MAGNETIC FOILS FOR SRF CRYOMODULE*

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Abstract

High quality factor niobium SRF cavities require minimal residual magnetic field around the cavity high RF magnetic field region. Global magnetic shields use more material and provide less effective magnetic screening. On the other hand, local magnetic shields have complex geometries to cover access ports and instrumentation, and need thermal straps for cooling. Local magnetic sources and thermal currents will increase residual fields seen by the cavities regardless of the local magnetic shields. Magnetic foils that are cryogenically compatible could increase shield effectiveness and reduce residual magnetic fields. This paper will describe the evaluation of such magnetic foils in both vertical and horizontal tests.

INTRODUCTION

Record high operational quality factors have been routinely demonstrated in nitrogen doped niobium cavities[1,2]. The residual surface resistance of a nitrogen doped cavity, however, is slightly more sensitive to trapped magnetic flux [3]. As the cavity operational Q and BCS surface resistance are inversely proportional, it is important to reduce the residual resistance.

As magnetic trapped flux is a very important contributor to residual surface resistance, it is highly desirable to use local magnetic shields of single or multiple layers to reduce the magnetic field at the cavity surface when the cavity transitions from the normal to the superconducting state. Due to the mechanical necessity in a cryomodule setting, it is common to have openings in the local magnetic shield to allow access to cavity supports, tuner arms, thermal straps, couplers and instrumentations as illustrated in the LCLS-II magnetic shield design shown in Figure 1.

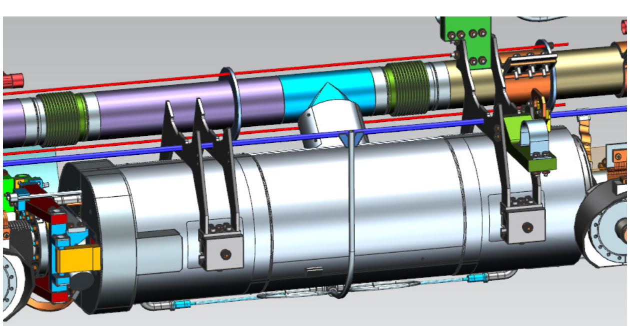

Figure 1: LCLS-II cavity magnetic shielding that leaves openings to coupler, tuner and cavity supports.

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The openings in the local magnetic shield allow the ambient magnetic field to leak into the shield and increases the possibility of flux trapping during the superconducting transition.

It is not always practical to design a solid magnetic shield that accommodates the penetrating component. Both fabrication cost and assembly complexity have to be considered.

A magnetic foil that is flexible and has high permeability can be used to cover the openings of the solid magnetic shield. It can magnetically reinforce the overlap in the solid shield or can cover gaps that may be present due to fabrication defects of the solid magnetic shield. Magnetic foils can also be used to create a shield extension, like a hat, that provides shielding of the openings. This has been proven to be effective to reduce field penetration through the openings.

Certain METGLAS® foils have been used elsewhere which has demonstrated the relative permeability of greater than 10,000 at liquid helium temperatures [4]. A different but larger size METGLAS® foil called 2605SA-1 was selected for evaluation in SRF applications. METGLAS® SA-1 foil is 22 µm thick and 8-inch wide. It costs significantly lower than other solid cryogenic magnetic shielding material for similar shielding effectiveness. Its magnetic properties were measured and compared to other common cryogenic magnetic shield materials. It was later used in a horizontal test of a LCLS-II 9-cell cavity and has been proven effective as augmentation with solid magnetic shielding.

MAGNETIC PROPERTY MEASUREMENT

Two properties of the magnetic foil were measured; magnetic field attenuation and initial permeability at various temperatures.

A 250 mm long, 55 mm diameter G-10 tube was used as a mandrel to create a simple cylindrical shield. A permanent magnet was placed outside the tube near the longitudinal center of the tube. The magnetic field was measured inside the tube, with and without the foil, as the number of layers of foil wrapped on the outside of the tube was increased. The attenuation factor is plotted in Figure 2.

It is shown that 20 layers of magnetic foil is equally effective compared to a 1 mm Cryoperm® 10 solid magnetic shield. Fifteen layers provided a factor of 100 attenuation, suggesting that the transverse geo-magnetic field could be shielded to below 5 mG.

A small sample of foil was wrapped into a 3 mm diameter open cylinder with a height of 5 mm. The sample was inserted into a measurement chamber that was cooled by a cryocooler. A strong solenoid magnet created a uniform ambient field up to 2.5 Gauss in the sample space. Magnetic sensors were placed near the sample to measure the magnetization of the sample using vibrating sample magnetometry. Figure 3 shows the magnetization curve of the sample at room temperature. The material started to show saturation around 500 mG which is acceptable for geo-magnetic shielding applications.

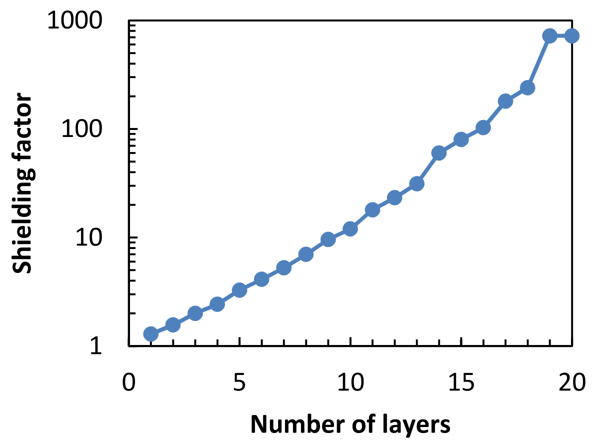

Figure 2: The measured attenuation factor of transverse magnetic field in a cylinder wrapped with magnetic foil.

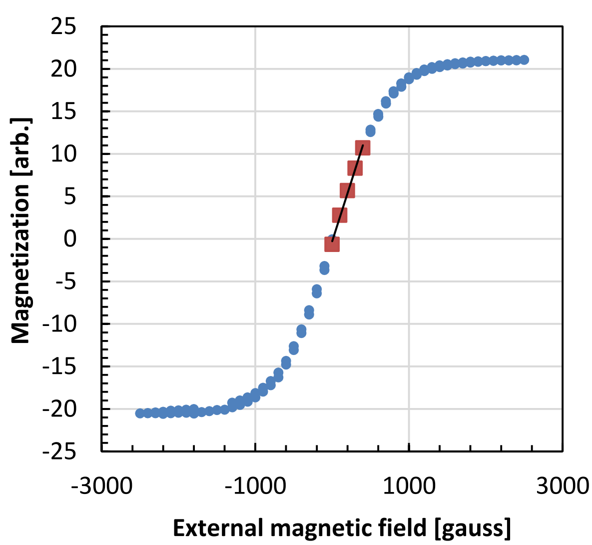

Figure 3: A magnetization curve with external field from -2.5 Gauss to 2.5 Gauss. The red squares represent the linear regime of magnetization which can be used to derive the permeability.

Due to the edge effect of the small sample which has the form of an open cylinder, it is difficult to derive the initial permeability of the material. A relative measurement was used to measure the material's permeability at cryogenic temperature.

Figure 4 shows the relative permeability at various temperatures derived from the material's permeability at room temperature. The room temperature permeability was assumed to be 45,000 as reported in the vendor's material data sheet.

The permeability drops until 50K, where permeability was restored to a value similar to that at room temperature. It could be due to a material phase change or, more likely, due to sample movement from 50K to 80K, as the sample was formed using thin foil and the thermal contraction plus the vibration could disturb the edge effect of the samples. A repeat test is planned with improved sample preparation. In the meantime, a possible extrapolation based on the continuity of the data estimates the permeability was around 23,000 at 50K and remained above 10,000 at 4K. This estimated data was consistent to the earlier measured permeability of other types of METGLAS® foil [4]. For SRF applications, the permeability of 10,000 is quite acceptable.

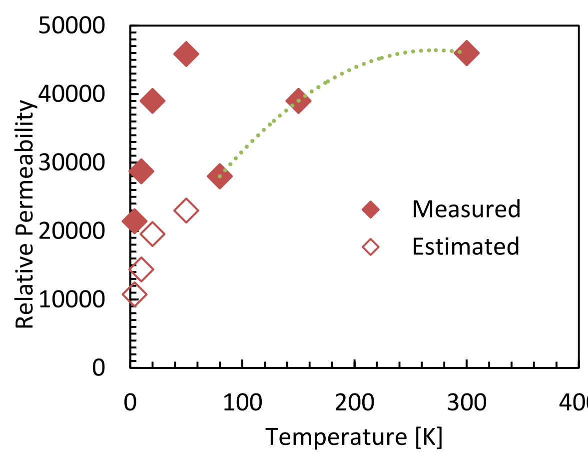

Figure 4: A relative measurement of cryogenic permeability, based on vendor provided room temperature permeability. Empty diamonds represent the extrapolation of the permeability at 50 K and below under the assumption of a disturbance due to thermal contraction.

MAGNETIC FOIL FOR HORIZONTAL CAVITY TEST

Based on the foil's promising permeability at cryogenic temperature, 10 layers of foil was used to augment the magnetic shielding of a cavity setup for horizontal test. As mentioned earlier, the local magnetic shielding is made of solid Cryoperm®-10 and contains many large openings to allow easy assembly. The 10-layer foil was used to reduce the shield's openings to more closely accommodate the penetrations. Gaps between individual shield assemblies were all covered. In addition, the foil was used to create "chimneys" that extended the magnetic shielding from any openings at penetrations a length twice the opening diameter. This proved very effective as the magnetometer inside the cavity showed a marked reduction after the "chimney" shielding was applied.

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Figure 5 showed a 9-cell dressed cavity that was fully patched by magnetic foil. Table 1 lists the comparison of the magnetic field measured before and after magnetic foil patches. The field was measured using a miniature 3-axis milli-Gauss meter. It is worth noting that the test was in an open environment with ambient geo-magnetic field and no active cancellation.

A similar setup was applied during the actual horizontal test at the HTS test cave at Fermilab that has additional active cancellation coils applied. Testing showed the residual magnetic field was satisfactorily met the specification, despite the surrounding highly magnetized support structure in the cryostat [2].

Figure 5: A dressed 9-cell cavity covered with local magnetic shield and augmented with magnetic foils.

Table 1: Magnetic Field Measured inside a Cavity End Cell before and after Foil Patch

Location above axis	B field Before [mG]	B field after [mG]
0	8.7±1.3	4.7±1.3
39 mm	6.9±1.3	3.9±1.3
80 mm	4.0±1.3	0.7±1.3

CONCLUSION

The magnetic foil described in this paper is an attractive supplement to any SRF magnetic shield design due to its flexibility and extremely low cost. The permeability is also very high compared to other magnetic foils. The use of this material at the HTS test cave at Fermilab has demonstrated it is effective and provides a potential cost savings compared to more complex shield designs.

ACKNOWLEDGMENT

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