

UPDATES ON THE DC FIELD DEPENDENCE CAVITY*

J. T. Maniscalco[†], M. Liepe, CLASSE, Cornell University, Ithaca, NY, 14853, USA

Abstract

Work at Cornell has demonstrated good agreement between a theoretical model by A. Gurevich of the anti-Q-slope (a field-dependent decrease of the microwave surface resistance) and experimental results from impurity-doped niobium. As a corollary, the model predicts that a strong DC magnetic field applied parallel to the RF surface will produce a similar decrease in surface resistance. In order to explore this prediction for many materials, we have designed a new coaxial cavity with a strong, uniform DC field superimposed over a weak RF field on a removable and replaceable niobium sample. Here we present updates on the progress of this new cavity.

INTRODUCTION

Much of recent fundamental superconducting radio-frequency accelerator physics (SRF) research has focused on the so-called “anti-Q-slope”, a field-dependent decrease of the Bardeen-Cooper-Schrieffer (BCS)[1] microwave surface resistance R_{BCS} that can give rise to an increase in intrinsic quality factor Q_0 . This exciting and puzzling phenomenon has been observed in impurity-doped 1.3 GHz niobium cavities[2, 3] and lately in clean niobium cavities at frequencies ≥ 2.6 GHz[4, 5]. Nitrogen doping is being employed in the LCLS-II accelerator project[6] to exploit this anti-Q-slope on the industrial scale.

One promising theoretical explanation for this phenomenon by A. Gurevich[7] has shown reasonable agreement with experimental results for nitrogen-doped cavities[8] as well as low-temperature impurity-doped cavities[9]. In these experimental cases, the anti-Q-slope is caused by strong RF magnetic fields parallel to the cavity surface; however, the theory proposes that DC magnetic fields on the surface would achieve similar results.

In order to investigate this claim, and to continue exploratory investigations of the anti-Q-slope on a fundamental level, we have proposed a new cavity which will allow measurements of the SRF surface resistance as a function of applied DC magnetic field (up to 200 mT) superimposed over a relatively weak (≤ 10 mT) RF field. The cavity is a coaxial quarter-wave resonator with a normal-conducting outer conductor and a superconducting inner conductor; the former allows the penetration of the external DC field into the RF cavity, and the latter is a removable sample that can be given a treatment to be investigated (*e.g.* nitrogen doping) and then be placed back in the cavity. The cavity has three intended resonant modes, at 548 MHz, 1.27 GHz, and

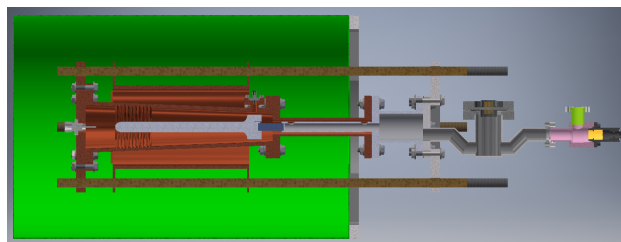


Figure 1: The full assembly of the coaxial sample host cavity.

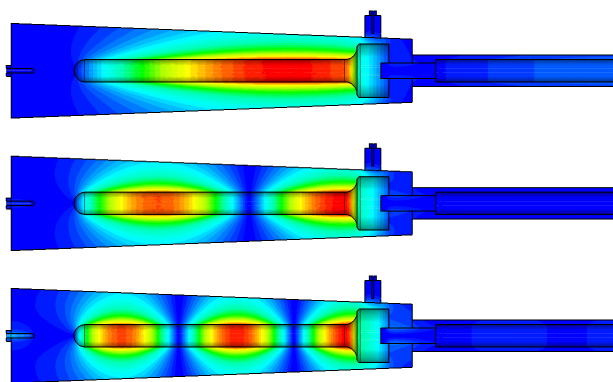


Figure 2: The three main RF modes of the cavity; color indicates the magnitude of the magnetic field, which is directed azimuthally.

2.05 GHz (the $1/4$ -, $3/4$ -, and $5/4$ -wave modes, respectively). Surface resistance measurements will be made calorimetrically, by determining dissipated power by the temperature gradient generated along a thermally isolated pathway.

This paper is an update of work previously presented at SRF 2017[10].

UPDATES

Since the last report on this cavity, we have made numerous updates and improvements on the design of this cavity. These design choices were largely motivated by the results of simulations of multipacting, RF coupling, and thermal effects, as well as issues of practicality of manufacture and assembly. Figure 1 shows an overview of the cavity design, and Fig. 2 shows the main RF modes. Figure 3 shows a closeup of the resonator assembly.

The outer conductor of the cavity shows perhaps the most striking change since the previous report. Its shape has been updated to a conical bore with a corrugated section; both changes have been implemented to mitigate multipacting. We performed multipacting simulations with the Multipac code[11]; example results are shown in Fig. 4. The conical bore effectively pushes emitted electrons down the length of the cavity, so they do not impact close to their origin.

* This work was supported by the U.S. National Science Foundation under Award No. PHY-1549132, the Center for Bright Beams. Travel to IPAC 2018 supported by NSF, APS-DPB, and TRIUMF.

[†] jtm288@cornell.edu

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

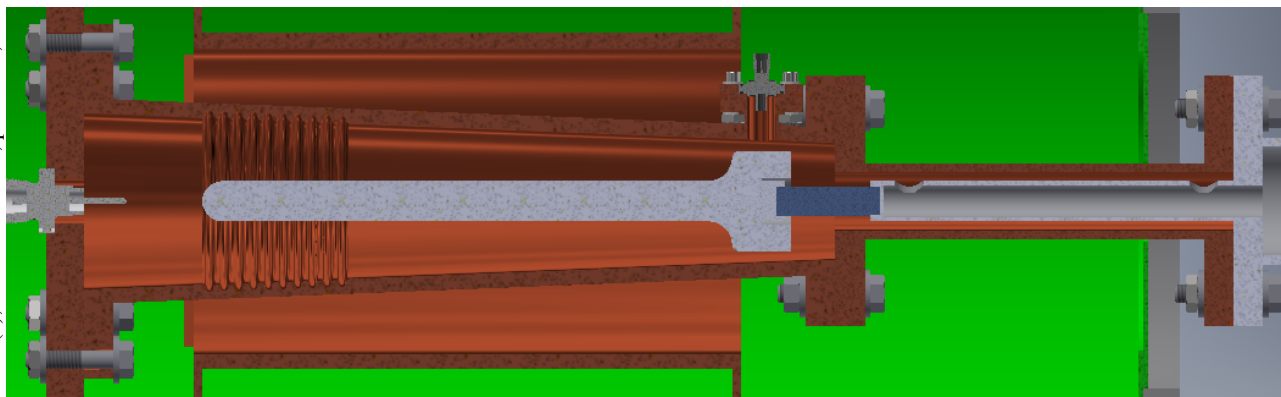


Figure 3: Closeup of the RF resonator portion of the cavity. The sapphire rod (in blue) separates the resonating section (at left) from the thermal pathway section (at right).

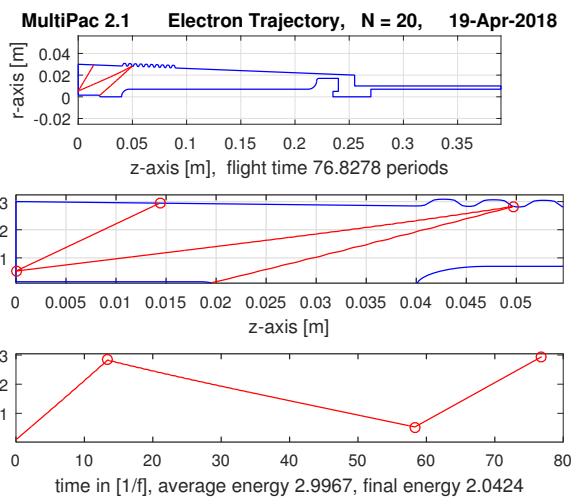


Figure 4: Multipacting simulation results. After updating the design of the outer conductor, multipacting appears to be mitigated; the above result does not indicate multipacting as the electron does not return to its origin.

The corrugation mitigates some multipacting modes which persisted in the $1/4$ -wave mode.

Another significant change was setting the forward power coupler (axially aligned with the cavity) to a fixed length. This was done to simplify cavity operation and assembly. The coupler length was optimized to yield the highest sensitivity of calorimetric surface resistance measurements. Figure 5 shows the results of these sensitivity simulations. We chose a coupler length of 1.49 cm as it yielded the best overall sensitivity, with better than 2% accuracy at almost all operating parameters (excluded operating conditions were 1.6 K and 2.1 K operation at 548 MHz; under these conditions dissipated power is extremely low). Sensitivity was calculated using the nominal sensitivity of Cernox sensors, *i.e.* ± 3 mK, and the temperature-dependent thermal conductivity of niobium[12].

We also added a transmitted power coupler to help with field level calculation and with the phase-locked loop sys-

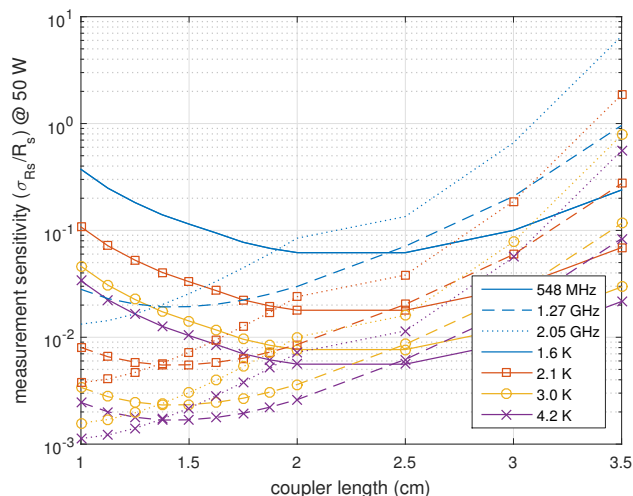


Figure 5: Sensitivity simulation results. Shown here is sensitivity to relative changes in resistance as a function of main coupler length for the three modes and at different operating temperatures, with 50 W power incident on the coupler.

tem. The length was similarly optimized to yield sensitive measurements of field level while maintaining high Q_{ext} .

Further modifications include a wider inner conductor. Thermal simulations of the previously reported design showed substantial temperature gradients (≈ 1 K) along the length of the inner conductor. We increased the width from 0.5 cm to 1.4 cm, which reduced this gradient significantly. This comes at the cost of lower RF field levels for a given energy in the cavity, since B scales with $1/r$. Nevertheless, we should expect to achieve peak surface fields up to 10 mT with negligible thermal gradient along the inner conductor.

We made an additional modification to the sapphire rod, shown in blue in Figs. 1 and 3, which serves to electrically isolate the inner conductor from the outer conductor and thereby prevent propagation of RF waves down the thermal pathway. The radius and length were reduced in order to minimize RF volume losses in the dielectric.

CONCLUSIONS

We have made significant progress in the design of our coaxial sample host cavity, which will allow for the measurement of the superconducting surface resistance as a function of the strength of an applied DC magnetic field parallel to the RF surface. This will provide a unique probe into the physics of the anti-Q-slope phenomenon, which has until now largely been limited to TE-mode elliptical RF cavities with no applied DC field. Design parameters for the cavity have been finalized, and production will be underway soon.

REFERENCES

- [1] J. Bardeen, L. N. Cooper, and J. R. Schrieffer, "Microscopic theory of superconductivity," *Phys. Rev.*, vol. 106, pp. 162–164, 1 Apr. 1957. doi: 10.1103/PhysRev.106.162. <http://link.aps.org/doi/10.1103/PhysRev.106.162>
- [2] A. Grassellino *et al.*, "Nitrogen and argon doping of niobium for superconducting radio frequency cavities: A pathway to highly efficient accelerating structures," *Superconductor Science and Technology*, vol. 26, no. 10, p. 102001, 2013. <http://stacks.iop.org/0953-2048/26/i=10/a=102001>
- [3] P. Dhakal *et al.*, "Effect of high temperature heat treatments on the quality factor of a large-grain superconducting radio-frequency niobium cavity," *Phys. Rev. ST Accel. Beams*, vol. 16, p. 042001, 4 Apr. 2013. doi: 10.1103/PhysRevSTAB.16.042001. <http://link.aps.org/doi/10.1103/PhysRevSTAB.16.042001>
- [4] M. Martinello *et al.*, "Advancement in the understanding of the field and frequency dependent microwave surface resistance of niobium," in *Proceedings of SRF2017, Lanzhou, China*, 2017.
- [5] P. Koufalas, M. Liepe, J. Maniscalco, and T. Oseroff, "Experimental results on the field and frequency dependence of the surface resistance of niobium cavities," in *Proceedings of IPAC18, Vancouver, Canada*, 2018.
- [6] M. Liepe *et al.*, "The Joint High Q0 R&D Program for LCLS-II," in *Proceedings of IPAC14, Dresden, Germany*, 2014.
- [7] A. Gurevich, "Reduction of dissipative nonlinear conductivity of superconductors by static and microwave magnetic fields," *Phys. Rev. Lett.*, vol. 113, p. 087001, 8 Aug. 2014. doi: 10.1103/PhysRevLett.113.087001. <https://link.aps.org/doi/10.1103/PhysRevLett.113.087001>
- [8] J. T. Maniscalco, D. Gonnella, and M. Liepe, "The importance of the electron mean free path for superconducting radio-frequency cavities," *Journal of Applied Physics*, vol. 121, no. 4, p. 043910, 2017. doi: 10.1063/1.4974909. <http://dx.doi.org/10.1063/1.4974909>. <http://dx.doi.org/10.1063/1.4974909>
- [9] J. Maniscalco, P. Koufalas, and M. Liepe, "The importance of the electron mean free path for superconducting RF cavities," in *Proceedings of SRF2017, Lanzhou, China*, 2017.
- [10] J. Maniscalco, M. Liepe, and R. Porter, "Design updates on cavity to measure suppression of microwave surface resistance by dc magnetic fields," in *Proceedings of SRF2017, Lanzhou, China*, 2017.
- [11] P. Ylä-Oijala and D. Proch, "Multipac - multipacting simulation package with 2d fem field solver," in *Proceedings of SRF2001, Tsukuba, Ibaraki, Japan*, 2001.
- [12] F. Koechlin and B. Bonin, "Parametrisation of the niobium thermal conductivity in the superconducting state," in *Proceedings of the 1995 Workshop on RF Superconductivity, Gif-sur-Yvette, France*, 1995.