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CHARACTERIZATION OF SMALL AMR SENSORS IN LIQUID HELIUM TO MEASURE RESIDUAL MAGNETIC FIELD ON SUPERCONDUCTING SAMPLES

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Abstract

Trapped residual magnetic flux is responsible of residual surface resistance degradation on superconducting materials used in SRF technologies. To characterize this effect on superconducting samples, compact sensors are required to mount on sample characterization devices. In this paper, we present results on AMR sensors supplied from different manufacturers in the temperature range from 4.2 K up to 300 K.

INTRODUCTION

The trapped magnetic flux during normal conducting to superconducting transition is a part of the increase of residual resistance. Several sensors could be used at helium liquid temperature. The requirement of these sensors is to be compact to work in confined environment, reliable at liquid helium temperature and to have high sensitivity to measure magnetic field in the range 0.1 – 100 mG. Last work of HZB laboratory [1] has shown that AMR sensors could be adapted to measure the magnetic field map in the vicinity of SRF cavities. Although tested AMR sensors present good overall performances, compact tri-axis devices are required to monitor directly the magnetic field on superconducting samples which are tested in RF regime [2-6]. We present here preliminary results with AMR sensors coming from Honeywell to compare with results on Sensitec components [1].

DESCRIPTION OF THE APPARATUS

The main objective of the characterization setup is to identify AMR sensors which can operate at super fluid helium temperature down to 1.6 K and measure residual magnetic field as low as 0.5 mG. To provide this environment, Helmholtz cell has been built with ABS support from 3D printer to control the 3 components X, Y and Z of the magnetic field. The coils are made of 10 turns copper wires and mounted as it is shown in Figure 1.

Figure 1: Helmholtz cell formed by 3 paired coils (∅ 110 mm / 96 mm / 76 mm). Left: sketch of the ABS supports. Right: Picture of the assembled coils.

The apparatus is mounted into a cryostat as shown in Figure 2. The cryostat is shielded from magnetic fields with 2 mm thick mu-metal cylinder closed on the bottom. It allows finely controlling magnetic field in each direction. The size of the coils and the number of turns has been calculated to reach the earth magnetic field with a current in the range of 100 mA – 200 mA.

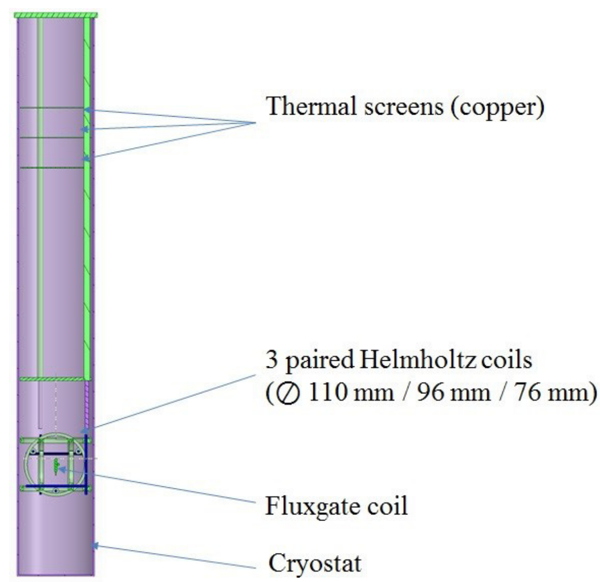

Figure 2: Drawing of the cryostat equipped with Helmholtz cell.

Five magnetic sensors are mounted in the Helmholtz cell. Figure 3 shows the AMR sensors which are mounted on their PCB. The first one is a fluxgate sensor provided by Stefan Mayer®. This sensor will be the reference measurement of the magnetic field. It has been successfully tested in superfluid helium at 1.65 K with home-made conditioning and has the required specifications for this test. The four others are AMR sensors. The first one is a Sensitec AFF755B which has been successfully tested and integrated by HZB laboratory to monitor magnetic map in the environment of superconducting cavity [1]. The three others have been supplied from Honeywell. The HMC1001 is one axis high sensitivity sensor. The HMC1021S is one axis sensor and the HMC1053 is a three axis sensor. Table 1 gives datasheet overview of tested magnetic sensors. These specifications are extracted from manufacturers and are established for operations at room temperature.

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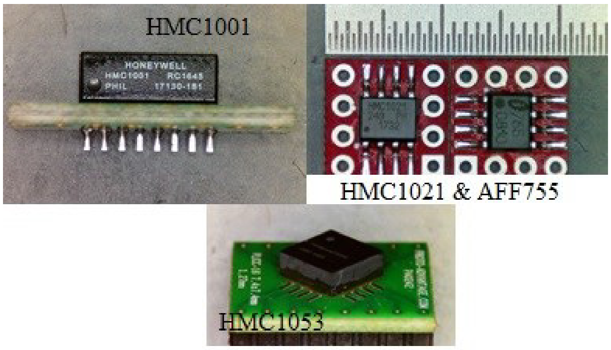

Figure 3: AMR sensors mounted on their PCB.

Table 1: Specifications of Stefan Mayer Fluxgate and Tested AMR

Parameters (unit)	FLC100-ext	AFF-755B	HMC-1001	HMC-1021	HMC-1053
Range (mG)	±1000	±500	±2000	±6000	±6000
Accuracy (mG)	±2%±3	2.0±0.02	2±0.03	0.5±0.1	1.0±0.1
Bandwidth (Hz)	0-1000	1 10^6	5 10^6	5 10^6	5 10^6
Supply Voltage (V)	5	1.2-9.0	<12	2-25	1.8-20
Sensitivity (mV/G)	2500	1.4-10.8	5-36	1.6-25	1.8-20
# axis	1	1	1	1	3

To operate with best accuracy, the application note AN213 from Honeywell gives useful tips to manage correctly the set/reset signals. The main reason to use this function in our case is to avoid variation of the offset under changing temperature conditions. Another reason is to decrease self-noise coming from thermal energy over time especially for low field measurements in sub-milligauss range. As recommended, electronic circuits has been adapted to perform the set/reset function for each AMR sensor as shown on Figure 4.

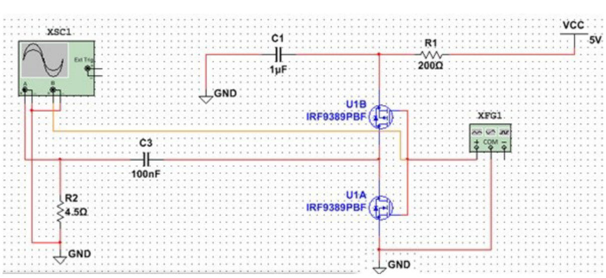

Figure 4: Simulation of the Set/Reset device. The capacitances must be adapted to S/R coil impedance R2.

To drive the set/reset function, a DC generator is connected to provide Vcc and charge the capacitor C1. A pulse generator Tektronix AFG3000 commands the mosfet transistors of each circuit to discharge the capacitance C1 in the set/reset coils of the AMR which is simulated by R2 in the Figure 4. By this way, a few microsecond width current pulse signal is generated. The amplitude of the signal is tuned with V_{CC} and the capacitance C3 to satisfy requirements of each AMR sensor.

Because of the AMR effect, sensors are mounted in Wheatstone bridge to maximize AMR effect and stay in linear sensitivity. The structure is similar to strain gages which are mounted in bridge. A well suited device to perform acquisition of these sensors is the NI-9237 module from National Instrument. Indeed, it has been developed for measurement of bridge-based sensors (strain gage) with input range ±25 mV/V on 24-bits full scale (noise 1 µV/V). Then, the external trigger of pulse generator is connected to the NI-9237 module for synchronization. The supplying voltage of the AMR is set at 5 V. To simplify acquisition, we have not performed the offset subtraction as it has been done at HZB [1].

EXPERIMENTAL RESULTS

The five sensors have been placed in the center of the Helmholtz coils. The cryostat is then filled with liquid helium at atmospheric pressure. The sensors are oriented on Z-axis and the magnetic field is controlled by applying current step into the Z-coils. Figure 5 shows results with the fluxgate at 300 K and at 4.2 K. A part of the variation of the slope is attributed to the positioning of the fluxgate because of the bad stability of the sensors handler. It is possible that the fluxgate has moved because of thermal strain on materials.

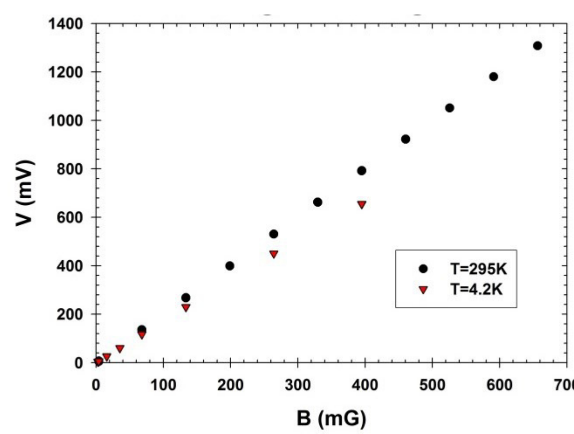

Figure 5: Output signal for fluxgate at T = 295 K and T = 4.2 K.

Figures 6 and 7 show measurements of AMR for various steps of magnetic fields at respectively 4.2 K and 295 K. We can see on both figures the good linearity of the sensors. The slope of these lines gives directly the sensitivity of the sensors. We have performed these measurements during the warm up of the apparatus. Then, we obtain the dependence of the sensitivity in the temperature range from 4.2 K up to 295 K which is presented on Figure 8.

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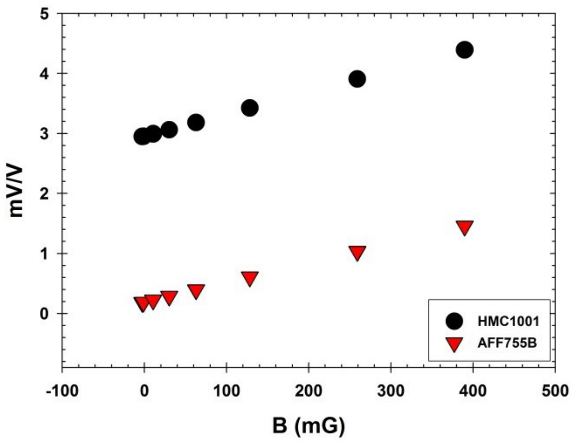

Figure 6: Results in the magnetic field range of 0-650 mG at 4.2 K. Black circle: HMC1001. Red triangle: AFF755B.

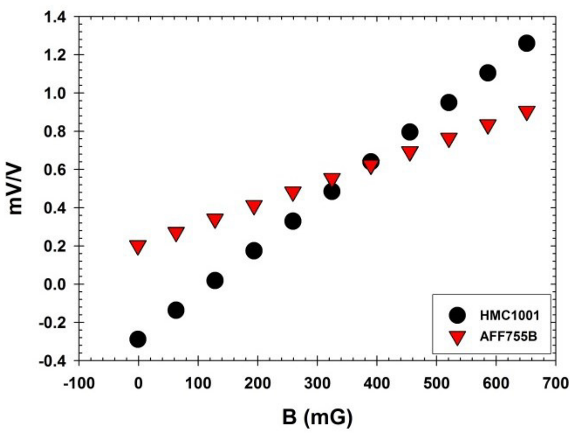

Figure 7: Results in the magnetic field range of 0-650 mG at 295 K. Black circle: HMC1001. Red triangle: AFF755B.

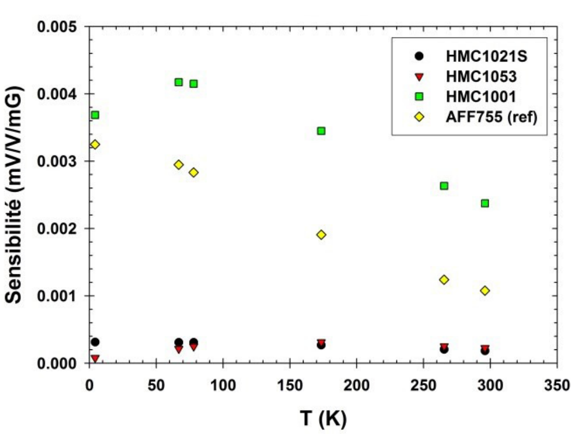

Figure 8: measured sensitivity for Sensitec AFF755 and Honeywell sensors from 4.2 K up to 295 K.

Results for HMC1021 and HMC1053 show low sensitivity with the temperature. After verifications, it has been attributed to a bad connection with the set/reset circuit. This confirms that a good set/reset function must be performed. For these sensors, there are no results and the experiment must be done again.

For Sensitec AFF755B and Honeywell HMC1001, the set/reset signal worked as expected. Sensitivity at 300 K is in agreement with datasheets in Table 1. For AFF755 sensor, the sensitivity over the temperature range in monotone whereas it is not for the HMC1001. Indeed, we can observe that the sensitivity is decreasing in the temperature range from 50 K down to 4.2 K. As a main result, the sensitivity of tested AMR sensors is increasing at low temperature which is more convenient for low field measurements.

CONCLUSION

First test of AMR sensors shows the efficiency of these components. HMC1001 and AFF755B have presented no issues during the test form 295 K down to 4.2 K. The sensitivity makes them suitable for low magnetic field measurement. This experiment was the opportunity to test the behavior of electronic devices and different components in cryogenic conditions. Despite the lake of result with HMC1021 and HMC1053, overall results are very promising to find a compact 3-axis sensor to measure residual magnetic field on small superconducting samples. Next step will be to do the experiment again for all sensors. The offset of sensors will be measured by changing set/reset sequence in acquisition and sensitivity will be measured in superfluid helium.

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