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AMR SENSORS STUDIES AND DEVELOPMENT FOR CAVITIES TESTS MAGNETOMETRY AT CEA

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Abstract

Studying flux expulsion during superconducting cavities test increases the need for exhaustive magnetometric cartography. The use of Anistropic Magneto Resistance (AMR) sensors, much cheaper than commercial fluxgates, allows the use of tens of sensors simultaneously. Such sensors are developed and sold for room temperature application but are resistant to cryogenic temperatures. However, they need proper calibration, which is more difficult at cryogenic temperature. Actually, this calibration uses the flip of the magnetization of the anisotropic ferromagnetic element, which coercitive field is increased at low temperature. We will present the development of method and software carried out at CEA for the use of such sensors, as well as the preliminary design of a rotating magnetometric device destined to elliptical cavities.

AMR SENSORS CHARACTERIZATION

In order to achieve high performances for superconducting cavities it is necessary to control their material behavior and their environment during operation. In our laboratory we are currently designing a suite of detectors that will focus on superconducting cavities diagnostic during their test in liquid helium bath.

The magnetic field, even if lower than the earth magnetic field, increases the Joule losses, thus it is important to control it. We are currently developing detectors able to map the magnetic field around the cavity at cryogenic temperature. The sensors are AFF755 from Sensitec. They exploit the anisotropic magnetoresistance (AMR) of a ferromagnetic material at their core. They are much cheaper than the current standard for this kind of measures (Fluxgate) and should enable to equip a cavity cryostat or even a cryomodule with more detectors.

However, they need a calibration step to get their sensitivity, which is the relationship between the voltage measured by the sensor and the magnetic field, and which varies with temperature. Our calibration procedure uses two specific coils already implemented in the sensors: the flip coil, which magnetizes the ferromagnetic material, made of permalloy, and the test coil, which generates a controlled magnetic field. This calibration can be achieved in situ, when the sensors are placed inside a cryostat, and in an unknown magnetic field.

We defined a calibration procedure that allows calibration even in an unknown ambient magnetic field. The first step is to characterize the test coil (TC) for each sensor by the relationship between the coil current and the coil generated magnetic field. To this intend, the sensor response to the test coil is compared to the sensor response to a reference Helmholtz coil and the α coefficient is deduced:

$$B_{TC} = \alpha I_{TC}$$

We have verified that α does not change at cold temperatures. Actually the only effect of the temperature change on the coil is thermal shrinkage, which is very small.

The second step is to apply a set of TC field after a positive flip coil $B_{TC}(Flip_+)$ and after a negative flip coil $B_{TC}(Flip_-)$, and to measure the corresponding voltages $U(Flip_+)$ and $U(Flip_-)$.

We get two curves with B_{TC} vs U, one for Flip+ and one for Flip-,

$$B_{TC}(Flip_+) = a_1 U(Flip_+) + B_1$$

$$B_{TC}(Flip_-) = a_2 U(Flip_-) + B_2$$

From which we extract a_1, a_2, B_1 and B_2.

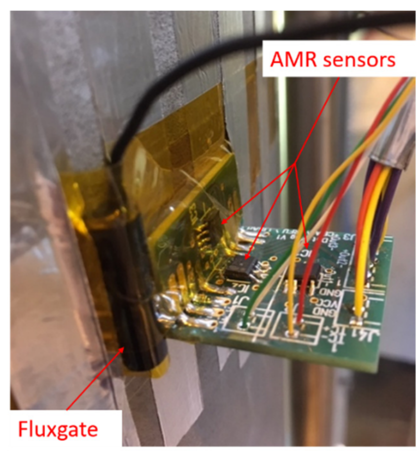

Figure 1: Set of three AMR sensors (X, Y and Z) and fluxgate installed on a cavity.

The slopes, a_1 and a_2, are opposite to each other. The offsets B_1 and B_2 contain both the electrical offset of the sensor and the ambient magnetic field, which are unknown. In order to get rid of the ambient field, we calculate the electrical offset, which is supposed to be the same for both flips:

$$B_{OFF} = \frac{B_{Flip-} + B_{Flip+}}{2} = \frac{B_1 + B_2}{2}$$

And then the real magnetic field:

$$B = a_2 U + B_2 - B_{OFF} = a_2 U + \frac{B_2 - B_1}{2}$$

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This procedure was tested at room temperature with good results and reproducibility (the sensitivity of one sensor varies less than 5 %). We used a flip current value equal to 200 mA.

A set of three sensors was placed on a cavity, besides a fluxgate (Fig. 1) and their sensitivity was measured during cavity cool down. The results are shown in Fig. 2 where our results are also compared with other labs [1-5]. The sensitivity is increased at low temperature. This is due to the permalloy's remnant field decrease, shown on the hysteresis curve in Fig. 3.

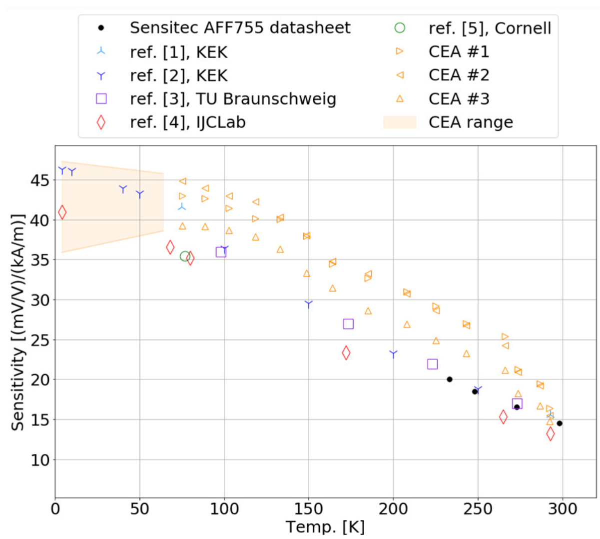

Figure 2: AMR sensors sensitivities versus temperature. CEA measurements for three sensors. For T < 60 K, only a result range is shown.

It appeared that the sensitivity reproducibility is much degraded for temperature lower than 60 K, thus only a range of results (in orange) is shown. This is probably due to the increase of the permalloy's coercive field (Figure 3). The level of flip magnetic field necessary to properly remagnetize the permalloy material should also be increased. During this set of experiment, we could increase the flip current up to 380 mA but it was not enough to get a satisfying reproducibility. Moreover, the offset measurements, necessary for the calibration and not shown on the figure, were even less reproducible. For those reasons, it was not possible to measure the magnetic field under 60 K.

In a next set of measurements we plan to apply flip current values higher than 380 mA and observe if we can get some reproducible values.

The difficulty of measuring an accurate value for the magnetic field at 4 K is also mentioned in reference [2] from KEK, where they explain that their offset value is not reproducible after initialization. Up to now they consider using their sensors to measure relative change of the magnetic field distribution.

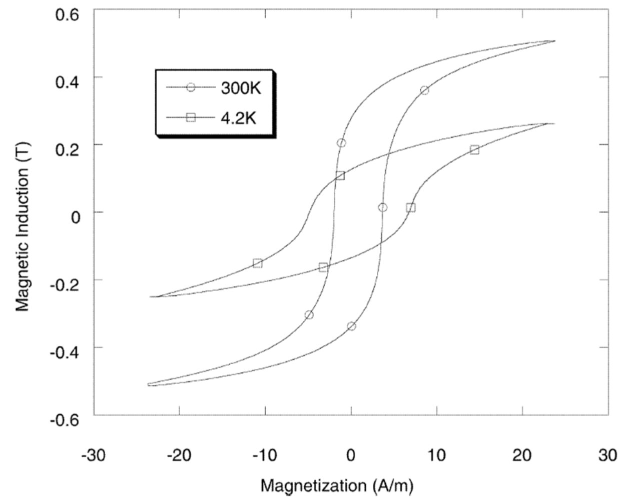

Figure 3: Mumetal torus magnetization as a function of applied field at two different temperatures [6].

MAGNETOMETRIC DEVICE

In the meantime, we are developing a rotating frame with diagnostics destined to mono cell elliptical cavities. It will support temperature, X-rays and magnetic sensors.

We have reshaped the 3 sensors (X, Y and Z) configurations to this purpose. In the new configuration, two of the three sensors (r and z) are positioned so that their distance to the cavity is 1-2 mm, allowing good detection of the flux expulsion (Fig. 4). Moreover, the size of the configuration is decreased. This allows the implementation of nine sets of three sensors along a cavity profile.

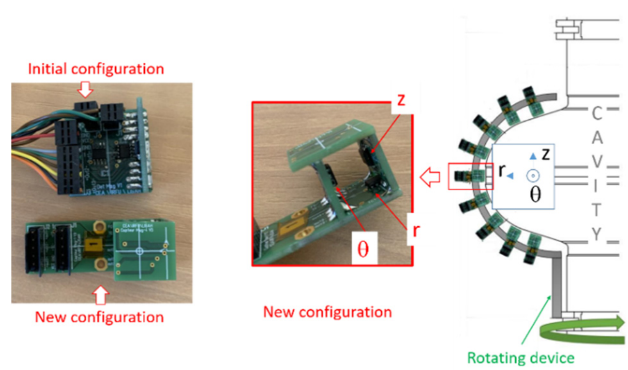

Figure 4: Set of three sensors, initial and old configuration (left), rotating frame with 9 sets (right).

The calibration and data acquisition procedure was implemented on an acquisition device (National Instrument) with the Labview software.

The electronic card allowing the operation of 27 magnetic sensors is ready (Fig. 5). It includes the flip coil generation, the sensor output amplification (x100) and decoders driven by the acquisition device.

The rotating support frame for the sensors is under development.

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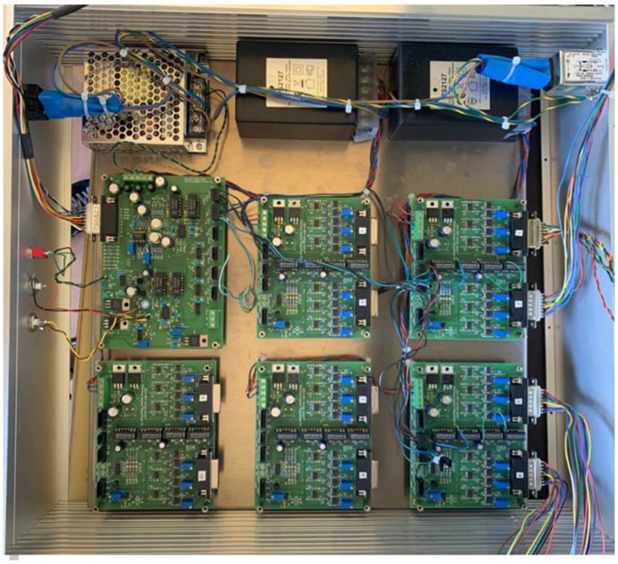

Figure 5: Electronic card for the 27 sensors.

CONCLUSION

We have developed and tested magnetic sensors based on AMR resistance destined to superconducting cavities magnetometry at 4 K. The reliability of these sensors at 4 K is still to be improved, and a rotating support frame is to be developed.

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