The MAP Superconducting RF R&D Program

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Abstract

This document describes the Superconducting RF (SRF) R&D activity within the MAP program. We first briefly discuss the motivation for this effort. We then indicate the requirements for the most challenging cavities compared with the present state of the art. Next, we identify the main R&D issues and describe the program we propose to address them. This program is led by a team from Cornell University who are world experts in the field, and is supported by the U.S. National Science Foundation as an important contribution to the MAP.

1 INTRODUCTION

A program of R&D on low-frequency superconducting RF cavities has been carried out by the SRF group at Cornell and their collaborators over the last several years. The purpose of the program is to develop high accelerating gradient superconducting RF cavities to provide rapid acceleration of low energy muons to high energy for injection into a muon storage ring or collider.

1.1 Requirements

The primary focus of the superconducting RF R&D activities at Cornell in recent years has been the development of a single-cell superconducting cavity operating at 201 MHz with an accelerating gradient of at least 15 MV/m. These parameters come from an early design for the initial acceleration system for a Neutrino Factory or a Muon Collider [1]. The high gradient requirement arises because rapid acceleration is needed to mitigate the loss of the muons due to decays.[1] A relatively low frequency (201 MHz) is called for in order to be compatible with the upstream RF systems in the muon cooling channel. The low frequency also has the advantages of providing a cavity with large stored energy and of making it easy to have a large beam aperture for the intense, but relatively high emittance, muon beam. Although normal-conducting 201-MHz cavities could be considered for the acceleration, they have a significant practical disadvantage in this

[1] The substantial decays are a consequence of the short muon lifetime (2.2 μs in their rest frame).

application—the duty factor needed for the acceleration system is at least an order of magnitude higher than that for the cooling channel, so the average power required, and its removal as heat, become very unattractive.

1.2 Previous activities

Two cavities were manufactured by Cornell's collaborators at CERN by sputter coating electropolished copper cavities with several micrometers of pure Nb. The copper cavities themselves were made by spinning each half cell, electron beam welding the two halves together at the equator, and then electropolishing the inner walls to provide a very smooth surface for better adhesion of the Nb film. The finished cavity (see Fig. 1) was then high pressure rinsed with ultra-pure water.[2]

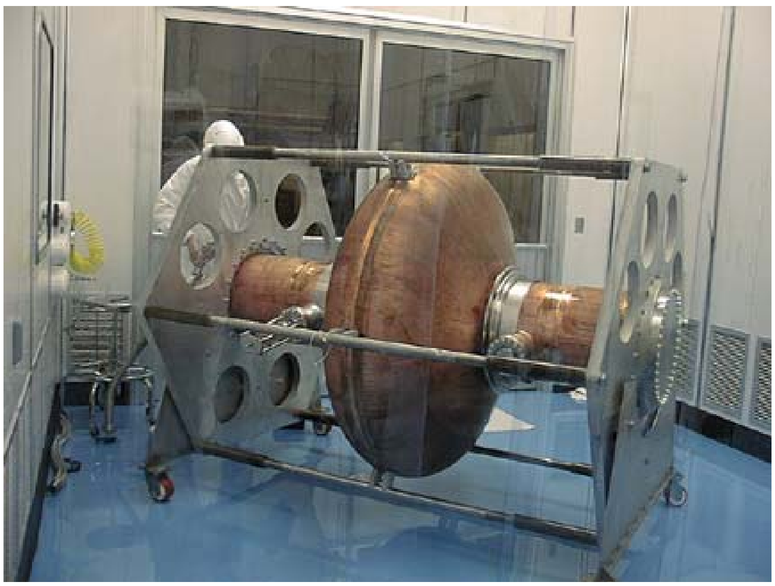

Fig. 1. 201 MHz SRF cavity on its horizontal supporting frame.

One of the 201-MHz cavities achieved [2] an accelerating gradient of 11.4 MV/m, but had a significant *Q* slope at higher gradients, indicating poor Nb surface quality. The other cavity never reached more than 3 MV/m due to severe multipacting that could not be processed away, again indicating poor surface quality of the Nb film. It appears that, because of the large physical size of the cavity, achieving a consistent high-quality film of Nb by sputtering will be very difficult. In any case, sputtered cavities are known to be prone to the so-called "*Q* disease," which causes a substantial decrease in the cavity *Q* at high gradients.

To avoid such issues, a program to develop other techniques for depositing a high quality Nb surface film on copper was carried out on small samples. This development program included DC bias sputtering, vacuum arc sputtering, and using electron cyclotron resonance to ionize a Nb vapor generated by electron beam melting of Nb. The surface

[2] It is worth noting that these were the techniques later successfully applied to the normal-conducting 201-MHz RF cavity being tested in the MuCool Test Area (MTA) at Fermilab as part of the MuCool program.

quality of some of the samples was significantly better, but transferring the techniques to actually coating a cavity was not done. As a result, no large cavity was coated with any of these techniques.

In parallel with the sputtering program, one square meter sheets of a 1 mm thick Nb sheet explosion bonded to a 3 mm thick sheet of Cu were manufactured in Japan. Similar sheets of 1 mm Nb bonded to 3 mm of Cu by another process, called hot isostatic pressure bonding (HIP), were also made in Japan. One sheet of explosion-bonded material and one sheet of the HIP material were spun into single-cell 500-MHz cavities by a Cornell collaborator in Italy, Enzo Palmieri. The explosion-bonded material produced a good cavity with a high quality Nb inner surface. In contrast, the cavity made from the HIP material had areas on the inner surface where it was clear that delamination had occurred between the Nb and the Cu. The delaminated areas would have very poor thermal conductivity and hence would probably not support high gradients. Both cavities were sent to ACCEL (now Research Instruments, GmbH) in Germany to have beam tubes and flanges electron-beam welded onto them. Unfortunately, the funding for the program ran out before the cavities could be completed and tested. The two cavities remain at Research Instruments and we intend to test them as part of the MAP effort described below.

As sputtered SRF cavities were used successfully at LEP many years ago, it is clear that such devices are possible, even at a size not that much smaller than what is needed for muon acceleration.[3] (The LEP devices operated at a lower gradient than we require, however.) Thus, what we are attempting is more in the nature of optimizing the fabrication approach to make a layered cavity that behaves on the inside as though it were made from bulk niobium.

2 R&D issues

From the experience with the sputter-coated cavities, the poor quality Nb surface that is produced by sputtering is the main limitation to their performance. The thin coating is fragile and it is simply not possible to use the surface processing techniques that have been so successful in achieving high accelerating gradients (up to 59 MV/m) in solid Nb cavities. If we are successful in using the bonded materials with ~1 mm thick Nb for the inner cavity surface, the solid Nb surface preparation techniques[4] can be used. The use of the bonded material also preserves the excellent thermal conductivity provided by the Cu, producing a much more thermally stable cavity. By soldering copper tubing to the outer cavity surface, such a cavity can be cooled by circulating LHe through the tubing instead of immersing the cavity in a LHe bath. Pure Nb cavities do not permit this type of cooling because of the much poorer thermal conductivity of Nb at 4 K. Thus, for the 201-MHz cavities needed for muon acceleration, the LHe inventory needed to cool the

[3] The LEP cavities were 353 MHz, so less than a factor of two smaller than the devices we require.
[4] Typical surface processing consists of a buffered chemical polish to remove approximately 40 microns of Nb followed by an electropolish to remove an additional 30 to 40 microns of material and provide a very smooth surface. A high-pressure ultra pure water rinse completes the surface preparation.

cavities can be very much reduced, thereby simplifying the cryogenic system and reducing its cost.

3 R&D plan

The MAP effort will provide a continuation of the program mentioned above to demonstrate the feasibility of producing high-gradient superconducting low-frequency RF cavities for efficient rapid acceleration of low-energy muons to the high energies needed. The plan is to finish the assembly of the explosion-bonded cavity presently at Research Instruments, to construct a second cavity using the remaining sheet of explosion bonded material, and to procure a third sheet of explosion bonded material, with slightly thicker Nb, and produce a cavity from it. For obvious reasons, the HIP cavity will be scrapped.

The spinning of the two new cavities would be carried out by our collaborator at INFN in Legnaro, Italy, with the final assembly again being done by Research Instruments. These three explosion-bonded cavities would then go through our standard chemistry and final high-pressure water rinsing at Cornell. The cavities would then be tested in the Cornell SRF test facility. We envision six tests, two for each cavity, over a duration of about two and one-half years.

Choosing to work at 500 MHz instead of the actually needed 201 MHz reduces the cost of producing the cavities. The savings in materials and in LHe needed to carry out the tests are very significant, enabling more detailed exploration of the properties of these cavities than would be possible at 201 MHz. As 500 MHz is sufficiently low in frequency to require a cavity with surfaces of a similar scale to the 201-MHz cavities, we are confident that these “scale models” will address all of the relevant technical challenges to be faced later in producing the larger 201-MHz single-cell RF cavities.

In more detail, year one will be devoted to finishing the cavity that is already at Research Instruments, interviewing and hiring a post-doctoral fellow to begin mid-year, performing the final surface preparation of the cavity, carrying out the initial testing of the finished cavity, procuring the materials for cavity number two and cavity number three, and arranging for the spinning and final fabrication of both of these cavities. Year two will see the finishing of cavity number two, its surface preparation, its initial testing, and the spinning of cavity number three. Year three will see the final testing of cavity number two, the finishing of cavity number three, its surface preparation, and its initial and final testing. With the three cavities, the variability of the production processes will be determined, any production problems will be understood, and the feasibility of producing high-gradient low-frequency superconducting RF cavities will have been demonstrated.

4 Summary

The demonstration of high gradient superconducting cavities produced from explosion bonded Nb on Cu can lead to reduced costs and greater thermal stability compared with solid Nb cavities. The training of a post-doctoral fellow in the testing and surface preparation of these cavities will provide a skilled scientist in a field that is in desperate need of more skilled people. Because the project is imbedded in a larger program to study superconducting RF in general, the graduate students in the larger program will have an opportunity to observe, and perhaps work on, this project as well. Involvement in exciting development programs such as low-frequency high-gradient superconducting cavities can lead to more students and post-docs choosing to pursue accelerator physics—a valuable contribution to the entire field. These new young researchers will be the ones to develop the new ideas for the accelerators that will benefit the MAP activity and society in general.

References

[1] "Feasibility Study-II of a Muon-Based Neutrino Source," ed., S. Ozaki, R. Palmer, M. Zisman, and J. Gallardo, BNL-52623 (2001).

[2] Rongli-Geng *et al.*, "First Test of Superconducting 200 MHz Nb-Cu Cavity," in 2003 Particle Accelerator Conference Proceedings, p.1309 (2003).