DEVELOPING A SETUP TO MEASURE FIELD DEPENDENCE OF BCS SURFACE RESISTANCE*

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Abstract

The temperature-dependent part of the microwave surface resistance of superconducting radio-frequency (SRF) cavities has been shown experimentally to depend on the strength of the applied magnetic surface field. Several theories have recently been proposed to describe this phenomenon. In this paper we present work on the development of a microwave cavity setup for measuring the field-dependence with an applied DC magnetic field.

INTRODUCTION

The Bardeen-Cooper-Schreiffer (BCS) theory of superconductivity shows that the surface resistance R_S of superconductors in radio-frequency (RF) fields exhibits a strong dependence on temperature [1]. Experimental results have shown that this temperature-dependent component also depends on the strength of the magnetic field on the surface [2, 3]. In particular, this has been observed especially for niobium surfaces with small mean free path ℓ on the order of the coherence length ξ of clean niobium.

Several theories have been proposed to explain this field dependence with adjustments to the density of states of Cooper pair electrons in the RF-exposed superconducting surface [4, 5]. Cornell is developing a new cavity to study this field dependence and test these theories.

The motivation of the design of this new cavity was the desired ability to measure the BCS surface resistance as a function of the strength of an applied DC magnetic field on the RF surface. To probe this phenomenon effectively, it is necessary to have a fairly uniform DC field in the area dominating RF losses, so that the effects of the desired DC field can be isolated from losses on the surface where DC field strength may be higher or lower. In addition, we sought the ability to measure R_{BCS} as a function of the RF field, at least up to medium-field values. Finally, we wanted to use a high-frequency design in order to facilitate construction and testing.

The initial design phase of this cavity has now been completed. Details on this design process, outcomes of simulations, and future plans and expectations are outlined below.

CAVITY DESIGN

As previously mentioned, the main design goal of this new cavity was to establish a large area of homogenous DC magnetic field along the inner surface of the cavity in the peak RF magnetic field region. This was achieved by using a pillbox-like cylindrical design for the central "body" section of the cavity, connected to the beam tubes by a conical "loft" section, with the DC field generated by an external electromagnet. Because of the Meissner effect, any magnetic flux that enters the cavity through one beam tube must exit through the other beam tube. This flux expands uniformly to fill the body of the cavity, projecting the desired uniform field along the central cylinder. Due to this expansion/compression, the field is stronger on the inner surface of the beam tube than on the body surface; we sought to design the cavity in such a way that the strength of the RF field in this region was highly attenuated to limit the impact of the beam tubes on the measurements of surface resistance, which will be performed with RF-off Q_0 measurements.

After preliminary pen-and-paper sketching, we performed initial modeling and refinement of the cavity design in CST's Microwave Studio (MWS) simulation software, seeking to define a 6 GHz fundamental TM mode with high quality factor and high attenuation of the RF field in the beam tubes.

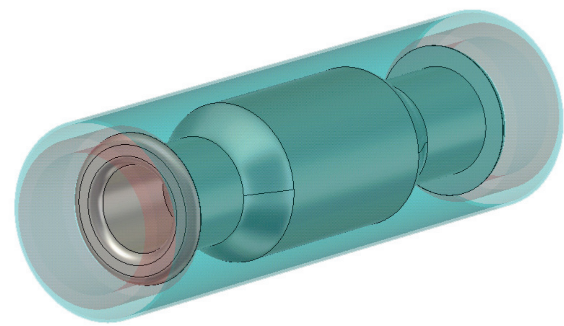

Figure 1: A CAD depiction of the field dependence cavity, shown with dressing. The magnetic shielding is shown in transparent blue, and the twin solenoids are shown in transparent red.

Table 1: Field-Dependence Cavity Parameters

Parameter	Value
Frequency	6.06 GHz
Geometry factor G	396 Ω
Quality factor Q_0	1.29×10^{10}
$B_{\mathrm{solenoid}}/B_{\mathrm{surface\ DC}}$	6.5
RF mode	TM_{010}
Total cavity length	141 mm
Cavity body radius	39 mm

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ISBN 978-3-95450-178-6

Here we optimized the lengths and radii of the main body of the cavity and of the beam tubes, as well as the parameters of the loft sections, which include the length and the smoothness of the curvature connecting the the lofts to the beam tubes and to the central body.

The beam tubes were designed with stainless steel (SS) flanges in mind to allow the external magnetic field to penetrate to the interior of the cavity while maintaining an internal vacuum. To optimize the length of the tubes for testing practicality (shorter is better), their length was set to the point where exchanging the SS flanges with superconducting Nb flanges would account for a 10% change in the intrinsic quality factor Q_0.

The loft sections were designed with an ellipse-line-ellipse cross-section to mitigate field enhancement effects.

After completing initial RF design, we turned to MWS's sister software EM Studio (EMS) for magnetostatic simulations. We considered several electromagnet array designs, generally falling into two categories, one with a single solenoid wrapped around the cavity, and the other with twin solenoids located at either end of the cavity. Ultimately, a twin solenoid design was chosen due to the cost efficiency of solenoid production as well as an observed improvement in the ratio of peak solenoid field to surface field on the central section of the cavity. The solenoids are placed around the SS flanges at either end of the cavity. In addition, a cylinder of mu-metal magnetic shielding is wrapped around the cavity and solenoids to protect the outer surface of the cavity from the DC magnetic field. Further, curvature was added to the edges of the niobium flange lips of the cavity to prevent field enhancement.

Finally, after the completion of magnetostatic optimization, we modeled the cavity using the CLANS software to verify the RF mode, find the surface field profile, more accurately calculate Q_0, and determine the geometry factor G. Table 1 shows the final design parameters of the cavity, and Fig. 1 shows a CAD representation of the cavity with shielding and solenoids.

Figure 2 shows the DC magnetic field in two-dimensional cross-section. Figure 3 shows the DC magnetic field strength and the squared RF magnetic field strength along the surface of the cavity as a function of axial position. Critically, the peak RF field is located in a large area of homogeneity of the DC field. This will ensure the sensitivity of measurements of the field-dependent BCS resistance.

UPCOMING WORK

Now that the design of this cavity has been completed, there are still several steps to complete before RF testing is possible. Before we can begin fabrication, further design is needed for a coupler and for the testing support structure, including vacuum connections and external magnetic shielding to protect the testing environment from the strong fields generated by the solenoids. In addition, we must build and test the solenoids, which will be wound with superconducting wire. Once the cavity is fabricated, it will be necessary to calibrate the solenoids with respect to the strength of the DC field generated on the inner surface of the cavity.

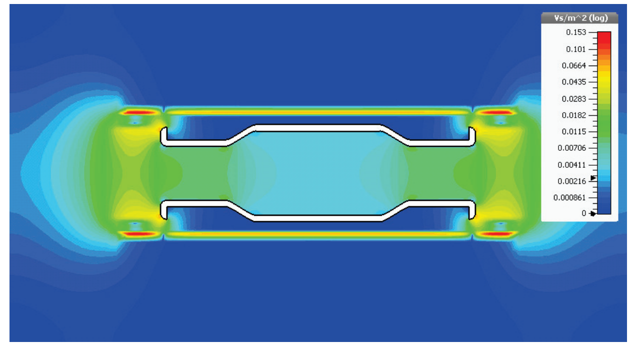

Figure 2: The absolute DC magnetic field strength in a cross section of the cavity assembly.

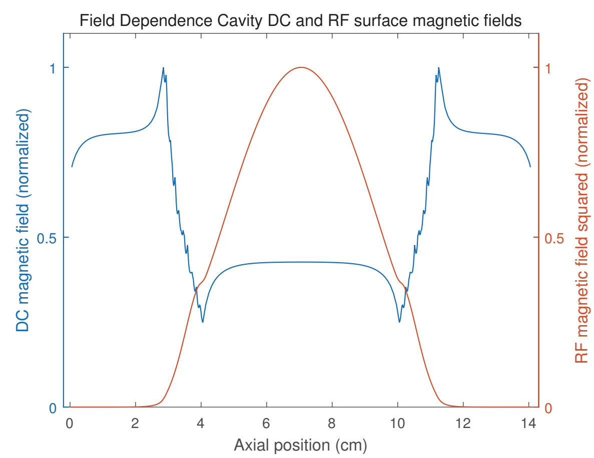

Figure 3: The DC magnetic field and the square of the RF magnetic field on the cavity surface as a function of axial position. The DC magnetic field is largely homogenous in the peak RF region, along the central barrel section of the cavity.

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