SAMPLE PLATE STUDIES USING A HIGH FIELD TE CAVITY WITH THERMOMETRY MAPPING SYSTEM*

D.L. Hall†, C.D. Burton, M. Liepe
Cornell Laboratory for Accelerator-Based Sciences and Education (CLASSE),
Ithaca, NY 14850, USA

Abstract

A TE-Mode sample plate cavity capable of sustaining peak fields of >90 mT on the surface of a 10 cm diameter sample plate has been developed and tested at Cornell. A thermometry mapping system composed of 40 Allen-Bradley resistors, mounted on the outside of the sample plate, is capable of measuring the surface resistance of the sample with a resolution of 1 nΩ and a spatial resolution of 0.5 cm. In this paper we present the design and expected performance of this high field TE cavity, and show data taken with a sample plate of niobium as well as results from tests qualifying the performance of the thermometry mapping system.

INTRODUCTION

As the fundamental limits of bulk niobium are explored and attained, Cornell has been developing TE mode sample host cavities for the purpose of studying alternative materials such as Nb_3Sn and MgB_2. These cavities are designed to accommodate a flat, circular sample plate that can be easily removed for inspection following a test. Furthermore, the addition of a Thermometry Mapping (T-Map) system allows for studies of isolated areas on the sample plate that are subject to higher losses.

In this paper we will present results from a test done using a niobium sample plate, which is necessary for correct calibration of the T-Map system for use with other materials and different niobium preparations. The design process of the cavity will be briefly touched upon, as well as the experimental procedure. Furthermore, results from an experiment to qualify the accuracy of the T-Map system will also be shown. Finally, plans for further work will be discussed.

Cavity Design

The cavity presented and discussed in this paper is the third iteration in the design process carried out at Cornell. The first two, a pillbox-style cavity and a mushroom-style cavity are described in further detail in [1, 2]. Photographs of these two cavities, as well as the latest BOB-style design, are shown in Fig. 1.

Figure 1: The three generations of TE-mode cavities, from left to right: A) The pillbox cavity, B) the mushroom cavity, C) the latest BOB style cavity.

The latest BOB-style cavity has been designed using insight gained from studies on thermal runaway quenches [2], which is the limiting factor in the pillbox and mushroom-style designs due to their higher operating frequency of 6 GHz. Comparatively, the BOB design operates at 4 GHz, pushing back the limit imposed by thermal runaway occurring due to frequency-dependent losses in the cavity walls. Using a genetic optimisation algorithm and the solver code CLANS [3], the BOB-style was developed to have a maximum field on the sample plate of approximately 120 mT before a quench due to thermal runaway occurs on the walls of the cavity. The cavity design is expounded further in [4,5].

T-Map System

The T-Map system is composed of 40 (upgradeable to 56) Allen-Bradley 100 Ω 1/8 W carbon-composite resistors which are mounted on a Teflon disc that is attached to the reverse (LHe) side of the sample plate during operation. A photograph of the T-Map is shown in Fig. 2. Once calibrated using a niobium sample plate prepared with the same recipe as the cavity, the T-Map is capable of detecting areas of increased surface resistance with resolution of 1 nΩ and a spatial resolution of 0.5 cm.

Figure 2: A photograph of the T-Map, which is mounted to the LHe side of the sample plate. The system is composed of 40 Allen-Bradley resistors, which can be upgraded to 56 by adding another layer of resistors to the outer ring.

* Work supported by NSF Grant DMR-0807731
† dlh269@cornell.edu

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EXPERIMENTAL PROCEDURE

Cavity Preparation and Test

Following completion of the cavity welds, the cavity received a 2 µm BCP, followed by a 100 µm inside vertical EP. The cavity then received a 700 °C degassing bake for 4 days and a 5 µm inside EP before a final 120 °C bake for 48 hours. The niobium sample plate used received the same treatment, albeit without the initial 2 µm BCP.

T-Map Testing

Separate from the test performed with the cavity equipped with the niobium sample plate, a test rig was developed to test the fidelity of the T-Map. Three 75 W resistors were mounted to the underside of a 1/4" steel plate, onto which the T-Map was mounted. By passing a current through a selected resistor, an artificial hotspot could be created. This was used to ensure that the location of the hotspot as determined using the T-Map corresponded to the known location of the resistor.

RESULTS

A plot of the cavity quality factor against the peak field on the sample plate is shown for 2 separate ranges of the RF input coupling factor β in Fig. 3. The maximum field achieved of (93.5 ± 9.3) mT was limited only by the RF input power available, due to the necessity of having to operate the cavity at a very low coupling factor. Coupler losses were found to be considerable at $\beta > 0.2$, decreasing the measured quality factor by a factor of 5. It is therefore currently necessary to operate the cavity with a β of no greater than 0.1-0.2 to ensure accurate results.

An example of a T-Map taken using the steel test plate equipped with selectable heaters is shown in Fig. 4. The location of the hotspot is clearly visible in the lower region of the T-Map. As the heater wattage is increased, the temperature increases linearly, as would be expected ($P \propto \Delta T$). This dependence can clearly be seen in Fig. 5. The small amount of heating seen relative to the power dissipated in the heater is primarily due to the fact that the majority of the power is lost directly into the LHe bath, as well as the thickness of the steel plate. Comparatively, when attached to a sample plate 3 mm thick on a cavity held under vacuum,

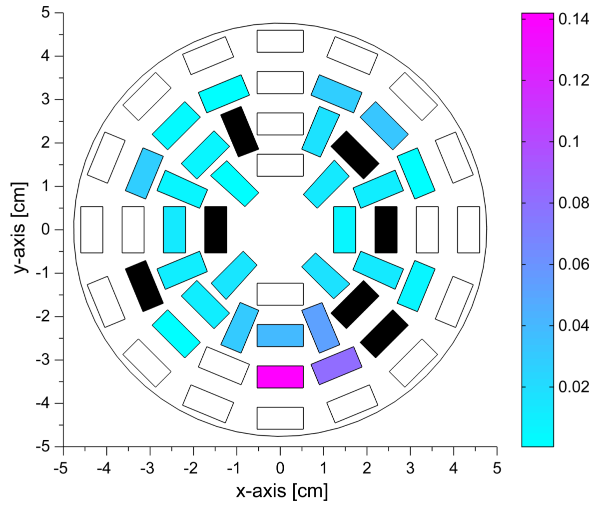

Figure 4: A temperature map of the steel plate equipped with heating resistors. Each box represent a resistor's location on the plate; white boxes indicate a resistor that is either missing (the entire outer ring) or currently unmapped. Resistors in black have failed to calibrate correctly during cooldown to 1.8 K. With a power of 10 W being dissipated in the resistor, the hotspot is clearly visible in the lower section of the temperature map.

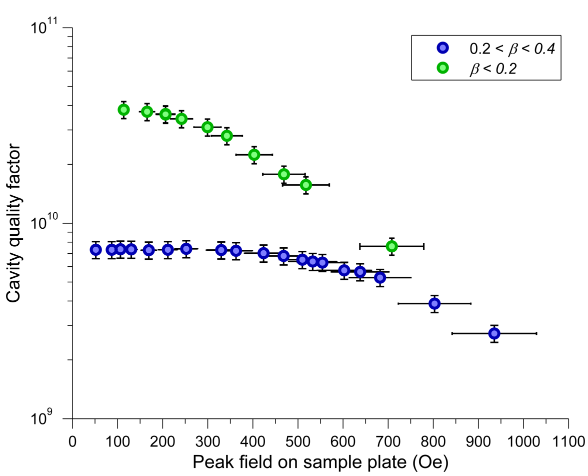

Figure 3: A plot of the quality factor of the cavity against the peak field on the surface of the sample plate, for two different ranges of the coupling β. The lower quality factor observed at higher coupling is due to losses in the coupler.

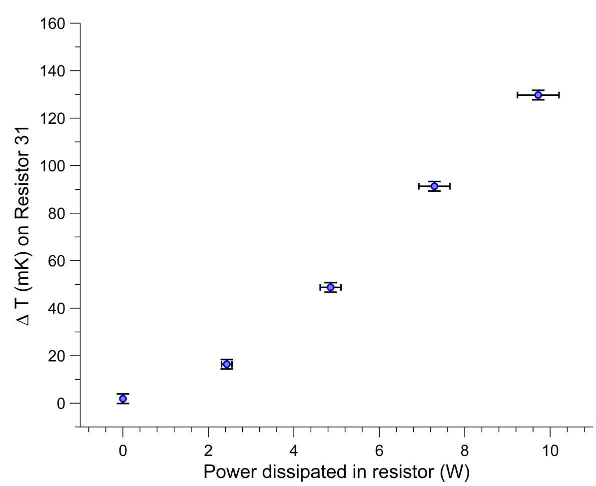

Figure 5: A plot of the temperature difference between the bath and the resistor located above the heater on the steel plate, ΔT, as a function of the power dissipated in the heater. As expected, the dependence between power dissipated and ΔT is linear.

only a comparatively small amount of power is required before a detectable signal is seen on the T-Map.

CONCLUSION AND FUTURE PLANS

The cavity currently achieves above 90 mT peak field on the sample plate, limited by the RF input power available due to the necessity to operate at low values of the coupling β. To assist with this, the tuning motor that moves the coupler in and out of the cavity is being replaced with a more advanced stepper motor for precise control of the coupling. Furthermore, the coupler is undergoing more intensive cleaning and polishing to minimise any possible losses on the coupler. Concurrently, plans are being made to replace the detachable tip of the coupler with a superconducting niobium version that will reduce coupler losses even further, allowing operation at higher values of β.

The test of the T-Map with the selectable heating plate confirms that hotspots seen on previous niobium sample plates [4] are being accurately located. Once the RF power limitations have been overcome and the coupling is precisely controlled, the cavity is expected to reach a field of 100-120 mT before a quench occurs on the cavity walls due to a thermal runaway instability. The cavity and sample plate will be calibrated using methods described in [2] to measure the microwave surface impedance of hotspots on sample plates whose composition differs from that of the walls of the cavity. The cavity shows distinct promise to be a useful tool in studying alternative materials to niobium.

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