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MAGNETIC FIELD MAPPING SYSTEM FOR CORNELL SAMPLE HOST CAVITY*

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Abstract

Dissipation due to flux trapping is a persistent problem experienced in SRF cavity testing and cryomodule operation. This work addresses accurately and cheaply measuring magnetic fields in a cryostat without using delicate and expensive fluxgate magnetometers. Anisotropic Magnetoresistive (AMR) magnetic field sensors were investigated for the detection of small fields in a cryogenic environment. Initial development of instrumentation using 16 AMR sensors is presented for the purpose of measuring magnetic fields perpendicular the normal of a 5" diameter sample plate on the Cornell sample host cavity.

INTRODUCTION

A magnetic field mapping system was developed to explore local ambient magnetic fields during the RF performance testing of superconducting radio-frequency (SRF) cavities. The magnetic field mapping system consists of a prototype board that could hold four vertically-orientated AMR sensors. AMR sensors are potentially more useful than the currently used magnetic field fluxgate sensors because they are smaller, so they can be easier orientated in all three axes, and less expensive. This novel magnetic field mapping system will allow for the detection of local quench in the superconductor and for the closer monitoring of dc field dynamics during a helium transfer.

The goal was to design a system that could measure the magnetic field on the outside of the sample plate of the Cornell sample host cavity in more places and in more directions. This work followed research done at Helmholtz Zentrum Berlin (HZB). AMR sensors were chosen for several reasons: (1) they can measure magnetic fields in a broad range from 100 Gauss to 10^{-7} Gauss [1] (the fields expected in our magnetically shielded cryostats would be within this range); (2) they have a large sensitivity that increases at lower temperatures, and (3) they are small and inexpensive (so several sensors could be used at once to get several different magnetic field readings around our plate in three dimensions).

Anisotropic Magnetoresistance (AMR)

AMR is a property of ferromagnetic materials where the electrical resistance varies based on the angle between the current and magnetization vectors. The AMR effect has been used in many applications that detect a change in magnetic field such as vehicle detection, directional compassing, rotational sensing, current sensing, plane yaw rate sensors, etc. [1].

AMR sensors' unique geometry allows for a change in magnetic field magnitude to be detected. Strips of aluminum (called barber-poles) are placed on a thin film of ferromagnetic material (ferrites) at a 45° angle. These barber poles force the current to flow at a 45° angle to the preferential magnetization axis of the ferrites. If the magnetization direction is parallel to the current, the ferrite's resistance is a maximum, and vice versa if perpendicular to the current. Four of these barber poles are arranged together in a Wheatstone bridge to form one AMR sensor so that the output signal can be maximized. This configuration allows for a change in bridge resistance to create a bridge voltage that is proportional to the applied field:

$$V_{out} = V_{cc}\frac{\Delta R}{R}$$

where V_{out} is the bridge voltage, V_{cc} is the AMR supply voltage of 5V, ΔR is the change in bridge resistance, and R is the resistance of one of the barber poles; see Fig. 1. For a more complete discussion, refer to the HZB paper [2].

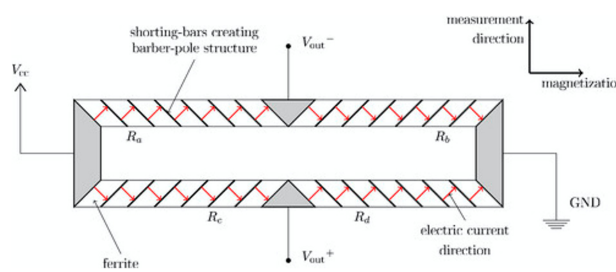

Figure 1: AMR sensor composed of Wheatstone bridge of four ferrites and aluminium barber-poles [2].

MAGNETIC FIELD MAPPING SYSTEM

The magnetic field mapping system (Fig. 2) was developed by soldering AMR755 sensors onto a SOIC-8 to DIP8 connector. This would allow the small surface mount AMR sensor to be placed into a standard PCB, breadboard, or prototype board to thus be read out. Four of these AMR sensors were then soldered onto a 6cm x 6cm prototype board. The appropriate connections, (+I/-I flip coil, Vsupply, +V/-V readout, and ground) were also soldered to the AMR pins on the prototype board. Finally, these AMR sensors were placed appropriately to allow the vertical magnetic field (above the plate) to be measured when the prototype board was laid vertically on top of the plate. Ultimately, this allows for many magnetic field measurements to be taken, in small areas above and next to the Cornell sample host cavity [3].

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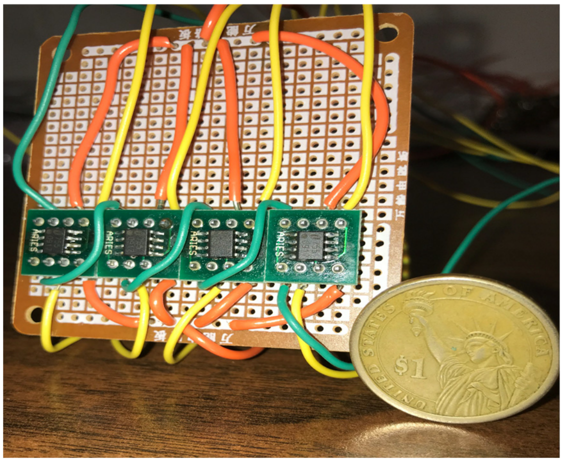

Figure 2: Four AMR sensors on a 6cm x 6cm prototype board ($2 each).

Multiple of these boards could be developed to fit on top of Cornell's 5" diameter sample host cavity. In order for the sensors to measure a vertical change in field, the prototype boards need to be secured in a vertical position. This could be done with a ribbed semi-circle G-10 holder. The ribs in the G-10 holder would be small cut-outs designed to fit the width of the prototype board. Multiple ribs would be present in the holder so that 16 AMR sensors could simultaneously measure a change in magnetic field above Cornell's sample host cavity. Furthermore, there is unused space on the prototype board and above the four sensors that could house additional sensors. These additional sensors could be positioned to measure a change in horizontal field, or to provide more sensitivity in the vertical field measurements.

Problems Encountered

The AMR sensors worked well when the sensors were tested individually. However, many problems were encountered when the sensors were soldered onto the SOIC-8 to DIP8 connector (green board in Fig. 2) and when the sensors were connected to each other on the prototype boards. Some of these problems, and their solutions are listed below:

- Sensors would break when soldering flux was used; sensors needed to be soldered without flux.
- Troubleshooting became difficult when multiple sensors were connected on one prototype board; careful monitoring of data-sheet-values—magnetic field, temperature, current, voltage, etc.—was needed during tests.
- Ordinary pointed tips could not solder surface mount connections; flat soldering tips were needed.
- The terminals on three of the four side rails of the 6cm x 6cm prototype board are connected to each other; the side rails needed to be broken if units were soldered to them.

The first problem listed was the most notable. Directly soldering the small AMR sensors onto the connector was difficult and time-consuming as the sensor would slide away from metal pads on the connector. To make this process easier, soldering flux was used to hold the sensor in place and create a better electrical connection.

However, the sensors began to exhibit strange behaviour when this method was used: the sensor's bridge resistance and flip coil resistance were significantly off the values listed in the data sheet, indicating an internal problem in the AMR sensor; the sensors read high voltages at room temperature and liquid nitrogen temperature; and the sensor's voltage readout began steadily dropping over the course of several minutes from its initial voltage reading. This could be because the soldering flux was allowing the pins to communicate via an electrical connection or because the soldering flux underneath the sensor heated up so much that it overheated the sensor.

The other major problems encountered occurred when multiple sensors were connected to each other on the prototype board. Because the sensors' flip coils were all connected in series (so that one could flip the flip coils simultaneously), if one sensor was broken, they all did not work. Therefore, any errors made in the soldering process would lead to the whole board giving erroneous data.

Viability of Sensors

The data recorded for the geometry factor, sensitivity, and voltage response to a fluctuating magnetic field matched that of HZB [2]. HZB's process for measuring these variables was used.

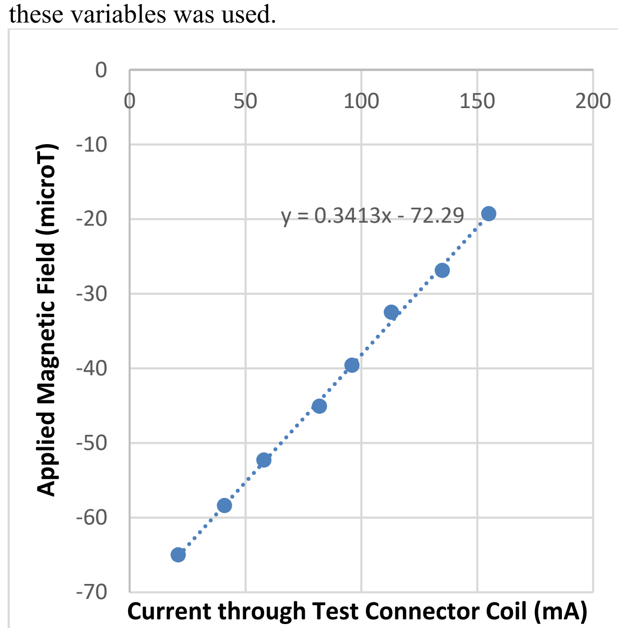

Figure 3: Cancelling applied magnetic field from a Helmholtz coil with a test coil to measure the geometry factor.

To collect the data shown in Fig. 3, a Helmholtz coil was used to provide a known magnetic field, which was then cancelled with a similar field from the AMR's Test Connector (a Helmholtz coil built inside the AMR sensor). The slope of the data shown in the graph is the geometry factor of the coil; 0.3413 microT/mA for the example shown in Fig. 3.

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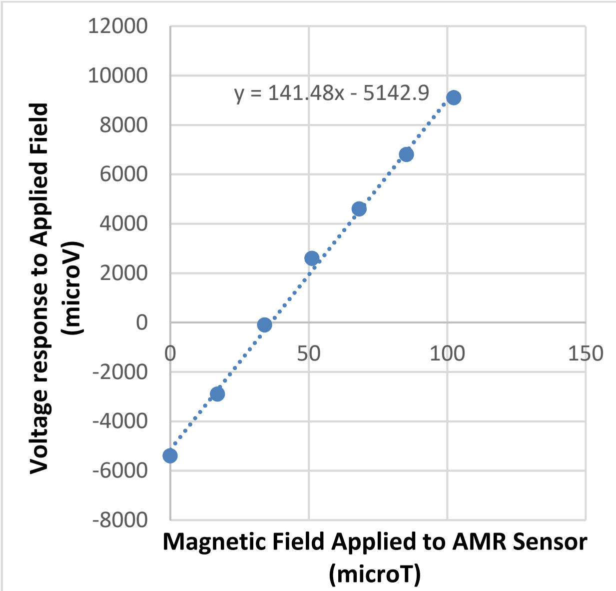

Figure 4: Sensitivity of AMR sensor at 77K.

To collect the data shown in Fig. 4, the voltage response to multiple different known fields created by a Helmholtz coil was measured. The slope of the points gave the sensitivity of the AMR sensor at 77K. This value was slightly smaller than that measured at HZB, partially because HZB went to large magnetic fields beyond the range specified in the data sheet.

Every sensor used had different properties: they had different bridge resistances and flip coil resistances; they read different voltages at the same temperature, even though they were created and soldered in the same manner; and their internal coils had different geometry factors, which caused their sensitivity to be different from one another at different temperatures. However, they still exhibited a linear response to incident field; see Fig. 5. While this linear response is not perfect, the sensors could be calibrated so that a small change in magnetic field at cryogenic temperatures registers a known change in voltage.

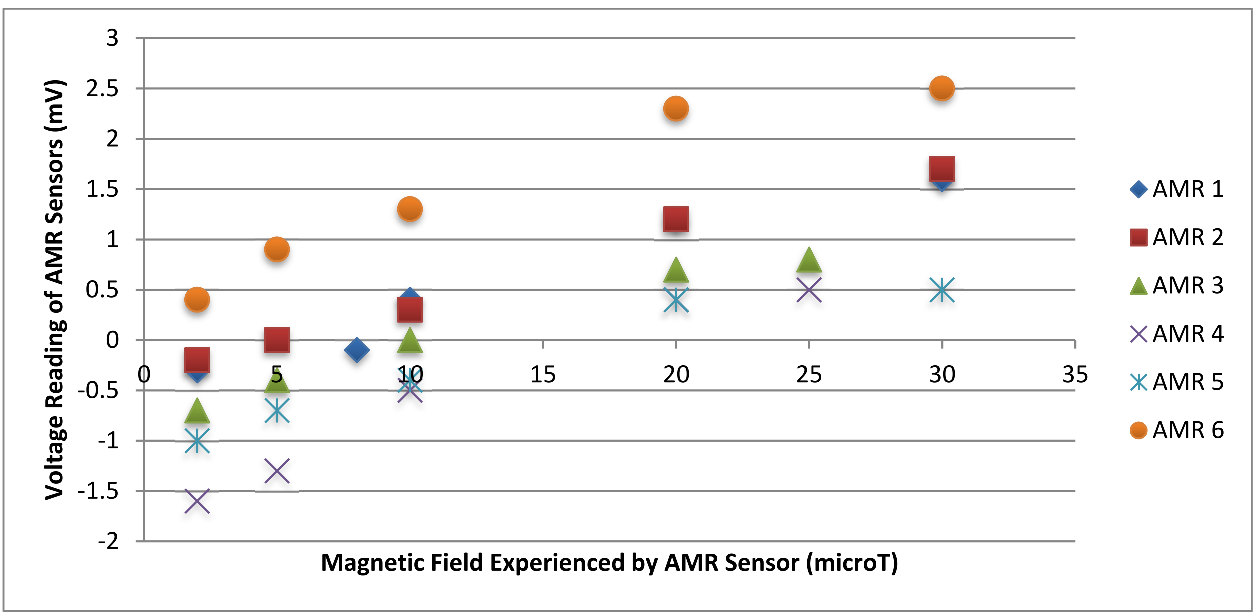

Figure 5: AMR voltage response to fluxgate measured magnetic field.

CONCLUSION

An AMR sensor based magnetic field mapping system could determine the source of high ambient magnetic fields during the cool down and warm up of SRF cavities, could be used to localize trapped flux, and has the potential to localize a quench due to an increase in localized magnetic flux. If more research is done on these sensors, they could prove to be very powerful and valuable for SRF research.

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