Passive Magnetic Shielding for the Submillimeter and Far Infrared Experiment

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Abstract

Goddard Space Flight Center is developing the Submillimeter and Far Infrared Experiment (SAFIRE). SAFIRE will use SQUIDs as amplifiers for detectors, which must be shielded from the magnet cooling system, an Adiabatic Demagnetization Refrigerator (ADR). The magnetic field at the detector package must remain at or below the 10^{-7} tesla level while the detectors are operating. We discuss laboratory tests of the passive shielding and simulations.

Key words: SQUID; ADR; passive shielding; salt pill

1. Introduction

SAFIRE is the first airborne telescope operated at 100 mK making use of ADR. SAFIRE requires the field at the detector package to be at or below the 10^{-7} tesla level while the detectors are operating. However, the ADR produces a central field in the magnet while the detectors are operating of 0.1 tesla. In order to meet the requirements, we developed magnetic shielding between the magnet and detectors.

We have already reported an effectivity of passive magnetic shielding consisting of ferromagnetic material and superconductor[1][2]. In ferromagnetic shielding, field lines are concentrated in the ferromagnetic material, reducing the fringing fields. Passive superconducting shielding uses the diamagnetism of superconductors to block the magnetic field. In this paper, magnetic shielding for an engineering model of SAFIRE was developed based on above concept. We have taken the paramagnetic salt pill effect into account in the calculation as well as the nonlinear property of ferromagnetic material.

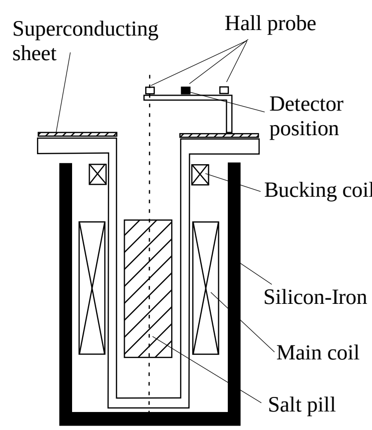

Fig. 1. Cross section of shielding experiment

2. Experiment

Cross section of our engineering model is shown in Fig. 1. In the engineering model, not only the mail coil but also all necessary ADR devices such as a salt pill(ferric ammonium alum; FAA) and a gas gap heat switch(not shown in the figure) were built together to see both of cooling and shielding performance of ADR. A bucking coil was used to cancel part of the origi-

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nal magnetic field produced by the main coil. 3 Hall probe with the sensitivity of 10^{-2} mT are located 10 cm above the magnet flange and provide data on the field strength parallel to the axis. One is placed on the axis of magnet center, the others are off the center at intervals of 2.5 cm each in the radial direction. For the engineering model, a vertically movable prove along the axis was not used because the magnet hole is filled with the salt pill. For the ferromagnetic material, Silicon-Iron was chosen for its high saturation. Niobium superconducting disk was also used to block the remaining field.

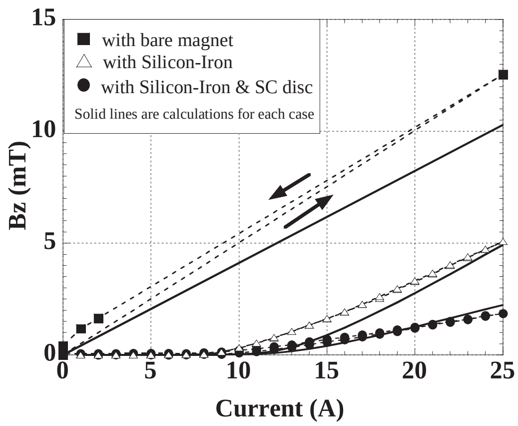

Fig. 2. Fringing field vs current at detector

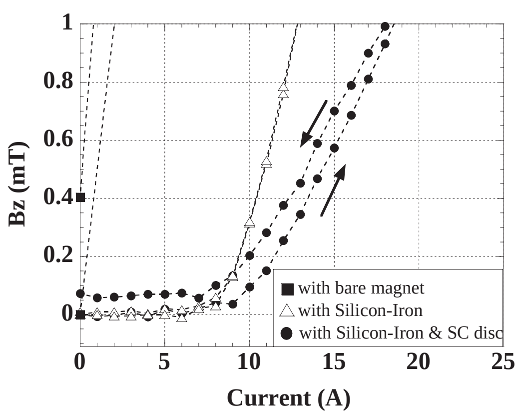

Fig. 3. Field vs current at the detector, Calculation is not shown because the simulation does not properly calculate the hysteresis.

3. Results and Discussion

We performed three different kinds of shielding tests; with bare magnet, with Silicon-Iron and with superconducting disk together with Silicon-Iron. Fig. 2 shows results from these tests at the second probe from the center where the detector is planned to be located. Normally, abscissa in the figure should be labeled as the field at the center of magnet instead of the current, but it was not possible due to the salt pill as mentioned before. 1 ampere is converted roughly into 0.1 T which is operating field. The magnetic field was first ramped up and then down by controlling the current to see hysteresis. As can be seen, the field was drastically reduced by Silicon-Iron at small currents, but lifts off around 9 amperes due to saturation. It was also observed that the field was further reduced by adding thin superconducting disk in large current region. Calculations show satisfactory agreement with measuremets for each case. It was found from the calculation that the field induced by salt pill is less than 5% of the total field, which is almost negligible.

In order to see hysteresis of Silicon-Iron and frozen flux of niobium disk precisely, which are not desirable for shielding, Fig. 2 is closed up and shown in Fig. 3. In the figure, it seems that Silicon-Iron shows no sizable hysteresis, if any, it is negligible. The test with Silicon-Iron alone already achieved our goal in this experiment, which is the field less than the range of error of the Hall probe at 1 ampere. Strange to say, if you add superconducting disk to enhance the shielding performance, the results get worse at small currents as can be seen in the figure. Superconductor exhibits a residual magnetic field along the way back to zero current and doesn't work well as a shield. One of the reasons for this is thought to be not due to frozen flux but due to supercurrent responding to residual field of the main coil itself. Since the main coil is niobium-titanium which is a type II superconductor, the flux will be trapped if the field exceeds 10 mT. In our experiment, the field goes up to 2.5 T at the center of magnet and residual field does appear and induce the supercurrent on the sheet. Therefore, care must be taken not only frozen flux but also supercurrent induced by remaining field from the main coil.

So far, we have successfully designed passive ferromagnetic shield although there is a room left for improvement in the optimal position of superconductor. These results will be used for further improvement on SAFIRE shielding with more sensitive detectors.

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