Title
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Publication Date
2005-05-20

THE RF EXPERIMENTAL PROGRAM IN THE FERMILAB MUCOOL TEST AREA*

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Abstract

The rf R&D program for high gradient, low frequency cavities to be used in muon cooling systems is underway in the Fermilab MUCOOL Test Area. Cavities at 805 and 201 MHz are used for tests of conditioning techniques, surface modification and breakdown studies. This work has the Muon Ionization Cooling Experiment (MICE) as its immediate goal and efficient muon cooling systems for neutrino sources and muon colliders as the long term goal. We study breakdown, and dark current production under a variety of conditions.

INTRODUCTION

The MUCOOL Test Area (MTA) rf program will be directed at solving a number of problems related to muon cooling, including specific issues related to the Muon Ionization Cooling Experiment (MICE), while looking at the general problems of high gradient rf fields in low frequency cavities, with and without high magnetic fields [1][2]. Vacuum breakdown and dark currents are not completely understood, although people have been working on the problem for over 100 years [3].

The goals of the rf program in the MTA are well defined. In order to optimize the design of the MICE experiment we want to understand the interactions of high gradient rf structures in high magnetic fields so we can use the highest gradients, and we would like to understand and minimize the x-ray backgrounds produced by field emitted electrons. Minimizing damage from breakdown events, if possible, is also desirable,

The MICE experiment will use 201 MHz cavities with dome shaped Be windows 42 cm in diameter and ~350 μm thick. Previous tests have shown that the solenoidal fields can be a problem when attempting to operate at the highest electric fields, and the effects of the larger cavities and larger stored energy are not well understood. While our tests of Be showed that this metal worked well with the 805 MHz cavity, the tests with thin, flat windows showed some instabilities. The experimental program will study these problems before MICE begins.

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THE EXPERIMENTAL PROGRAM

The Fermilab MTA facility was recently constructed at the downstream end of the linac for R&D on muon cooling technology involving high gradient rf fields, high magnetic fields, liquid hydrogen targets and high intensity beams. It has been occupied on an accelerated schedule since the Lab G facility had to be decommissioned due to the loss of the klystron used there. The initial program is underway and involves hydrogen and rf tests.

General Layout

The site of the MTA was chosen to permit reasonable lengths of coax and waveguide to power experimental 805 and 201 MHz systems using the spare klystrons in the Fermilab linac gallery. The facility can also be used for hydrogen target tests, high intensity beams to test hydrogen absorbers and cavity systems with high magnetic fields. The MTA experimental area is shown in Figure 1.

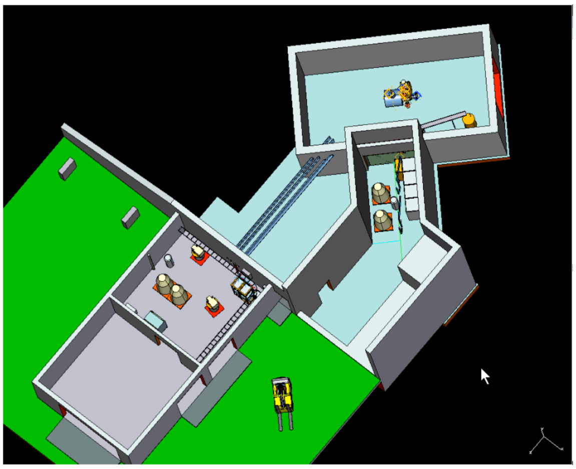

Fig. 1, The MUCOOL Test Area. The experimental area (top) is connected to hydrogen refrigeration equipment (lower left). Beam will enter from top right.

The construction of this facility was finished last year and we have begun to exploit the features with initial tests using hydrogen cavities and the solenoid magnet and pillbox cavity used in Lab G.

The 805 MHz Program

Initial tests on thin, flat Be windows seemed to show that they could be unstable at high power levels, with slow drifts in the frequency as the cavity was operated at higher powers, and difficult restarts after sparks. The curved Be window should be more mechanically rigid and dimensionally stable, while maintaining the same advantages over copper seen in earlier operation.

We will do tests on buttons of different materials (Figure 2). Comparisons of different materials in an rf environment is difficult, because cavities are very complex objects and cavity surfaces involve many mechanisms. Mo, W, SS and Be have been shown under some circumstances to work better than copper, and Au has been shown to be not as good. However, experiments have been complicated by the difficulty in understanding surface effects, different conditioning requirements and different assembly procedures. In order to attempt to control these variables, we have designed a system that allows us to change out "buttons" so that tests of these various effects can be done quickly. One important constraint in these tests is that the surface is affected by contamination thrown onto the buttons by breakdown in other parts of the cavity.

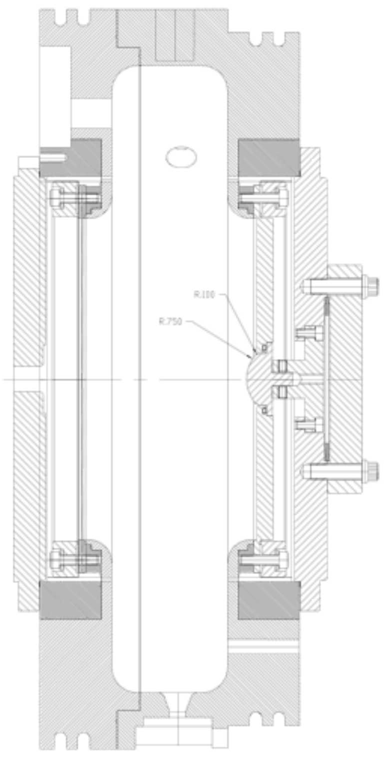

Fig. 2, The Button Test Assembly in the 805 MHz pillbox cavity

One of the challenges encountered in the Lab G program was the decrease in the maximum rf gradient that could be supported in a cavity when the solenoidal field was applied, and the conditioning program that was required any time the field was turned on or off. A simple explanation of this effect is that $\boldsymbol{j} \times \boldsymbol{B}$ forces within the field emitters can damage or alter them, and tests of different materials at different orientations to the field may be useful.

One of the main uncertainties of the MICE experiment is the magnitude of the x ray background produced by field emission of electrons in the cavity. In principle this background can be controlled by suppressing field emission with coatings in the cavity. There are a number of experimental problems that have been encountered with this approach however, since it is not clear which coatings would be most useful, what the best method of application is, what the bonding strength of the coating to the substrate is, and is what happens if the coating comes off. The 805 MHz cavity is a more efficient test assembly than the 201 MHz cavity, which is more expensive. An experimental program is being set up at Northwestern University Center for Atom Probe Tomography to use field ion microscopes to understand the basic material science behind breakdown and dark current phenomena.

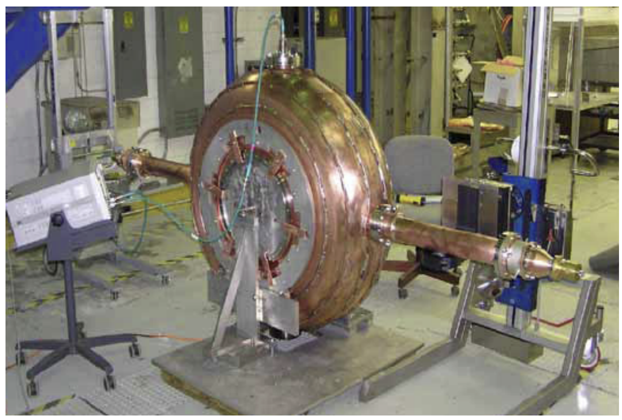

Fig. 3, The 201 MHz Cavity.

We have also constructed aluminum waffle grids to be inserted in the pillbox cavity as an experimental test of the calculations done by Alsharoa [5].

The 201 MHz Program

This cavity is essentially the prototype for the MICE experiment, but we will not initially be able to operate the cavity at the MICE magnetic field values. Construction is essentially completed and the design and fabrication is described in this conference [6].

There are a number of uncertainties involved with the conditioning of a 201 MHz cavity, such as the maximum fields that can be produced, the time needed to reach maximum field, and the radiation levels, (and shielding) that must be accommodated during the process. This is one of the primary uncertainties. We need to know the optimum method of conditioning

We will not initially be able to put the 201 MHz cavity in the high field region of the solenoid, so it may be difficult to look directly at the limits imposed by the field. On the other hand, we will be able to produce significant fields and these may be useful for understanding the physical mechanisms involved.

At the present time the primary method of controlling dark currents and x ray backgrounds is modification of the surface. The size of the cavity, its stored energy, and access to the interior are severe constraints on the control we can have of the surface. Thus, it seems desirable to look at surface modifications such as in-situ coating, cleaning and polishing. Results from the 805 MHz cavity and the Northwestern program will be useful, since the range of experiments that can be done will be limited by cost and risk.

High Pressure Tests

The parameter space of rf breakdown in high pressure gasses has never been systematically explored, and tests are underway which will study the effects of different materials, different gasses and different surface treatments. Results from previous tests have shown that high pressure hydrogen (~100 atm.) can be used to retard breakdown in rf cavities. (Muons can enter and exit a cavity thru thick windows without hard scattering.) A group from Muons Inc. is pursuing this option [7].

Modelling Dark Currents and X Rays

An extensive program has been underway to model field emission and dark currents in the MICE experiment since they are responsible for backgrounds in the detectors. This effort has produced a detailed picture of electrons and x rays in the setup and is helping us determine the allowable levels of field emission in the 201 MHz cavities [8].

A complete model of the dark currents and x ray production requires additional information on field emission within the cavities: radial distribution, dependence on E and B fields and damage sites. The experimental program will try to provide this information to increase the value of the modelling effort.

Atom Probe Tomography Studies

Work in the MTA is proceeding in parallel with a laboratory study of materials at high fields using Atom Probe Tomography. This effort, done with Prof. David Seidman and Jason Sebastian at the Northwestern University Center for Atom Probe Tomography, can provide an atomic scale picture of the behavior of materials at high electric field limits. We plan to use information on coatings and field emission, done at atomic scale, with this work [9].

PLANS

The first experiments with hydrogen began last May with the operation of the KEK absorber test assembly, and these tests will resume in the late summer. The hydrogen facility is being expanded with the installation of refrigerators and compressors.

Tests with rf began at the beginning of May, and should continue indefinitely. Both the 805 and 201 MHz cavities can be operated at the same time remotely from the linac gallery. Initially the small 44 cm ID 5T solenoid will be the only high field magnet, however we can move the low frequency cavity close to the solenoid to produce some field. We have designs for a large "coupling coil" from the MICE experiment to be built and installed around the large cavity that would provide useful high field tests, however this coil is presently not funded.

Plans for extracting both high and low intensity beams from the Fermilab linac are well advanced, however these are not, at present, funded,

SUMMARY

After finishing a productive experimental program in Lab G of Fermilab, we have moved our experimental program to the MUCOOL test area, near the 805 and 201 MHz power supplies of the Fermilab linac. Our experimental program primarily consists of understanding issues relevant to the operation of the MICE experiment. We plan to continue the experimental program of the 805 MHz pillbox cavity, extending our studies of different materials, high magnetic fields and high gradients, and we will start a program with the 201 MHz cavity, which will look at some of the same issues, along with studies of conditioning and production of x ray radiation, which will impose limits on the counting rate in the counters of the MICE experiment.

REFERENCES

[1] M. Alsharoa et. al., Phys Rev STAB, 6, 081001, (2003)

[2] http://hep04.phys.iit.edu/cooldemo/

[3] R. F. Earhart, Phil. Mag. **1**, 147, (1901)

[4] J. Norem, P. Gruber, A. Bross, S. Geer, A. Moretti, Z Qian, D. M. Kaplan, Y. Torun, D. Li, M. Zisman and R. Rimmer, Proceedings of the 2003 PAC Conference, Portland OR, May 12 – 16, 2003, (2003) p 1183.

[5] M, Alshiroa, PhD Thesis, Illinois Institute of Technology, 2004

[6] R. Rimmer, S. Manning, R. Manus, L Phillips, M. Stirbet, G. Wu, D. Li, R. MacGill, J. Staples, S. Virostek, M. Zisman, R. Hafley, R. Martin K. Taminger, M. Reep, D. Summers, this conference.

[7] P. M. Hanlet et. al, this conference.

[8] R. Sandstrom, *Simulation of RF-induced background in G4MICE,* http://mice.iit.edu/mnp/MICE0092.pdf

[9] J. Norem, P. Pauer, J. Sebastian and D. N. Seidman, this conference.