

DEVELOPMENT AND PERFORMANCE OF A HIGH FIELD TE-MODE SAMPLE HOST CAVITY*

†D.L. Hall, M. Liepe, I. Madjarov, K. McDermott, N. Valles

Cornell Laboratory for Accelerator-based Sciences and Education, Ithaca, NY 14850, U.S.A.

Abstract

A TE-mode 4 GHz sample host cavity has been designed and constructed at Cornell for the purpose of testing samples of niobium and other candidates for the construction of SRF cavities. Simulations made using CLANS and Omega3P indicate that when operating in the 4 GHz TE₀₁₁ mode the peak magnetic field on the sample plate will reach in excess 120 mT before a quench occurs on the surface of the cavity due to thermal runaway. The cavity underwent a first vertical performance test, achieving a peak field of the sample plate of (40.4±4.0) mT. The cavity did not quench, although RF drive resonances impeded operation at higher fields. Once these are removed, the cavity will undergo further performance tests, after which it will be used in studies of the superconductors Nb, Nb₃Sn and MgB₂.

INTRODUCTION

Cornell has been developing TE-mode sample host cavities [1] for the purposes of studying the superconducting RF properties of potential alternatives to niobium, such as Nb₃Sn and MgB₂. To date, three cavities have been built, shown in chronological order (left-to-right) in Fig 1. The purpose of each cavity is to achieve the highest possible peak magnetic field on the interchangeable sample plate without causing a quench elsewhere in the cavity. Results for the first generation “Pillbox” cavity and second generation “Mushroom” cavity are given in Refs. [2] and [3].

Both the Pillbox and Mushroom cavity operated at a resonant frequency of 6 GHz, with the Pillbox cavity achiev-

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† dlh269@cornell.edu

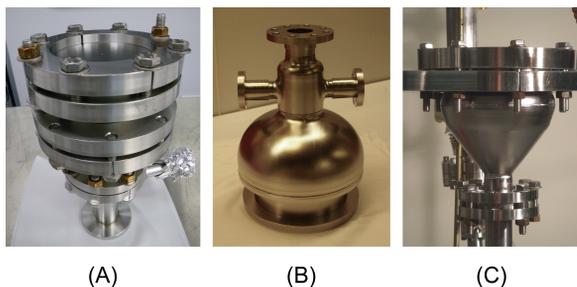


Figure 1: (A) Original pillbox cavity design (B) “Mushroom” cavity design (C) Latest “Bulge/Onion/Bulb” (BOB) cavity design.

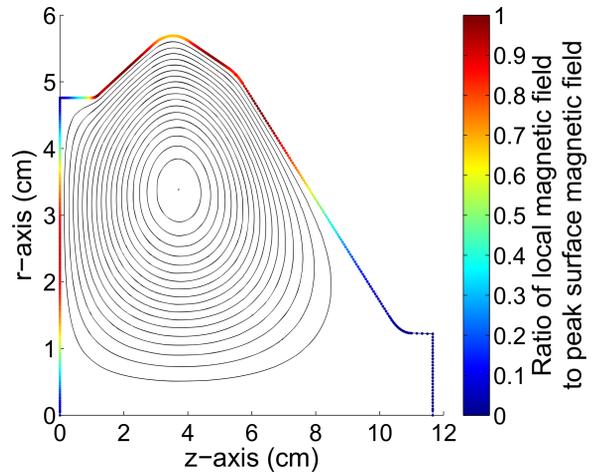


Figure 2: The surface field distribution, as a ratio of the peak surface field on the surface of the cavity, as calculated by CLANS. Magnetic field lines are shown in black for reference. The sample plate is located along the radial axis. The diagram shows a 2D cross-section of half the cavity; to obtain the 3D model, all points are rotated about the z-axis.

ing a peak sample plate field of 45 mT and the Mushroom cavity reaching 60 mT. Both of these cavities were limited by thermal runaway quench at these fields. This was later confirmed by thermal runaway simulations described in Ref. [3].

This latest generation “Bulge/Onion/Bulb” (BOB) cavity was designed to operate at a lower frequency of 4 GHz while maintaining the same sample plate size as the previous generation and a ratio of peak magnetic field on the surface of the sample plate to that on the surface of cavity walls of approximately unity. Simulations using CLANS [4] and Omega3P [5] suggest that this latest generation BOB cavity should be capable of reaching peak magnetic fields in excess of 120 mT before a quench due to thermal runaway on the cavity walls.

CAVITY DESIGN PROCESS

The cavity was designed using an optimisation interface written in MatLab that utilises CLANS for independent field simulations. The optimisation is iterative; from an initial given set of geometrical parameters, the optimisation software attempts to maximise the value of the expected thermal runaway quench field (assuming a niobium sample plate), B_{quench} , according to the relation

$$B_{quench} = B_0 \left(\frac{f_0}{f} \right)^2 R, \quad (1)$$

where f is the resonant frequency of the cavity, and R is the ratio of the peak magnetic field on the sample plate to the peak field on the cavity walls. The constants, $B_0 = 60$ mT and $f_0 = 6$ GHz, were obtained from thermal runaway simulations conducted as part of previous TE cavity work [3]. Simulations show that this latest model of TE sample host cavity has $R = 0.893$ and $B_{quench} = 123$ mT when operating in the TE₀₁₁ mode at 3.954 GHz. The surface field distribution and magnetic field pattern are shown in Fig. 2.

The cavity was constructed from high-RRR niobium, using traditional fabrication methods. The cavity was diepressed in two separate parts, which were then welded together using electron beam welding. The cavity accepts the same 5" diameter sample plates that were used for the Mushroom cavity, as shown in Fig. 3. The circular area of the sample plate exposed to the RF field inside the cavity has a diameter of 4". The cavity also utilises the same loop-style coupler developed at Cornell [6].

TEMPERATURE MAPPING SYSTEM

Cornell has previously developed a temperature-mapping (T-map) system for high resolution (≈ 0.2 mK) temperature studies of superconducting niobium cavities [7]. A new T-map system, based upon Cornell's ILC single-cell cavity T-map, has been constructed for use with this latest sample plate cavity, upgrading the previous TE cavity system from 6 sensors to 40, with the possibility of upgrading to 56.

The temperature mapping system, shown in Fig. 4, consists of a radial array of temperature sensors that are mounted in direct contact with the sample plate, on the outside of the cavity. Each sensor is a resistor with a high temperature coefficient in the <10 K region that, when calibrated using a high-fidelity Cernox sensor, allows for a measurement of the temperature difference between the

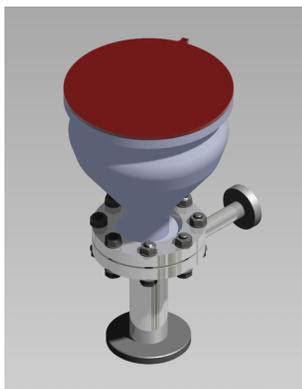


Figure 3: Location of the 5" diameter sample plate on the cavity, highlighted in red on the model.

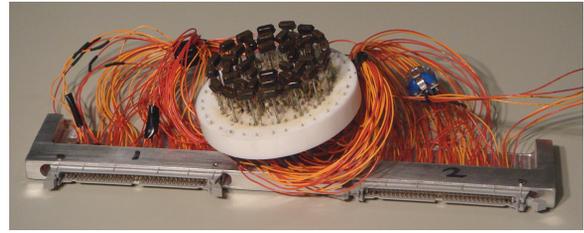


Figure 4: The new temperature mapping system built for use with the BOB cavity. The design currently incorporates 40 sensors, with the possibility to upgrade to 56. The system has a surface resistance resolution on the order of a n Ω .

area covered by an individual resistor and the bath, ΔT . From this, critical parameters such as surface resistance R_s can be obtained as a function of location on the sample plate to a spatial resolution of ≈ 1 cm and $\delta R_s \approx 1$ n Ω .

FIRST TEST RESULTS

The cavity was subjected to a vertical performance test to measure quality factor as a function of peak field on the sample plate surface. Prior to the test, the cavity received a 100 μ m EP, followed by a 700°C bake for 4 days and a 120°C bake for 48 hours. The TE₀₁₁ mode was found at a frequency of 3.949 GHz. The small deviation from the simulation value of 3.954 GHz is due to machining errors of up to 0.8 mm in the upper half-cell of the cavity, as confirmed by inspection with a coordinate measuring machine.

First test results were promising: the cavity achieved a maximum field of (40.4 ± 4.0) mT on the sample plate with a bath temperature of 1.5 K. No cavity quench was observed during the test, although the maximum RF input power was limited by drive line resonances. The cavity quality factor as a function of the peak magnetic field on the sample is shown in Fig. 5.

Throughout the test, drive line resonances impeded input

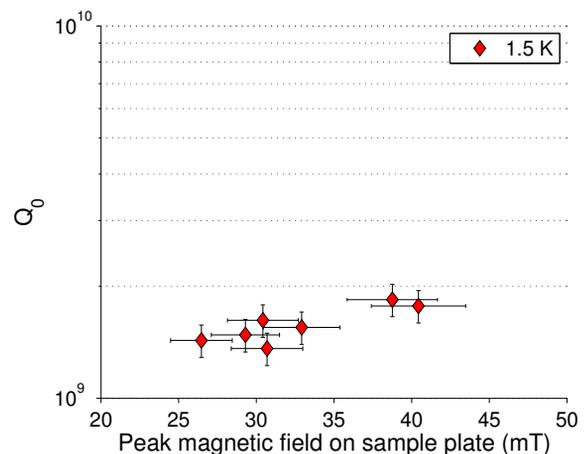


Figure 5: Intrinsic cavity quality factor Q_0 as a function of the peak magnetic field on the surface of the sample plate.

of more than 10 W into the cavity, and hindered effective coupling. Furthermore, due to the necessity for strong coupling to the cavity imposed by these resonances, coupler losses caused the measured quality factor to be artificially lower than the expected $Q_0 \approx 1 \times 10^{10}$.

CONCLUSION

The newly-commissioned BOB TE sample-host cavity achieved a field of 40 mT on the sample surface during its first test, limited only by the available input RF power. This is a promising result for the future potential of the cavity. Immediate efforts will focus on optimising the RF drive system for 4 GHz higher-power operation, after which the cavity will undergo further validation and performance tests with a niobium sample plate. The cavity will then see use in high-field studies of MgB₂ samples from Los Alamos and Temple University, Pennsylvania.

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