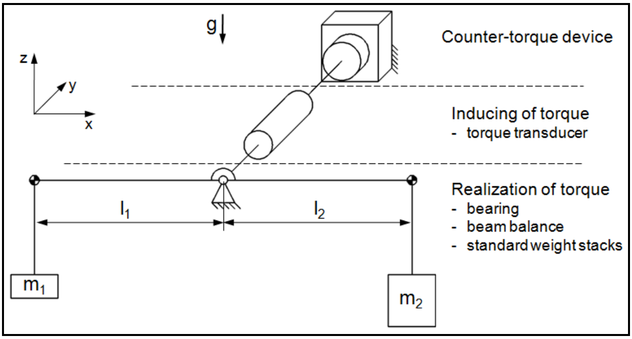


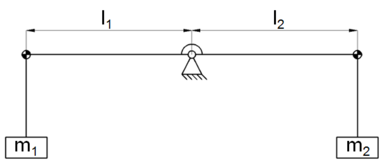
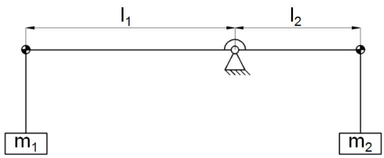
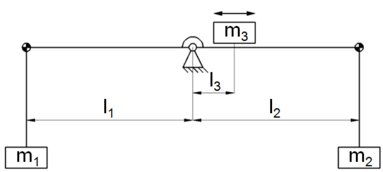
Figure 1: Dead-weight principle

The first group is used to realize the torque. This module consists of a beam, which is mounted symmetrically by an air bearing. At both of the ends standard weight stacks are attached, whose mass difference causes the torque. The investigation of this module describes the main part of the paper. The second module is used to support the measuring object in a suitable manner and to induce the torque to the object. To ensure a horizontal position of the lever, there is a counter-torque device. This module describes the third functional group of the 1 Nm TSM.

2 Determination of new principles

The task is to find alternative principles to realize a torque based on the dead-weight principle. The 1 Nm TSM of the PTB uses the mass difference to generate a torque. It raises the question of what else can be varied, to generate a torque. If there are two similar masses, you can generate a torque with a different lever-length. Another option is to hold the masses constant as well as the lever-length and generate a torque with a third movable mass. These options are shown in the following Table 1.

Table 1: Types of dead-weight principles

No.	Sketch of the principle	Description
1.	Principle of mass differences  	Torque by differences of the standard weights $l_1 = l_2$ $m_1 > m_2$ $\vec{M} = ((m_1 \cdot l_1) - (m_2 \cdot l_2)) \cdot \vec{g}$
2.	Principle of lever length differences  	Torque by differences of the lever length $l_1 > l_2$ $m_1 = m_2$ $\vec{M} = ((m_1 \cdot l_1) - (m_2 \cdot l_2)) \cdot \vec{g}$
3.	Principle of travelling weight  	Torque by the travelling weight $l_1 = l_2$ $m_1 = m_2$ $\vec{M} = m_3 \cdot l_3 \cdot \vec{g}$

The formulas in the left column of Table 1 describe the realized torque of each principle in a very simplified way. Nevertheless, it is shown that the number of influencing quantities can be reduced.

3 Conclusion

The full paper will show all the principles, which were found in a systematic survey. Furthermore the principles will be evaluated and the preferred principles will be elaborated in detail. However, in order to find new principles for torque realization it is necessary to deal with technical viability and uncertainty propagation [4]. A technical viability analysis is carried out based on the stability and accuracy of torque realization. The uncertainty analysis is carried out based on the uncertainty propagation equation for each solution principle.

The results, which will be presented, will provide a basis to the development of an enhanced torque standard machine for small torques.

Previous and running own state of the art research works in nanopositioning and nanomeasuring machines as well as the world's most precise 1 kg comparator are good proof for the successful use of the described methodology. Ongoing steps in more detailed development will profit from experiences, methods, mechanical and electronic hardware components adopted out of these projects.

References:

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