DOI 10.5162/SMSI2021/A3.1

Adjustment Concept for Compensating Stiffness and Tilt Sensitivity of a Novel Monolithic EMFC Weighing Cell

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Summary:
This paper describes the experimental investigation of a new adjustment concept for planar monolithic high precision electromagnetic force compensated weighing cells. The concept allows to adjust the stiffness and the tilt sensitivity of the compliant mechanisms to an optimum. A new prototype mechanism is set up and adjusted according to the developed mechanical model. For evaluation of the concept, the system was tested on a high precision tilt table and under high vacuum conditions.

Keywords: weighing cell; electromagnetic force compensation; flexure hinges; compliant mechanism; adjustment; stiffness; tilt sensitivity

Introduction

High precision mass comparison is a very recent issue. In 2019, the definition of the mass in the Système International d'Unités (SI) system of units was redefined by the use of fundamental physical and atomic constants [1]. With the redefinition the kilogram, as the last unit of the SI system, is no longer based on an artefact, the international prototype kilogram (IPK) [2]. This ensures an invariable definition. Nevertheless, there are uncertainty issues in determination of mass. The use of mass comparators for the determination of mass allows to shortcut some of the uncertainty sources. The heart of the mass comparators are electromagnetic force compensated (EMFC) weighing cells whose optimization in terms of sensitivity is the focus of this paper.

Description of the work

Further improvements in high precision mass comparison are subjects of investigation in the dissemination chain of the mass standard. One of the most precise methods of mass comparison is achieved by the use of high precision electromagnetic force compensated (EMFC) weighing cells as part of mass comparators. The mechanics of EMFC weighing cells are based on compliant mechanisms with concentrated compliances in form of flexure hinges. Total mechanical stiffness and tilt sensitivity are limiting factors with regard to the resolution of EMFC weighing cells. In order to optimize their performance, the stiffness and the tilt sensitivity of the systems need to be minimized. Due to manufacturing restrictions and robustness requirements, a further reduction of the thickness of the flexure hinges is not desirable. For a further optimisation of the mechanisms, a new adjustment concept is required.

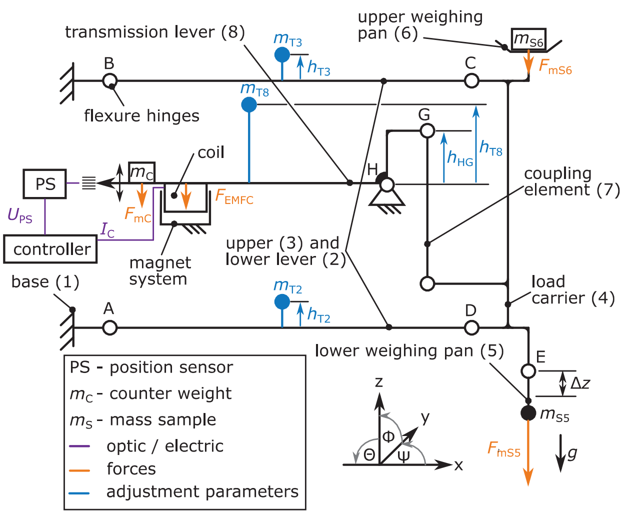

Fig. 1: Operating principle of prototype planar monolithic EMFC-weighing cell supplemented by adjustment possibilities.

In this paper, an alternative to reduce stiffness and tilt sensitivity by adding trim weights ($m_{\mathrm{T2}}, m_{\mathrm{T3}}, m_{\mathrm{T8}}$) at certain heights in combination with an astasizing adjustment (h_{HG}) is presented in Figure 1. Based on the results of the investigations, a new planar monolithic mechanism for an EMFC weighing cell is designed, providing

the possibility to adjust trim masses. For the investigation, the weighing cell was set up on a precision tilt stage [3] (also see [4] and [5]) protected by an enclosure and a windshield to reduce the influence of air movement.
The new mechanism was adjusted according to the developed mechanical model [6]. A parameter combination for a total stiffness slightly above zero and a tilt sensitivity close to zero is found. For the evaluation of the adjustment success and the vacuum compatibility, the system is tested under high vacuum conditions.
For the evaluation of the adjustment concept, the investigated properties were compared to the values from the initial investigation of the structure. In the first step, the initial stiffness $C_{\mathrm{init.}} = 21.560\ \mathrm{N/m}$ was reduced by the manufactured adjustment parameter h_{HG} (from figure 1) to $C_{\mathrm{m0}} = -33.5\ \mathrm{mN/m}$ in the pre-adjusted state (results in Table 1).
Caused by astasizing the mechanism ($h_{\mathrm{HG}} \neq 0$) for an optimized stiffness, the initial tilt sensitivity changes. In the second step the tilt sensitivity of $D_{\mathrm{m0}} = 5.511\ \mathrm{mN/rad}$ in the pre-adjustet state was reduced to $D = 0.1\ \mathrm{mN/rad}$ in the fine-adjusted state by optimizing the parameters of h_{T8}, h_{T2} and h_{T3}. The final stiffness in the fine-adjusted state was reduced to $C = 5.1\ \mathrm{mN/m}$. At the end, the initial stiffness was reduced to $< 0.3\ ‰$ and the tilt sensitivity to $< 2\%$ compared to the pre-adjusted state.

Summary

A new planar monolithic electromagnetic force compensated weighing cell, adjustable in its mechanical properties was designed, manufactured and investigated. The measurement procedure has proven the feasibility of the adjustment concept. The vacuum compatibility of the new mechanism was confirmed for further investigations in the environment of a vacuum mass comparator. Here, the performance of the system will be determined and compared to other systems. The knowledge about the manufacturing deviations in the mechanism will be used for further investigation and an advancement of the next prototype to be designed and manufactured.

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