SRF MATERIAL PERFORMANCE STUDIES USING A SAMPLE HOST CAVITY*

D.L. Hall†, M. Liepe, D.A. Gonnella, I.S. Madjarov
Cornell Laboratory for Accelerator-Based Sciences and Education (CLASSE),
Ithaca, NY 14850, USA

Abstract

A sample-host TE-mode cavity developed at Cornell for the purposes of studying novel superconducting materials has undergone further testing using a niobium sample plate. In initial testing the peak field achieved on the sample plate was (45 ± 4.3) mT, although this was limited by the amount of input power available. New tests have been performed using both an improved RF power system and a temperature mapping system for precision measurements of surface resistance as a function of location on the sample plate. Results of the most recent test, in which the cavity achieved a peak sample plate field of (81 ± 4) mT using a high-RRR niobium sample plate, are presented and future work on the cavity is discussed.

INTRODUCTION

As the fundamental limitations of niobium for superconducting cavities are reached, it will become necessary to find alternative materials that allow one to exceed these limitations. Recent developments with Nb_3Sn, as well as other materials such as MgB_2, hold the potential to replace niobium as the optimal material for use in accelerating cavities; however, the expense and difficulty of fabricating prototype cavities using these new materials is a hindrance to their development.

Cornell has been working on the development of TE-mode sample host cavities for the purpose of testing these new materials [1,2]. A sample plate, mounted onto the cavity yet easily removed for later inspection, is exposed to magnetic fields on par with those that would be experienced by the material in a standard accelerating cavity. A thermometry mapping system, mounted onto the reverse (LHe) side of the sample plate, will allow for precise measurements of the surface resistance as a function of location on the sample plate. The comparative ease and speed with which a sample plate can be prepared and tested means that greater statistics can be accrued in less time, consequently expediting the development of these alternative materials.

The third generation of these TE-mode cavities is presented here. In this paper we will briefly discuss the design of the cavity, and present the latest results of the cavity's performance with an improved RF power system. We will conclude with a discussion on improvements and possible studies that will be implemented as part of future work.

* Work supported by NSF CAREER Grant PHY-0841213
† dlh269@cornell.edu

CAVITY DESIGN

The newest BOB style of TE cavity is a development based upon studies done with the two previous styles of TE cavity: a pillbox design and a mushroom design, each limited to 45 and 60 mT peak field on the sample plate, respectively, due to thermal runaway. These three generations of design are shown in Fig. 1.

Assuming thermal runaway to be the dominant limitation on peak sample plate field, a genetic algorithm was used to maximise the estimated peak sample plate field before thermal quench,

$$B_q = B_0 \left(\frac{f_0}{f}\right)^2 \min\left[R, 1\right] , \quad (1)$$

where $f_0 = 6$ GHz and $B_0 = 60$ mT. For each iteration of the genetic algorithm, a CLANS [3] simulation was used to obtain the values of f, the resonant frequency of the cavity, and R, the ratio of the peak field magnetic field on the sample plate to the peak magnetic field on the surface of the cavity. This latest design has $f = 3.95$ GHz and $R = 0.89$, with a theoretical peak sample plate field of $B_q = 120$ mT. Further details on the design of the cavity are discussed in Ref. [4].

EXPERIMENTAL PROCEDURE

Cavity Preparation

Following completion of the 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 chosen sample plate was originally used on the previous generation mushroom-style cavity. Before use on the cavity, it received a 5 μm EP and a 120 °C bake for 48 hours.

(A) (B) (C)

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.

ISBN 978-3-95450-132-8

Both the cavity and the sample plate received a final high pressure rinse before mounting on the insert for test.

Sample Plate thermometry

The cavity is equipped with a thermometry mapping (T-map) system mounted on the outside of the sample plate. The T-map system consists of 40 (upgradeable to 56) Allen-Bradley 100 Ω 1/8 W carbon-composite resistors, which have a large temperature coefficient at cryogenic temperatures. When calibrated using a separate high-resolution Cernox sensor, this allows for temperature measurements at each resistor with a resolution of 1 – 2 mK. The output of the T-map system is the difference between the bath temperature and the temperature of a resistor, $\Delta T = T_{\rm res} - T_{\rm bath}$.

When calibrated using a niobium sample plate of the same stock and preparation recipe as the cavity itself, the temperature mapping system will be able to convert these values of ΔT into values of sample surface resistance, R_s, at the point covered by each resistor. The resolution of this measurement will be to a precision of ±0.5 cm spatially and ±1 nΩ in R_s.

TEST RESULTS

The cavity was tested using a new RF amplifier setup, which was found to resolve earlier RF drive problems [4] that limited the maximum field achievable to 45 mT.

A plot of intrinsic cavity quality factor against peak field on the sample plate for two different bath temperature ranges is shown in Fig. 2. The first data set chronologically was taken at temperatures between 1.85 – 2.05 K, beginning at 10 mT and increasing in field until a quench was observed between 80 – 90 mT. The cavity was then taken back above T_c and re-cooled to 1.6 K. The second data set was then taken starting at 40 mT until a quench was again observed between 80 – 90 mT. In both cases, the reflected power trace from the cavity strongly suggests a quench due to thermal runaway.

A series of temperature maps taken during the second data set at 1.6 – 1.7 K show the presence of two significant hot spots on the sample plate. A temperature map taken at 75 mT, just before the quench seen in the second data set, is shown in Fig. 3. It is likely that these regions are responsible for the thermal runaway quench observed at fields above 75 mT.

An analysis of the two hot spots demonstrates a marked difference in their behaviour as a function of field on the sample plate. The location covered by resistor 23 demonstrated ohmic heating $\left(P \propto H^2\right)$ beginning at 40 mT, whilst resistor 40 demonstrated ohmic heating 40 and 70 mT, after which heating in this region increased exponentially. The behaviour as a function of field for the two hot spots is seen in Fig. 4.

During the test, difficulty was had in reducing the coupling of the input coupler to the cavity to less than unity, which likely led to significant coupler losses that impacted the measured Q_0. This difficulty was compounded by the high sensitivity of the coupling to motion of the coupler. This suggests that the motor used in the tuning system was inadequate for the task, and that a slower, higher resolution motor is required.

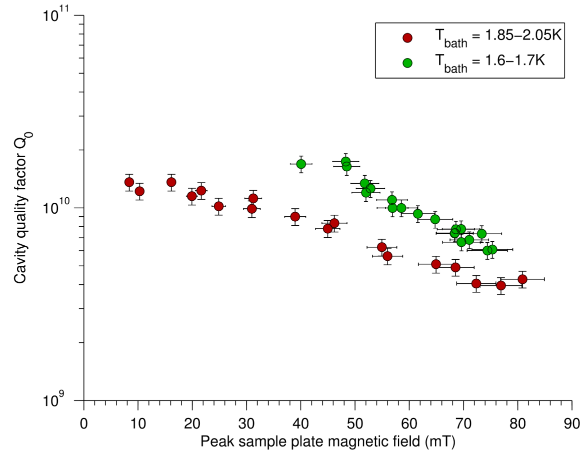

Figure 2: A plot of cavity quality quality factor against peak field on the sample plate. In both cases, a quench due to thermal runaway was seen between 80-90 mT.

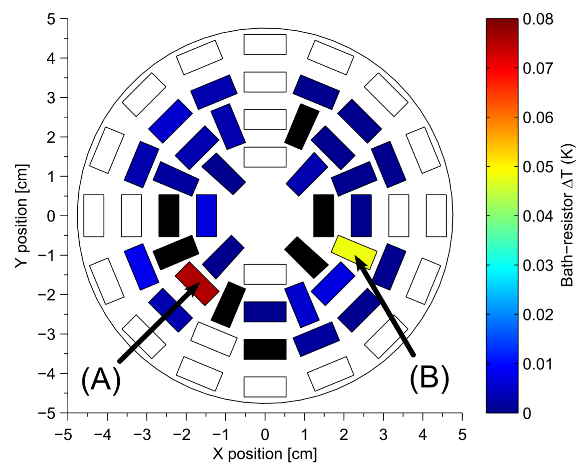

Figure 3: A temperature map of the sample plate, taken just before the quench seen in the second data set. The peak field on the sample plate is 75 mT. The two hot spots are located at A) resistor 23 and B) resistor 40. A white box indicates a missing resistor or one in need of repair, a black box indicates a poor calibration of the resistor. The outermost layer of resistors has yet to be added.

CONCLUSIONS

The new Cornell TE mode cavity has been shown to be capable of reaching at least 80 mT, currently understood to be limited by the choice of sample plate. Although the measured Q_0 was lower than expected, this is strongly suspected to be the result of coupler losses due to higher-than-desirable coupling between input power coupler and cavity. The thermometry system has been shown to work as expected and be capable of identifying areas of increased heating.

ISBN 978-3-95450-132-8

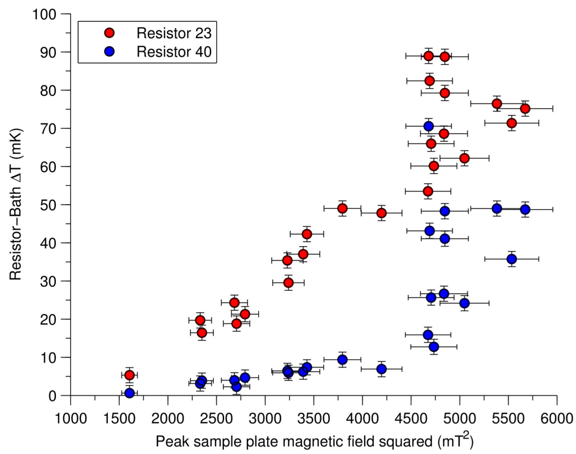

Figure 4: The difference between the bath temperature and the region covered by resistors 23 and 40 as a function of the peak field on the sample plate.

To improve the performance of the cavity and calibrate it for high-resolution sample studies, a number of improvements are currently underway. Firstly, the coupler tuning system is currently being upgraded with a fine-control stepper motor to allow for precise coupler motion, which will be used to study the effects of coupler losses on the cavity quality factor. Secondly, two niobium sample plates, from the same stock as was used to fabricate the cavity, are being prepared to serve as calibration plates. Finally, the thermometry system is currently undergoing maintenance, which should substantially reduce the number of unresponsive resistors seen during the test. Once these improvements are complete, the cavity is expected to be used for studies of sample plates of Nb_3Sn and MgB_2.

REFERENCES

[1] Y. Xie and M. Liepe, "First Results on Cornell TE-Type Sample Host Cavities," IPAC'12, New Orleans, Louisiana, USA, June 2014, WEPPC082, in Proceedings.

[2] Y. Xie, *Development of Superconducting RF Sample Host Cavities and study of Pit-induced Cavity Quench*, PhD thesis, Cornell University, January 2013.

[3] D.G. Myakishev and V.P. Yakovlev, "The new possibilities of SuperLANS code for evaluation of Axisymmetric Cavities," PAC'95, Dallas, Texas, USA, May 1995, in Proceedings.

[4] D.L. Hall, M. Liepe, I.S. Madjarov, K.P. McDermott, N. Valles, "Development and Performance of a High Field TE-Mode Sample Host Cavity," SRF'13, Paris, France, June 2014, THP038, in Proceedings.