

THE MUCOOL RF PROGRAM*

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Abstract

Efficient muon cooling requires high RF gradients in the presence of high (3 T) solenoidal fields. The Muon Ionization Cooling Experiment (MICE) also requires that the x-ray production from these cavities is low, in order to minimize backgrounds in the particle detectors that must be located near the cavities. These cavities require thin Be windows to ensure the highest fields on the beam axis. In order to develop these cavities, the MUCOOL RF Program was started about 6 years ago. Initial measurements were made on a six-cell cavity and a single-cell pillbox, both operating at 805 MHz. We have now begun measurements of a 201 MHz pillbox cavity. This program has led to new techniques to look at dark currents, a new model for breakdown and a general model of cavity performance based on surface damage. The experimental program includes studies of thin Be windows, conditioning, dark current production from different materials, magnetic-field effects and breakdown.

INTRODUCTION

Muon cooling requires a number of constraints on rf systems. They must be low frequency to accommodate the large bunches of muons produced at targets, they must operate within the high magnetic fields required to confine and focus the muons, and they must operate at comparatively high gradients. In addition to these constraints, the Muon Ionization Cooling Experiment (MICE), which is under construction at Rutherford Appleton Laboratory, requires that single particle counters be located very close to the rf system, and singles rates from these cavities must be low enough to do single track reconstruction, Fig. 1 [1, 2].

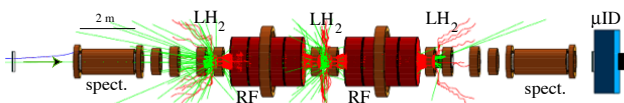


Figure 1: The MICE experiment, with x-rays (green) and electrons (red) from rf cavities, (the spectrometers at ends).

The MUCOOL RF program was designed to develop and test low frequency, high gradient rf systems appropriate to

the front end of a muon cooling line, or the MICE experiment, and began taking data in June of 2001. Initial tests utilized a 6-cell accelerating structure in a 5 T solenoid and subsequent tests have used 805 MHz and 201 MHz pillbox cavities [3, 4, 5, 6, 7, 8]. Initial tests were done in Lab G of Fermilab, however we have recently moved the experiment to the MuCool Test Area (MTA) where we can use standby power systems from the Fermilab Linac. The available power from these systems is (201 MHz: 5 MW, 200 μ s), and (805 MHz: 12 MW, 30 μ s), and the experimental program is underway. Both 805 and 201 structures can be tested using a 5 T solenoid, however the 201 structure can only see the magnet fringe field (Fig. 2). A 500 W LHe cryogenic system is under construction and the introduction of a 400 MeV proton beam into the facility is planned. Recent tests of high gradient limits with high pressure gas have been done by Muons Inc. [9].

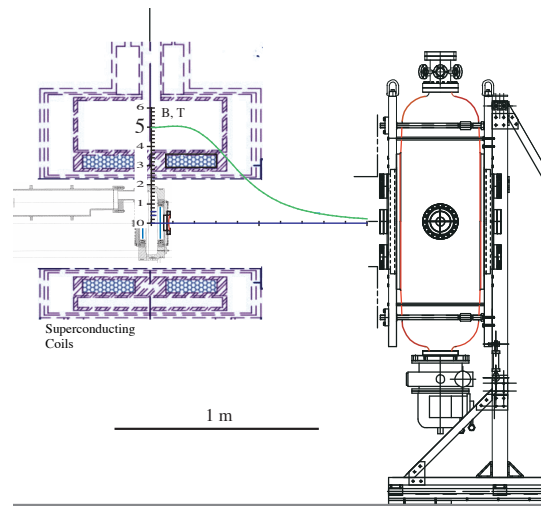


Figure 2: The 805 and 201 MHz cavities, which can be moved closer, in the fringe field of the magnet.

EXPERIMENTAL PROGRAM

The main thrust of the program has been experimental work with the immediate goal of understanding the behavior of the MICE structures and operational environment, this work has also led to a more basic understanding of the general limits of rf structures. The experimental facility

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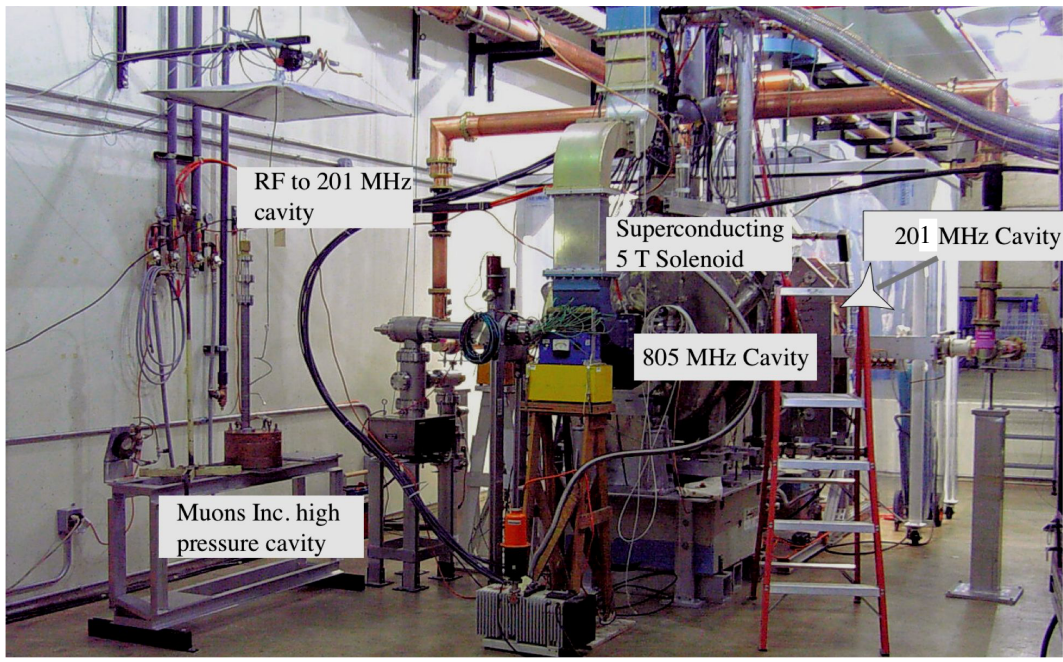


Figure 3: The 805 and 201 MHz cavities and the 5 T solenoid magnet, looking toward the linac where the power supplies are located.

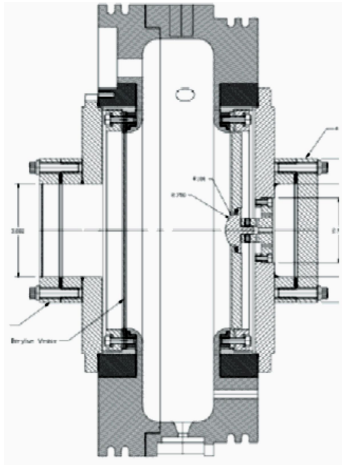


Figure 4: The 805 MHz cavity with a button sample holder on the right and thin windows on the left.

produces data with a wide range of experimental parameters.

Experimental Studies The primary uncertainties in the operation of the MICE experiment are due to the operation of the 201 MHz cavity with strong solenoidal fields and with low dark current / x-ray emission. We are also interested in understanding if the performance of the system can be improved *in-situ* using practical techniques.

As shown in Fig 2, the 201 MHz cavity is too big to fit in the bore of the magnet and, without additional coils it is not possible to produce more than about 1 T at one face of the cavity. Fig. 3 shows the experimental area. We eventually

plan to build a large coupling coil to carry flux through the cavity to realistically approximate the magnetic fields in the MICE experiment. The main thrust of the 201 MHz cavity studies is aimed at x-ray measurements during conditioning, with and without magnetic field. We are planning an extensive program to understand phenomena at the surface using dark currents and x-rays as we did with the 805 MHz cavity.

The 805 MHz cavity will also be used for studies of x-rays and magnetic fields, however we have built an assembly which can be used for studying small samples of different materials. This system, shown in Fig. 4, allows small samples, about 2.5 cm in dia. to be introduced in the cavity with a small turn-around time. The thin window system on the opposite side of the cavity will permit study of the development of damage on the samples.

Supporting Efforts In addition to the experimental rf studies, we have a small modeling effort studying the mechanisms that cause breakdown events and determining the operating conditions of rf structures in general. This work is summarized in Ref. [10]. We are also using Northwestern University Center for Atom Probe Tomography, to look at the interactions of high fields with surfaces. Using this technique, it is possible to isolate the effects of pulsed electrostatic fields at magnitudes that can damage warm copper [11].

RESULTS

Because the magnetic field has enabled us to produce detailed pictures of field emitters on the surface of the cav-

ity during operation, and the thin windows enabled us to look directly at dark current beamlets, we have been able to study the surface morphology of high gradient cavities with precision. This has allowed detailed measurements to be made of individual emitters during operation, and led eventually to a complete picture of the interactions of the structure and its operation.

Magnetic Fields, Dark Currents, and other variables

The primary new result is that our new 201 MHz MICE prototype cavity has now reached its operating field (without magnetic field) of 16 MV/m, see Fig 5. As a result of careful cleaning, electropolishing and assembly, this cavity reached this field gradient with only a very few breakdown events, following a short period of multipactoring. We expect to be able to maintain this cavity in a clean condition with a portable clean room which we can move over the cavity when windows, couplers or instrumentation are altered.

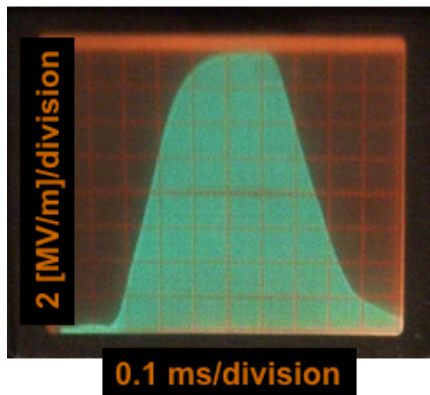


Figure 5: the 201 cavity reaches the design field of 16 MV/m with $B = 0$.

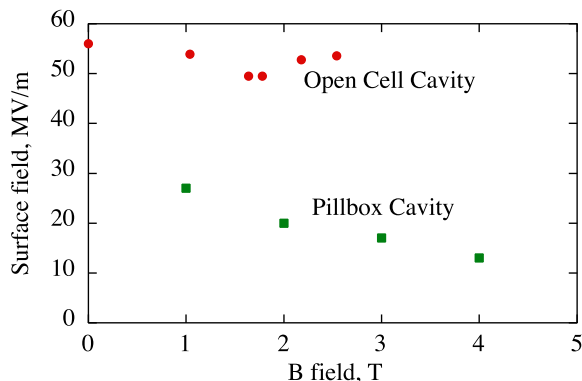


Figure 6: Data on the maximum surface fields obtained with two different structure geometries. The open cell cavity, where E is not parallel to B at the surface, shows better performance.

The experimental results obtained so far seem to show that the operation of the cavity depends in a complex way

on the geometry of the rf structure, the magnetic field, the electric field, pulse width etc. For example, the magnetic field changes the operating range of both, while it seems to limit the performance of the 805 pillbox cavity, but not the 805 open cell cavity. A summary of this data is shown in Fig. 6. We do not understand the dependence of the field on the particular cavity used, but assume that the lower fields obtained with the pillbox cavity are related to the fact the the electric and magnetic fields are parallel in that structure, which can effect the nature of the discharge.

Model of Cavity Operation We have just published a summary of a model which relates the rf operation to the cavity parameters and will be refining the model and improving the experimental data it is based on [7, 10],

SUMMARY

This program has been very useful, both for the immediate goals of the muon cooling effort but also, because the wide variety of instrumentation that has been used, for an improved understanding of the surface of high gradient structures and the mechanisms that control them. We expect this to continue to be a very productive facility.

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