euspen's 24th International Conference & Exhibition, Dublin, IE, June 2024
www.euspen.eu

Realization of a uniform magnetic field for the KRISS Kibble balance II

MyeongHyeon Kim[1], Dongmin Kim[1], Minky Seo[1], Sung Wan Cho[1], Jinhee Kim[1] and Kwang-Cheol Lee[1]

[1]*Quantum Mass Metrology Group, Quantum Technology Institute, Korea Research Institute of Standards and Science (KRISS) 267 Gajeong-ro, Yuseong-gu, Daejeon 34113 Republic of Korea*

mhkim@kriss.re.kr

Abstract

The Korea Research Institute of Standards and Science (KRISS) is currently in the process of creating a magnetic system intended for the KRISS Kibble balance II. In this engineered magnet system, two circular permanent magnets are employed. These permanent magnets are encased by a yoke, ensuring the establishment of a consistent magnetic field across the specified air gap. The air gap's width measures 15 mm, and its length, maintaining a uniform magnetic field, spans 40 mm. Through meticulous design optimization, the resulting magnetic field strength exceeds 0.4 T, and the uniformity is maintained at less than 20 ppm. Actual magnet fabrication was conducted based on the optimized design. To minimize temperature effects, special materials were employed for the magnets, and a detachable upper and lower structure was implemented to facilitate the insertion of the main coil into the air gap. The performance of the ultimately fabricated magnet system is assessed.

Kibble balance, Kibble balance magnet, planck constant, mass measurement

1. Introduction

The Kibble balance experiment is a methodology employed for the realization of the kilogram in the updated SI [1]. This experimental approach involves the comparison of mechanical and electrical power. Establishing traceability of mass standards to the Planck constant is made possible through the utilization of quantum electrical standards.

Typically, the realization of the kilogram using the Kibble balance experiment involves two modes: the moving mode and the weighing mode. Enhanced performance is achieved with a larger area featuring a uniform magnetic field. For this purpose, several magnet systems have been developed [2-4]. In pursuit of improved performance, KRISS initiated the development of the second model of the KRISS Kibble balance (KRISS KB-2). The magnet system to be applied to KRISS KB-2 aims for a target magnetic field of 0.4 T and a magnetic field uniformity of 100 ppm.

2. Design constraints of the magnet system

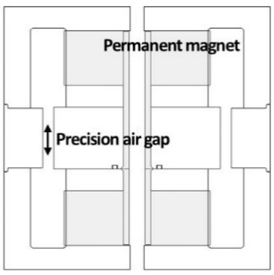

Figure 1. Structure of magnet system for KRISS KB-2

In Fig. 1, a schematic illustration of the magnet system for KRISS KB-2 is presented. During the moving mode, the main coil is designed to operate within a range of ±10 mm. The air gap's width at the designated coil position is 15 mm, and the length of the precision air gap, crucial for achieving a uniform magnetic field, is set at 40 mm, accounting for a safety factor.

The magnetic field is susceptible to temperature-induced changes, making the selection of magnet materials with low temperature coefficients a crucial factor in enhancing the performance of the Kibble balance. The EEC 2:17-TC16 provided by EEC is an excellent magnet material with a reversible temperature coefficient of -0.001 %/°C. This is utilized in the creation of permanent magnets.

3. Analysis and optimization for the magnetic field

3.1. Design parameters

Several variables, such as the thickness of the magnet and the size of the cavity formation entrance, are defined to design the magnet system. Based on these specified parameters, a magnetic field finite element method (FEM) simulation is conducted.

3.2. Optimization and results

The magnetic field intensity and uniformity within the cavity are optimized by iteratively adjusting the defined variable values. Considering a target magnetic field of 100 ppm and accounting for a safety factor, the simulation's uniformity must exceed the actual target. Table 1 and 2 presents the finalized results of the optimized design.

3.3. Modification for the vertical magnetic field

To minimize changes in the vertical magnetic field within the air gap, the heights of the inner yoke and outer yoke are asymmetrically adjusted [5]. Through several optimization iterations, it was observed that a height difference of 1 mm minimized the magnetic field variations.

Table 1 Dimension of the magnet system

Assembly size/mm^3	Magnet size/mm^3	gap/mm
360(OD)×25(ID)×360(H)	190(OD)×35(ID)×75(H)	15

Table 2 Magnetic field simulation results

Field strength [T]	Field uniformity [ppm]	∆Bz [G]
0.4167	19	0.6

Figure 2 presents the uniformity results of the radial magnetic field through magnetic analysis. Figure 3 represents the intensity of the vertical magnetic field.

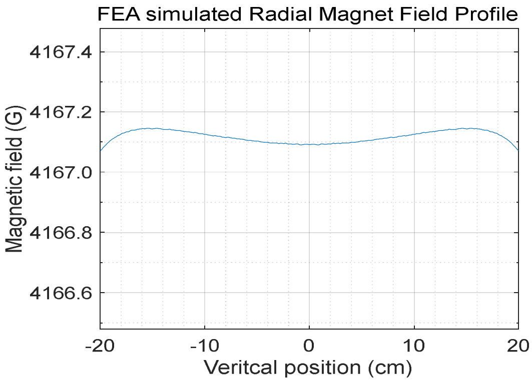

Figure 2. Radial magnetic field according to vertical position

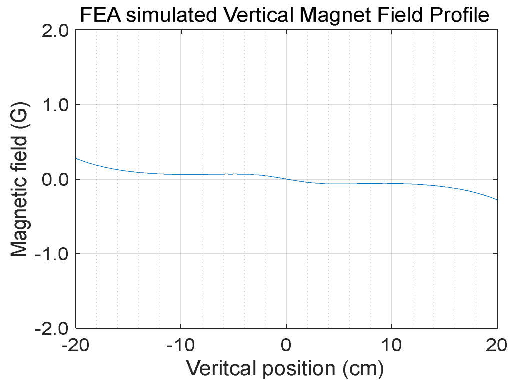

Figure 3. Vertical magnetic field according to vertical position

4. Manufactured magnet system

Based on the final design, the actual fabrication of the magnet was performed. The magnet has a total height of 360 mm and a diameter of 360 mm. There are 9 holes on the upper and lower parts, serving as optical paths for the laser interferometer to measure the motion of the coil and for the suspension of the coil to be inserted later. The entire upper yoke of the coil can be separated. For repetitive assembly and disassembly, guide pins are incorporated. Figure 4 shows manufactured magnet system.

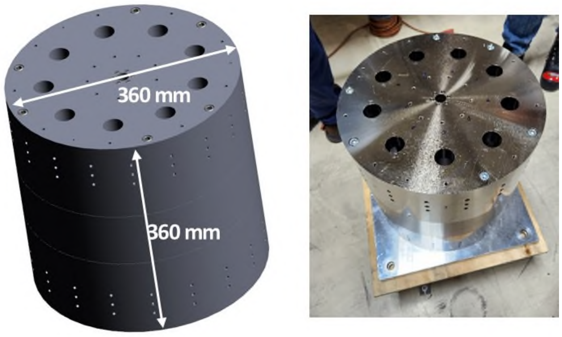

Figure 4. Modeling and manufactured magnet system

5. Magnetic field measurement

The magnetic field of the final polished magnet is measured, and its uniformity is analyzed. The uniformity of the magnetic field is the foremost performance goal in this fabrication. The uniformity measurement is also conducted through the 9 holes, where the average magnetic field values are measured by moving vertically based on the average values in a single plane. The figure below depicts the resulting values.

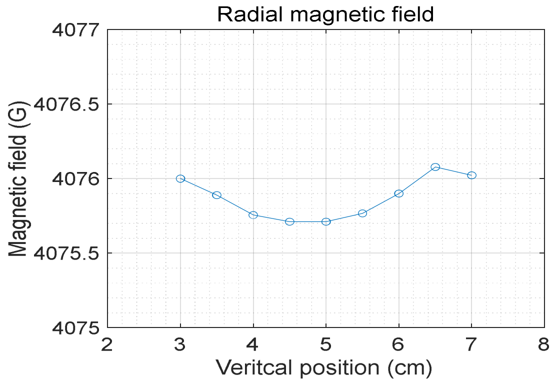

Figure 5. Measured uniformity of the magnetic field

The uniformity of the magnetic field measurement results shows ±45 ppm within a 40 mm range. This performance meets the initial goal and represents a world-class level of uniformity.

6. Conclusion

A magnet system design was undertaken for the KRISS KB-2. Design objectives were established, and parameters influencing performance were identified. Optimal values were determined through parameter analysis. The yoke height was optimized to minimize variations in the vertical magnetic field. In the specified region, achieving a magnetic field uniformity of less than 20 ppm and a magnetic field strength of approximately 0.4 T or higher, the design goals have been successfully met. Based on this, actual fabrication was carried out, and real magnetic field measurements were also conducted. As a result, a magnet system with outstanding uniformity of approximately ±45 ppm has been successfully implemented, and this will be utilized for the KRISS Kibble balance II.

Acknowledgement

Thanks to Dr. Heeju Choi, Sr. Project lead engineer, EEC for valuable and thoughtful discussions.
This work was supported by KRISS under the project grant 24011028.

References

[1] I. A. Robinson, "Towards the redefinition of the kilogram: a measurement of the Planck constant using the NPL Mark II watt balance", *Metrologia* **49**, 113–56, 2012.
[2] M.Kim et al, "Design of Magnet System for the KRISS Kibble Balance II", *2022 Conference on Precision Electromagnetic Measurements (CPEM)*, 2022.
[3] Rafael R. Marangoni et al, "Magnet system for the Quantum Electro-Mechanical Metrology Suite", *IEEE Transactions on Instrumentation and Measurement*, **69**, 5736-5744, 2020.
[4] Shisong Li, Michael Stock and Stephan Schlamminger "A new magnet design for future Kibble balances", *Metrologia* **55**, 319–325, 2018.
[5] Q. You, J. Xu, Z. Li, and S. Li, "Designing model and optimization of the permanent magnet for joule balance NIM-2," IEEE Trans. Instrum. Meas., vol. **66**, no. 6, pp. 1289 – 1296, June 2017.