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A vertically positionable permanent magnet system for the Planck-Balance

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Summary:

The Planck-Balance is a compact version of a Kibble balance, allowing a direct measurement of mass by means of electromagnetic force compensation (EMFC). This means that the effects of deformation have to be considered. The vertical position adjustment of the coil, which is discussed in this article, can reduce many errors, such as errors due to deformations during weighing, which lead to a non-proportional correlation between the current in the compensation coil and the compensated mass. In our setup, these errors can be up to about 8 ppm in the maximum case. In addition, there are other problems such as higher order harmonics in the velocity mode, which can be reduced.

Keywords: planck-balance, force factor, watt balance, kibble balance, mass, kilogram

1. Background and motivation

It would be desirable to be able to determine masses directly without having to calibrate the weighing instrument beforehand with other already calibrated masses. Since the redefinition of the kilogram, this is possible without traceability to the international prototype of the kilogram. This means that the maximum achievable accuracy is no longer limited by the uncertainty of the calibrated masses [1].

2. Introduction to the Planck-Balance

There are already realized Kibble balances in the world, but in most cases they are very large and heavy [2]. In our working group, we are improving the Planck-Balance, developed in a collaboration between the PTB and TU Ilmenau [3]. The working principle can be seen in figure 1.

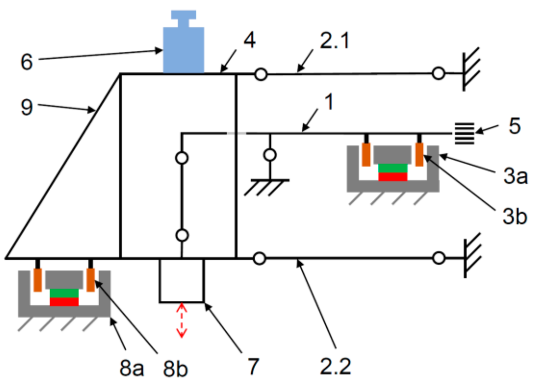

Figure 1: Principle of the modified weighing cell (Planck-Balance).

The load carrier (4) is suspended from a lever (1) and is constrained by a parallel guiding mechanism (2.1, 2.2). In the conventional method, the gravitational force of the mass (6) is compensated by the electromagnetic force of the coil and permanent magnet system (3b and 3a). The force equilibrium is verified by using the optical position indicator (5). In the Planck-Balance, the load cell was extended by an adapter (9) to which a second coil (8b) (with a corresponding stationary permanent magnet system (8a)) is attached. Furthermore, a reflector (7) is mounted to the load carrier, with which its vertical position can be measured interferometrically in order to determine the force factor *Bl* of the voice coil actuator (8b and 8a). *Bl* describes the product of *B*, which is the magnetic flux density and *l*, the coil length. It is also a quantification of the link between the current flowing through the coil and the Lorentz force acting on it.

3. Influence of elastic deformation

The force factor *Bl* depends on the position of the coil and permanent magnet relative to each other. The vertical dependence of the force factor of the magnet and coil combination (8a and 8b) is shown in figure 2, and was determined by weighing with the same mass at different vertical positions. If a mass is placed on top of the load carrier and its weight being compensated by means of a current flowing through the coil (8b), all components involved in the flow of forces are elastically deformed. In the following, only the coil and its attachment will be considered. The same applies to the permanent magnet, but the effect there is much smaller due to the higher stiffness. Figure 3 shows the displacement of the adapter when compensating a 100 g mass, calculated by means of the finite element method (FEM).

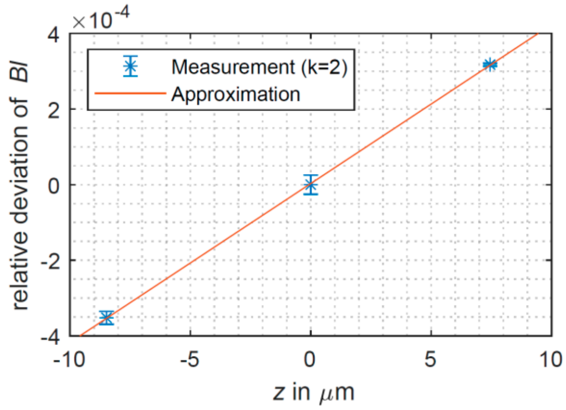

Figure 2: Relative deviation of the force factor as a function of the vertical position z, linearly approximated.

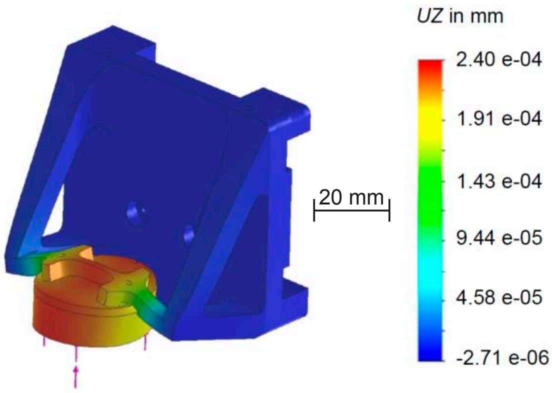

Figure 3: Vertical displacement of the components at a force corresponding to 100 g (FEM-model).

The average displacement of the coil along its axis due to the deformation of the adapter is about 200 nm for a force equivalent to a 100 g mass. This displacement in turn leads to a different vertical position of the coil and thus to a different effective force factor. In the case of a 100 g mass, this results in a *Bl*-value of about 8.4 ppm higher than at the zero position.

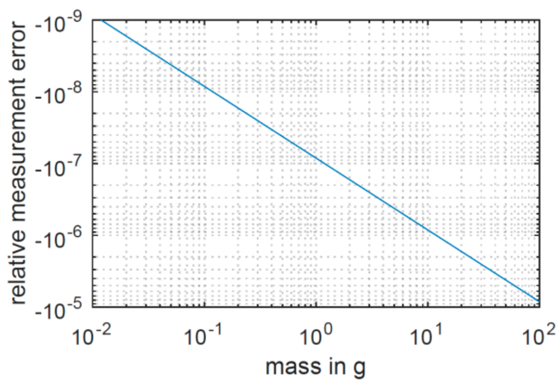

Figure 4: Relative error in Bl as a function of mass.

Assuming the deformation induced displacement to be proportional to the force, combined with the position-dependent force factor described in figure 2, this results in a calculated error in the *Bl* depending on the mass to be determined, which is shown in figure 4.

4. Approaches to reduce the error

Several design changes are to be implemented into the system, e. g. a magnet holder intended to enable vertical positioning (Figure 5). The magnetic circuit (1) is attached to a cylindrical mount (3), which is located in the guiding cylinder (4) so that it is secured against rotation and can be moved vertically. By turning the adjusting ring (5), which is coupled to the guiding cylinder by the connecting piece (6), the magnet can be moved vertically relative to the coil and its – also to be manufactured – more rigid holder (2, 7). In this way the electrical center of the coil is intended to be vertically positioned at the flattest point of the *Bl*-profile – which can be expected to have a global maximum – reducing the error. A scale on the adjusting ring allows the magnet to be positioned with a resolution of 20 µm, which is sufficient for our application.

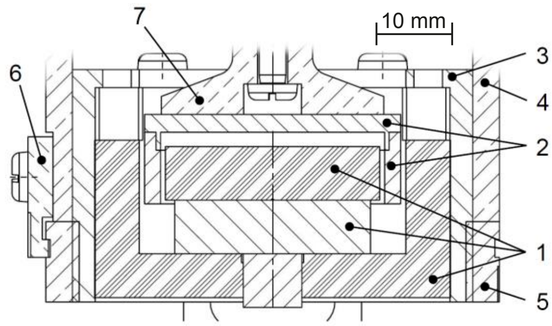

Figure 5: Sectional view of the new magnet holder including adjacent parts.

Since the position-dependent *Bl* can also lead to other errors, such as higher order harmonics in the induction voltage signal [4], an improvement in performance is expected.

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