

[Title] *less than 180 characters

The hybrid trapped field magnet as a desktop-type magnetic field source providing a quasi-microgravity space on Earth: concept and validation

K. Takahashi¹⁾, H. Fujishiro²⁾ and M. D. Ainslie³⁾

¹ Department of Physics, Faculty of Science, Gakushuin University, 1-5-1 Mejiro, Toshima, Tokyo, 171-8588, Japan

² Department of Physical Science and Materials Engineering, Faculty of Science and Engineering, Iwate University, 4-3-5 Ueda, Morioka, Iwate, 020-8551, Japan

³ Bulk Superconductivity Group, Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, UK

[Keyword]

1. Bulk superconductors, 2. Trapped field magnets, 3. Magnetic levitation, 4. Quasi-microgravity

[Abstract Topic] Large Scale System Applications (AP) *invited

[Abstract] *less than 5000 characters

A microgravity space is known to be an ideal environment without natural convection caused by differences in specific gravity, which has useful applications in the life/medical sciences such as protein crystallization and cell culture. Some experimental research has been carried out exploiting such microgravity conditions in the International Space Station as an environmental parameter.

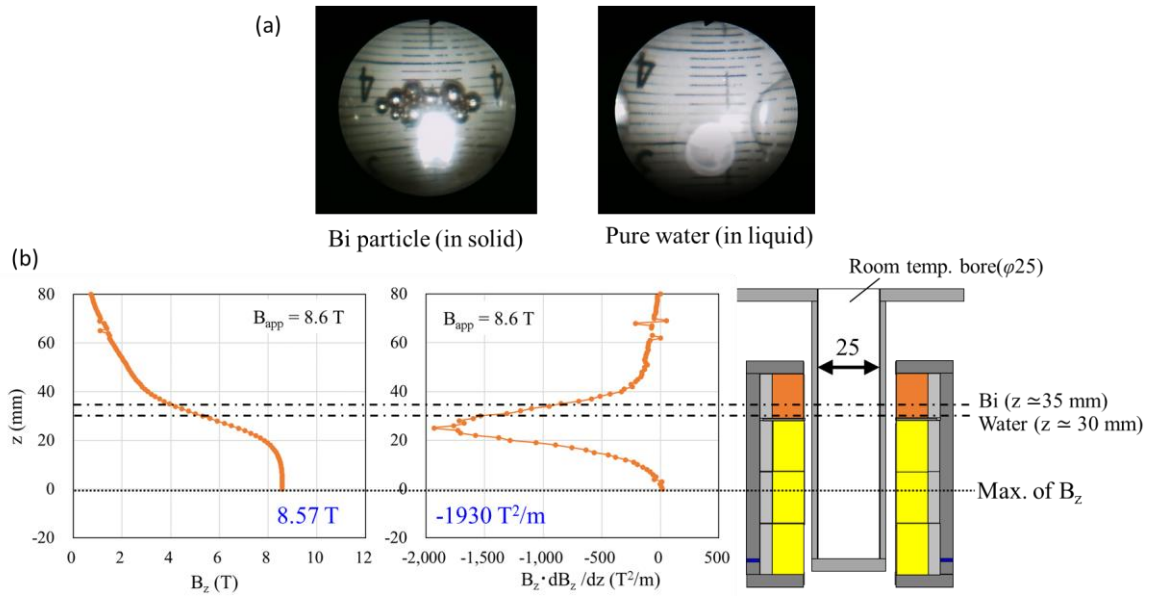
A large magnetic field, in combination with a large field gradient, can provide a repulsive force statically against gravity on the Earth and achieve the so-called “quasi-microgravity condition” for any diamagnetic materials such as water, common metals and even cells of the human body. Superconducting technologies have satisfied several demands for high magnetic forces including magnetic levitation, in which a water drop requires a magnetic field gradient product, $B_z \cdot dB_z/dz$ as large as $-1400 \text{ T}^2/\text{m}$ to levitate in an apparent zero-gravity condition. A large-scale, hybrid-type superconducting magnet (HM) has achieved the highest $B_z \cdot dB_z/dz = -3000 \text{ T}^2/\text{m}$ with a record-high magnetic field of 30 T, while a cryo-cooled superconducting magnet (SM) without liquid helium that can generate $B_z \cdot dB_z/dz$ up to $-400 \text{ T}^2/\text{m}$ with magnetic fields up to 10-12 T are more reasonable for operation in a laboratory setting. However, for practical use of a magnetic quasi-microgravity on Earth, it is desirable for the magnetic source to be lightweight, mobile, and cost-effective as a desktop-type apparatus, and preferably cryogen-free, i.e., operating without the need for any coolant such as liquid helium.

To provide a high magnetic field in a more cost-effective way, large-single grain bulk superconductors – such as the RE-Ba-Cu-O (RE: rare earth element or Y) family of materials – have shown promising potential for generating magnetic fields over several tesla as so-called trapped field magnets (TFM). Compatibility between the magnetic performance and flexibility in operation is required to realize a practical TFM device that can provide such high magnetic fields even in an open space outside the vacuum chamber. Since 2018, the author proposed a concept of the hybrid-type TFM exploiting arrangements of bulk superconductor parts that can improve magnetic performance: the trapped field, B_z , or field gradient, dB_z/dz , and hence, realize a higher $B_z \cdot dB_z/dz$ overall in the system compared with those of a single TFM. In this presentation, we report of the current state-of-the-art for two hybrid-type TFMs developed in Iwate University in recent years, relating to the numerical modelling of the bulk components and the magnetizing procedure, and the results of experimental validation.

Firstly, a hybrid TFM lens (HTFML), consisting of a cylindrical bulk TFM exploiting the vortex pinning effect, combined with a bulk magnetic lens exploiting the diamagnetic shielding effect, was proposed, which can reliably generate a concentrated field, B_z , at the centre of the HTFML higher than the trapped field from the TFM [1]. It was validated experimentally that an all-(RE)-Ba-Cu-O based HTFML magnetized by zero-field cooling magnetization under 50 K, could achieve a maximum B_z value of 9.8 T with an applied field of 7 T [2].

On the other hand, a high-gradient trapped field magnet (HG-TFM), which consists of slit ring bulks that can generate a downward-oriented magnetic field, are tightly stacked with conventional TFM cylinders; hence, the magnetic profile is sharpened such that it increases dB_z/dz [3]. It was estimated numerically that a magnetic field gradient product up to 6000 T²/m could be realized by field-cooled magnetization of such a device, even with a relatively small external field of 10 T at 40 K. This value is twice as high as that of the HTFML and conventional HMs. The superiority of this HG-TFM is that a wider bore as wide as ~30 mm in diameter in the stacked TFM would be more practical for applications. Recently, magnetic levitation was also performed for any fundamental diamagnetic materials by exploiting the HG-TFM with the inner diameter of 36 mm magnetized by FCM with 8.6 T at 22 K and demonstrated successfully in a quasi-microgravity space with an open bore space of 25 mm outside the vacuum chamber. The figure shows (a) photos of levitated material taken by a CMOS camera in a room temperature bore, where solid Bi particles or pure liquid water are used. The corresponding height position against the magnetic field, B_z , and the resultant $B_z \cdot dB_z/dz$ profile in the HG-TFM, are also shown in (b).

These results would show, positively, that the fundamental research on TFM carried out to date can proceed to application development using a hybrid-type TFM in a practical manner. The extensibility of the proposed hybrid TFMs will be discussed.



[References]

- 1) K Takahashi, H Fujishiro and M D Ainslie, Supercond. Sci. Technol., **31** 044005, 2018.
- 2) K Takahashi, H Fujishiro and M D Ainslie, Supercond. Sci. Technol., **34** 05LT02, 2021.
- 3) K Takahashi, H Fujishiro and M D Ainslie, Supercond. Sci. Technol., **34** 035001, 2021.

[Acknowledgements]

- This study was supported partially by JSPS KAKENHI Grant Number JP21J14069 for JAPS Research Fellow.
- This research is supported by JSPS KAKENHI Grant No. 19K05240, and by Adaptable and Seamless Technology transfer Program through Target-driven R&D (A-STEP) from Japan Science and Technology Agency (JST), Grant Nos. VP30218088419 and JPMJTM20AK.
- Engineering and Physical Sciences Research Council (EPSRC) UK, Early Career Fellowship, EP/P020313/1