ACTIVE MAGNETIC FIELD COMPENSATION SYSTEM FOR SRF CAVITIES

L. Ding, Laboratory GREYC, Caen, France Jian Liang, Hanxiang Liu, Zaipeng Xie[†], Hohai Ubiversity, Nanjing, China

Abstract

Superconducting Radio Frequency (SRF) cavities are becoming popular in modern particle accelerators. When the SRF cavity is transitioning from the non-conducting to the Superconducting state at the critical temperature (Tc), the ambient magnetic field can be trapped. This trapped flux may lead to an increase in the surface resistance of the cavity wall, which can reduce the Q-factor and efficiency of the cavity. In order to increase the Qfactor, it is important to lower the surface resistance by reducing the amount of magnetic flux trapped in the cavity wall to sub 10- G range during the Tc transition.

In this paper, we present a 3-axis automatic active magnetic field compensation system that is capable of reducing the earth magnetic field and any local disturbance field. Design techniques are described to enhance the system stability while utilizing the flexibility of embedded electronics. This paper describes the system implementation and concludes with initial results of tests. Experimental results demonstrate that the proposed magnetic field compensation system can reduce the earth magnetic field to sub 1 mG even without shielding.

Introduction

An important limiting factor in the performance of superconducting radio frequency (SRF) cavities in medium and high field gradients is the intrinsic quality factor and, thus, the surface resistance of the cavity [1]. The exact dependence of the surface resistance on the magnitude of the RF field is not well understood [2]. Lower Q factors may come from several sources, one of which is the presence of a trapped magnetic field inside the cavity walls at cool down [3], known as remanent magnetization,

Remanent magnetisation is often a function of the grain boundaries of the niobium material [4] used to construct the cavities. It is affected by the ambient field during the cooling cycle that necessary to superconductivity, and below 3 Gauss, 100% of the field is trapped [5]. A number of studies have been carried out on cool-down speed, and one report concludes that fast cool-down will be more uniform and can be expected to result in less trapped magnetic flux because perturbations to the phase boundary will be larger on average during slow cool-down [6] while others advocate a fast cool-down [7].

Therefore, if the magnetic field can be reduced during the cooling cycle this will reduce the remanent magnetisation in the SRF cavity.

Current state of the art is to place the SRF cavity in a tubular magnetic shield [8]. This tube and the SRF cavity

must then be located in an east-west orientation [8] [9]. In addition coils are then placed around the tube to provide further compensation. There is effectively no safety margin with this arrangement [8]. During the cool down phase fluxgate magnetometers monitor the magnetic field.

The typical remanent magnetic field requirement is less than 3-4 mG [10]. The earth's magnetic field is circa 500 mG so approximately 45dB attenuation of the earth field is required.

This paper proposes that the SRF cavity is placed inside a three axis Helmholtz coil system (Figure 1). Fluxgate magnetometers positioned as close to the cavity as possible, are used as feedback sensors for the cancellation system. With this active compensation in place, it is possible to achieve < 1 mG of trapped field in the cavity, thereby improving its RF performance.

Prior to the cooling cycle the compensation system is energized so the field in the SRF cavity is minimized. The monitoring and field adjustment continues during the cooling cycle.



Figure 1: Coil setup with magnetometers in red.

SYSTEM DESIGN

The system consists of a three axis Helmholtz coil around the SRF cavity, 3 axis fluxgate sensor mounted to the cavity, optional additional single axis sensors around the circumference of the cavity, and the control electronics. The sensors monitor the field seen by the SRF cavity to the control electronics. This signal is in analog form, so is digitized to provide a real-time update. The control electronics compares the signals from the sensors and immediately adjusts the current in the Helmholtz coils, thereby maintaining a very low level of magnetic field

[†] email address: zaipengxie@impcas.ac.cn

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The control electronics consists of analog to digital converters optionally feeding data to a PC. This data is updated at each sample (currently 32000 Sample/s). The control electronics software filters the data, processes it through an algorithm to compare axes, and send adjusted data in real-time to the digital to analog converters that control the current in the coils (Figure 2 shows the block diagram of the system). This current, flowing through the Helmholtz coils creates a magnetic field to instantly cancel that of the Earth and any local disturbance. The algorithm limits the rate of change in this field to prevent the system oscillating.



Figure 2: System block diagram.

INITIAL EXPERIMENT AND RESULTS

Initial setup was carried out with 2 Helmholtz coil sets; each coil system having 3 axes, a 0.6 m nominal system inside a larger 1.3 m nominal diameter coil set (Figure 3 – note 2 axes of the larger coil have been removed for a little more clarity in this picture). Each coil set is 3 axes. The larger coil set is used to create a changing disturbance and the smaller coil set compensated for that field change. A reference magnetometer, as well as the feedback magnetometer was placed inside the smaller coil set. Both magnetometers were 3 axis fluxgate sensors.



Figure 3: Test coil setup.

The smaller coil system was electronically adjusted to align the feedback magnetometer to the coils to ease mechanical alignment. The larger coil system was set to apply a field cancelling that of the Earth's field. A defined field (to simulate different Earth field) was applied to the larger coil system, measured using the reference magnetometer, before the cancelling smaller coil system was activated.



Figure 4: Digitiser and 3 axis magnetometer.

The field was also measured by the feedback magnetometer and its output was feed into the control electronics (Figure 4). The control electronics then was activated to produce the required current to generate the cancelling field. The remaining field was then measured. The simulated field was increased in steps, each time the cancellation system was turned off, so the simulation field could be measured, as in Figure 5.



An AC field was also applied of 35 mG rms. The frequency was stepped between 1 Hz and 60 Hz. The attenuation to this AC field was determined – Figure 6. Further work to the algorithm is to be undertaken to improve the attenuation.



PROPOSED SYSTEM REQUIREMENT

Magnetometer: Range 2 G Resolution better than 10 µG Operating Temperature range < 4 K to > 300 K 3 Axes or Single axis, alignment is electronic better than 0.1^o Linearity better than 0.01% Offset error less than 1 mG Coil Compensation system 3 Axes Range 1 G Size 1.3 m nominal diameter Range 2 G Resolution less than 1 mG Adjustment rate limited to prevent self oscillation DC field cancellation better than 46dB at typical Earth's field AC rejection better than 30dB at 60 Hz Multiple systems can be linked together

CONCLUSION

The work to date has shown that the Earth field can be reduced to significantly less than 2-3 mG required for state of the art SRF cavity operation during the cool down phase, as well as providing compensation for AC fields. Further work is intended to improve the algorithm to enable further attenuation without compromising system stability, as well as work utilising a real SRF cavity.

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