MAGNETIC FIELD MEASUREMENTS IN A CRYOMODULE WITH NEARBY WARM-SECTION QUADRUPOLE MAGNETS OF RAON HEAVY ION ACCELERATOR

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Abstract

In order to increase the quality factor of a superconducting cavity, a shielding mechanism against geomagnetic fields in a cryomodule is required. In this paper, we introduce the magnetic properties of Mu-metal specimens for global shielding in the cryomodule. Dramatic reduction of the geomagnetic fields in a real Mu-metal shielding structure is also reported.

INTRODUCTION

The superconducting linac of the RAON is composed of a number of cryomodules in which include niobium cavities and intermediate warm section modules for heavy ion beam collimation and diagnostic [1]. For the acceleration performance of a superconducting cavity, ambient magnetic fields around the cavity should be minimized as possible. In our case, the ambient fields are based on two magnetic factors: one is geomagnetic fields which can be trapped in the cavity surface during a cool-down process and the other is fringe fields from a warm-section quadrupole magnet which can be partially trapped at the cavity quench location [2]. In this study, we focus on the minimization of geomagnetic fields at the cavity position with the global magnetic shielding of a QWR cryomodule.

MAGNETIC PROPERTY MEASUREMENTS OF MU-METAL SPECIMENS

We prepared two kinds of Mu-metal samples: one was processed by just thermal annealing and the other was done by annealing again in hydrogen atmosphere.

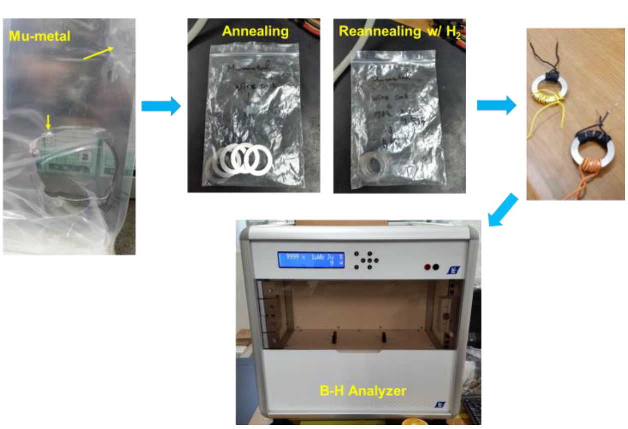

Figure 1: Preparation for magnetic property measurements of Mu metal specimens.

A magnetic analyzer was used for measuring the B-H characteristics of the Mu-metal samples. Yellow arrows in the left-side photograph of Fig. 1 indicate the pressed and stressed spots which can degrade the shielding property of the Mu-metal structure.

Figure 2 shows measurement results for the two kinds of samples. The magnetic property for shielding of the H_2-processed sample (red curve) is superior to that of the just thermally annealed sample (black curve). The treatment for shielding performance of Mu-metal is known to be annealed in the cooling rate of 200 ℃/hr after 1150 ℃ baking in H_2 atmosphere for 4 hours [3].

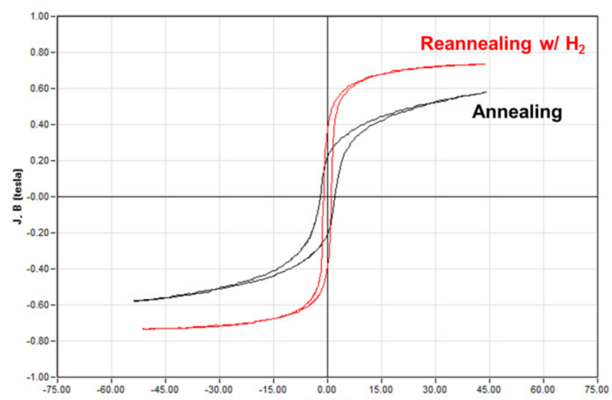

Figure 2: Comparison of measurement results for an annealed sample and a reannealed one with hydrogen supply.

We could also obtain a relative permeability curve for the H_2-processed sample as shown in Fig. 3. Supposed that the geomagnetic field is around 0.5 Oe (50 μT), the permeability of the Mu-metal sample corresponds to be approximately 18,000 in that field. However, it is possible to increase the relative permeability by optimizing the thickness and dimension of a Mu-metal structure as the following equation:

$$B = 1.25DH_0/t \qquad (1)$$

where B is a magnetic flux density induced to a shielding structure, D and t are a diameter and a thickness of the structure (cylinder), respectively, and H_0 is an external magnetic field [4]. The resultant permeability can contribute to improving a shielding factor of the Mu-metal structure.

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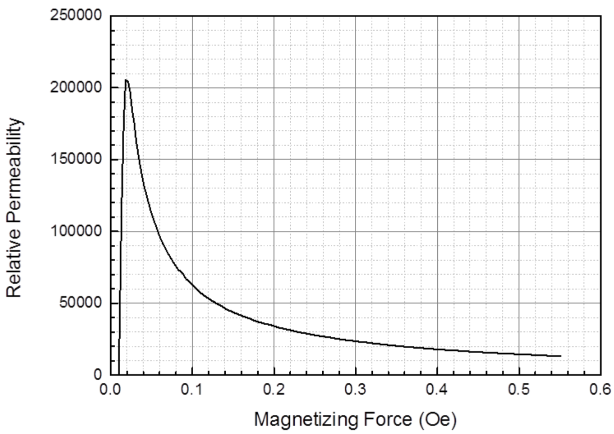

Figure 3: Relative permeability measured for a Mu-metal sample reannealed with hydrogen supply.

GEOMAGNETIC FIELD MEASUREMENTS IN MU-METAL STRUCTURE

Figure 4 shows the photographs on geomagnetic field measurements at the QWR cryomodule inside and outside. A yellow arrow in Fig. 4(a) indicates a hollow aluminum bar in which a magnetic sensor suspended by a fishing line can freely move in vertical direction. The sensor was lifted from bottom to top every 10 cm. As shown in Fig. 4(a), external geomagnetic fields were measured as a reference. Figure 5 shows the measurement results. The field fluctuation was observed by ~40 ± 10 μT month by month.

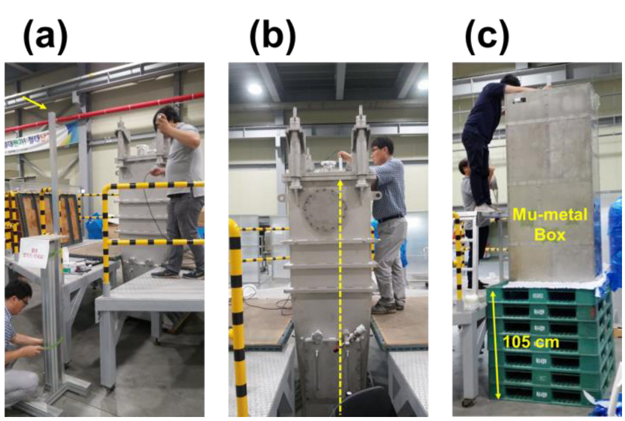

Figure 4: Geomagnetic field measurements at (a) the QWR cryomodule outside, (b) the cryomodule inside, and (c) the Mu-metal box inside.

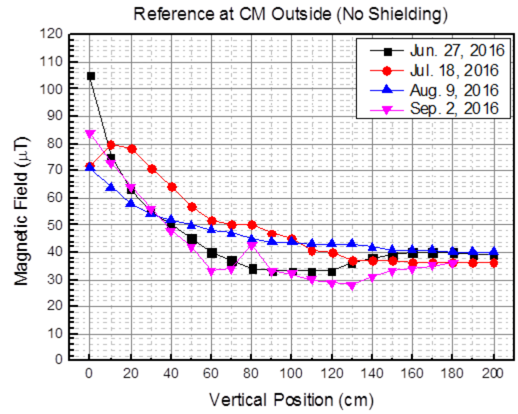

Figure 5: Geomagnetic field distribution measured at the QWR cryomodule outside.

In order to confirm the shielding efficiency of a Mu-metal structure, we started the measurements in the cryomodule in which a Mu-metal box exists as shown in Fig. 4(b). The yellow dashed arrow corresponds to measurement direction in the hollow bar. Due to the limited number of holes at a top cover of the cryomodule, we moved the Mu-metal box to the cryomodule outside as shown in Fig. 4(c). The cryomodule vessel was fabricated by stainless steel whose shielding effect is negligible. We measured the field distribution at various positions on the top of the box with minimizing the opening except the necessary holes. The box was also positioned with considering the real installation height in a tunnel.

Figure 6 shows the measurement results in the Mu-metal box. Especially, the geomagnetic fields at the QWR cavity wall positions were measured to be under 0.8 μT. This value corresponds to the shielding factor of ~50 and exceeds our goal of 2 μT for the QWR cryomodule.

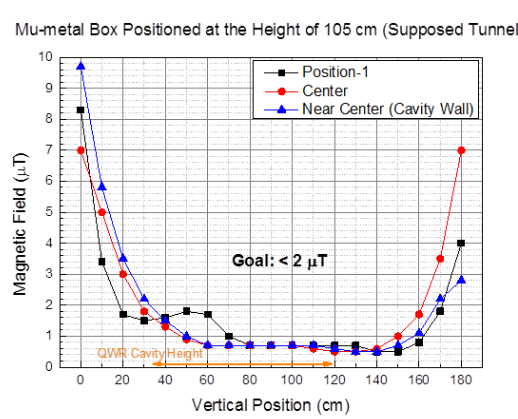

Figure 6: Geomagnetic field distribution measured in the Mu-metal box.

In the beginning of the study, we didn't utilize additional Mu-metal shields at the corners of the box and as a result the significant leakage of geomagnetic fields was observed. The concept of the additional magnetic shielding with a photograph on the measurement positions is shown in Fig. 7.

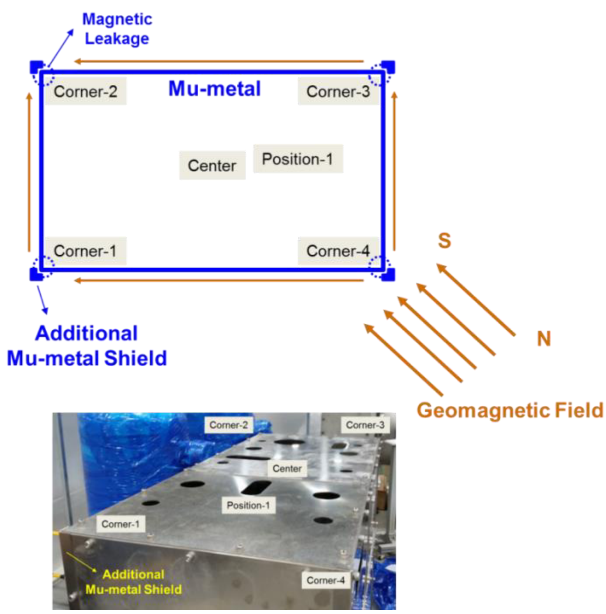

Figure 7: Schematic of the magnetic leakage and a photograph on the measurement positions.

The difference between the measurement results with and without the additional magnetic shields is shown in Fig. 8. The geomagnetic field leakage was measured to be approximately 2 ~ 10 μT.

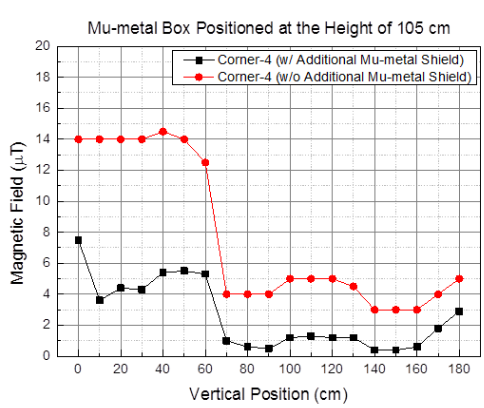

Figure 8: Comparison of geomagnetic field distribution with and without the additional Mu-metal shields.

CONCLUSION

Even though the relative permeability measured for the Mu-metal specimen is relatively small in the geomagnetic field range, it is possible to increase the permeability and the shielding factor by optimizing the structure of the global magnetic shielding like minimizing the geomagnetic field leakage. Magnetic field measurements in the QWR cryomodule with a nearby normal conducting quadrupole magnet will be followed in the near future. In addition, counterplans for avoiding magnetic contamination in the cryomodule will be discussed.

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