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# MAGNETIC FIELD SHIELD FOR SC-CAVITY WITH THIN Nb SHEET

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*Abstract*

While superconducting accelerating cavities can generate high electric fields with a small amount of high frequency power, they require a shield against faint environmental magnetic field. Because the material niobium is a type-II superconductor, it traps the environmental magnetic flux in the material during the superconducting transition, which results in loss during operation. This makes it essential to shield from faint magnetic field. However, high magnetic permeability magnetic materials for very low temperatures are expensive, not easy to handle, and increase costs. We are researching magnetic shields that utilize the diamagnetism of superconducting materials, rather than the magnetic flux absorption phenomenon caused by high magnetic permeability materials.

## INTRODUCTION

Superconducting accelerating cavities have become popular because of their low RF power consumption. Almost all of these cavities are made of niobium, which is a type-II superconductor, and trap the environmental magnetic flux in the material during the superconducting transition. When the trapped flux is shaken by RF electromagnetic field on the inner wall of the cavity, it generates heat and increases power load on the cryogenic system. This effect becomes more pronounced as the Q value of the cavity increases. This makes it essential to shield from faint magnetic field. However, high magnetic permeability magnetic materials for very low temperatures are expensive, not easy to handle, and increase costs. Furthermore, their permeabilities decrease at very low temperature and also low magnetic field. On the other hand, superconductors have perfect diamagnetism and can be complementary to the high permeability materials. Among the easy-to-handle superconducting materials, niobium has the highest transition temperature of pure metals (see Table 1). The transition temperature of Pb is the second highest, but the availability of sufficiently high purity may not be clear, and Pb is a restricted material such as RoHS (Restriction of Hazardous Substances). On these circumstances, niobium is the first choice as a shielding material, except that it can trap flux.

Table1: Superconducting Transition Temperatures of Pure Metals

| Material | In | Sn | Hg | Ta | V | La | Pb | Nb |
|---|---|---|---|---|---|---|---|---|
| Temperature [K] | 3.4 | 3.7 | 4.2 | 4.5 | 5.3 | 5.9 | 7.2 | 9.2 |

In recent years, it has become clear that the expulsion of magnetic flux is induced by making a superconducting transition of the cavity under a temperature gradient [1-4]. If the shield can be cooled with a sufficient temperature gradient before the cavity reaches the transition temperature, it may function as a weak magnetic field shield that complements a normal shield [5]. Since the cavity wall is about 3 mm thick for mechanical strength, it has a larger heat capacity than a thin niobium sheet of about 0.5 mm, for example. Figure 1 shows the possible shapes of the cell's Nb sheet cover [7]. The full cell on the right is covered with a pillbox-shaped hollow shield, and the unshielded left half-cell is shown for comparison. The flux component normal to the wall Bnormal in the shielded cell is less except at the iris region, where the Bnormal has less effect.

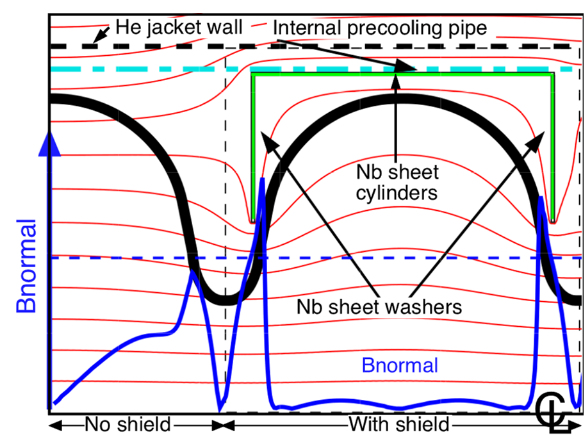


Figure 1: Possible geometry for the magnetic field shield with superconducting sheet.

This example of calculation includes one and a half cells with and without the shield cover, respectively. Since the effects from the adjacent cells would be small, both geometries are calculated in one calculation. A shield cover consists of one niobium sheet cylinder and two washers (thick green line). The leftmost half-cell does not have a shield. Black thick line shows the cavity wall, which has no effect on the magnetic field calculation. Red thin lines show calculated flux lines when immersed in a uniform magnetic field along the axis. The shielding effect is simulated by setting the permeability to 0.0001. The magnetic component normal to the cavity surface Bnormal is also plotted, which is a relative value to the immersed field. The thin broken line shows the immersed field level. The location of the He jacket wall is shown by the broken line and the possible location of the internal precooling pipe is shown by the chained line. The precooling pipe should contact all shield covers.

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The cover can be assembled from a laminated sheet of laminated film / niobium sheet / 5N aluminum sheet / laminated film as shown in Fig. 2. From the laminated sheet shown in Fig. 3, we can fold it to form a hollow pillbox-shaped cover (see Fig. 4).

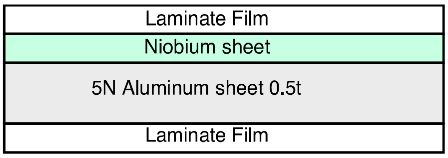


Figure 2: Possible configuration of laminated sheet layered with Niobium and 5N aluminum sheets sandwiched between laminated films [5]. Since the two metal layers should have good thermal contact, one can use rolling to bond the two materials [6].

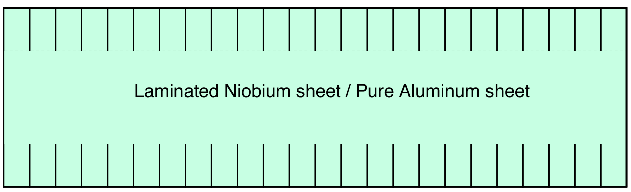


Figure 3: Cover can be formed by folding the strips of the laminate sheet with cuts at both edges.

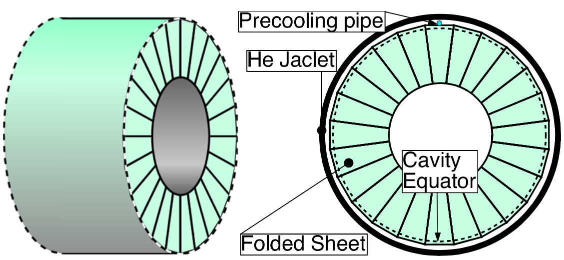


Figure 4: Cover fits inside of the jacket. A precooling pipe goes through the space between the He jacket and the cover. Thermal contact between the pipe and the cover may be realized by clamping or other means.

## EXPERIMENT

Experiments are being conducted to investigate the basic process of flux expulsion under temperature gradients (see Fig. 5). The stage is suspended from the upper flange of the dewar and both ends of the sample sheet are held by aluminum sample clamps (see Fig.6). Each sample clamp has a long tab that is immersed in LHe for cooling. Each temperature is measured by a CERNOX sensor and controlled by two heaters on the clamp plate (see Fig. 7). Two more CERNOX sensors are attached to the sample sheet to measure the temperature gradient. The magnetic field distribution can be measured with five 3D AMR sensors (B-map system). Fifteen signals from the AMR sensors of the B-map system are multiplexed and transferred to room temperature with only six wires (see Fig. 8).

The experiments are carried out at RCNP (Research Center for Nuclear Physics) at Osaka University (see Fig. 9). Once LHe is transferred from the 300L vessel to the small Dewar and the temperatures are settled down to

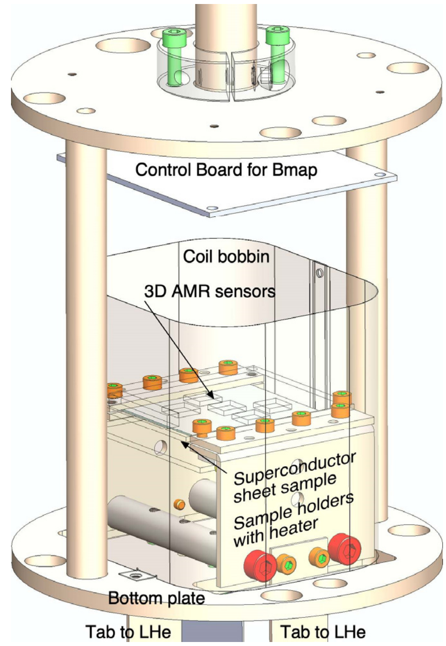


Figure 5: Setup for study of flux expulsion.

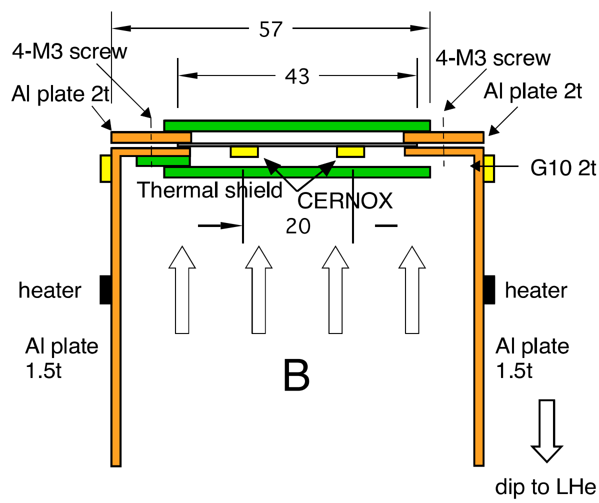


Figure 6: Layout of the sensors.

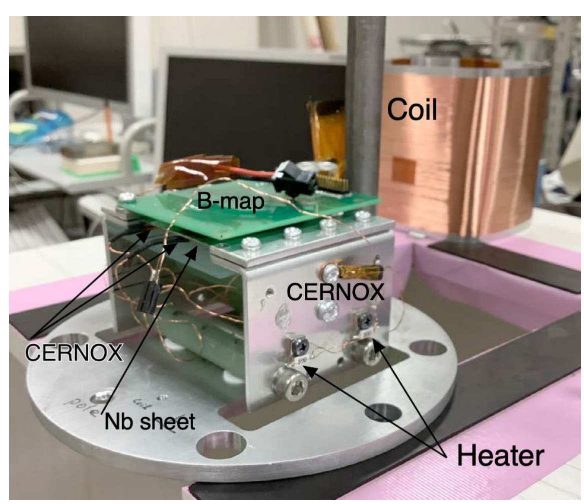


Figure 7: Real setup of the stage.

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4K, the temperatures are raised over the critical temperature Tc by the heaters and cooled down to pass the Tc to measure the magnetic field change. The temperature gradient is evaluated by two CERNOX censors attached on the niobium sheet. The first sample sheet was supplied by ULVAC, whose RRR is more than 300 and the sheet is annealed. Figure 10 shows a preliminary result on the magnetic field change at the transition as a function of temperature gradient on the sheet. Only the magnetic field component normal to the sheet is shown. Although the number of points may not be enough, the changes seem proportional to the temperature difference.

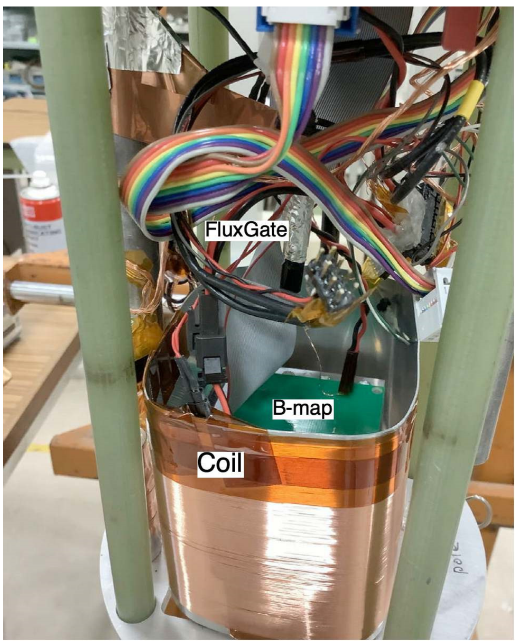


Figure 8: Connections in the stage.


Figure 9: Experimantal room at RCNP.

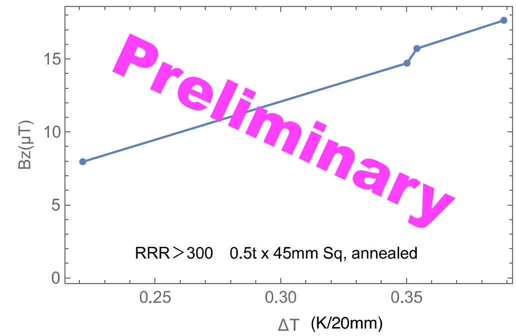


Figure 10: Preliminary result on the flux change at the superconducting transition as a function of temperature difference between two CERNOX sensors.

## CONCLUSION

A new magnetic shielding method is proposed and experiments to study the basic process of flux expulsion under temperature gradients are being conducted. Since it uses different mechanism from the conventional shielding with high permeability material, it can act as a complimentary magnetic shielding method. By using both the passive methods (with high permeability material and superconducting material) together, it may be possible to further enhance the shielding effect at the cryogenic temperature. This technique may be applicable to other fields such as physics experiments that need very low magnetic field environment. Further results are expected this year to evaluate the effect of flux expulsion on niobium sheets.

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