THE NORMAL CONDUCTING RF CAVITY FOR THE MICE EXPERIMENT*

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Abstract

The international muon ionization cooling experiment (MICE) requires low frequency, normal conducting RF cavities to compensate for the muon beam longitudinal energy loss in the MICE cooling channel. Eight 201-MHz normal conducting RF cavities with conventional beam irises terminated by large, thin beryllium windows are needed. The cavity design is based on a successful prototype cavity for the US MuCool program. The MICE RF cavity will be operated at 8 MV/m in a few tesla magnetic field with 1-ms pulse length and 1-Hz repetition rate. The cavity design, fabrication, post processing plans and integration into the MICE cooling channel will be discussed and presented in detail.

INTRODUCTION

Demonstration of muon ionization cooling is essential for a neutrino factory or a muon collider. An international collaboration was formed to carry out the muon ionization cooling experiment (MICE) and demonstrate cooling. The experiment is hosted by RAL (Rutherford Appleton Laboratory) in the UK. Significant progress has been made in recent years on the research and development for muon ionization cooling channel hardware by the US NFMCC (Neutrino Factory and Muon Collider Collaboration) and the MICE collaboration [1]. As muon beams are typically produced with large six-dimensional emittance, the emittance must be reduced (cooled) significantly before the muon beam can be further accelerated by an accelerator complex for a neutrino factory or a muon collider. Ionization cooling is considered to be the most promising transverse cooling scheme in practice. An ionization cooling channel consists of absorbing materials, RF cavities and superconducting solenoidal magnets. When traversing the cooling channel, a muon beam loses energy in absorbing materials (in all directions), whereas only the lost longitudinal energy is compensated by RF cavities. Both the absorbing materials and the RF cavities are enclosed within the superconducting solenoidal magnetic fields required to confine the muon beams. Consequently, the net effect is the reduction of the transverse emittance or cooling. This process can be repeated over a series of cooling channel cells. Moreover, muons decay and have a relatively short lifetime (~2 μs at rest), so a low frequency, normal conducting RF cavity with the highest possible accelerating gradient is called for.

The hardware development for a muon ionization cooling channel has been mainly conducted in the MuCool program of the US NFMCC. For the MICE cooling channel (based on the US Feasibility Study II for a neutrino factory), as shown in Fig. 1, there are 4 cavities in each RFCC (RF and Coupling Coil) module. Each cavity is a pillbox-like, 201-MHz normal conducting cavity with large, thin beryllium windows to terminate an otherwise conventional open iris.

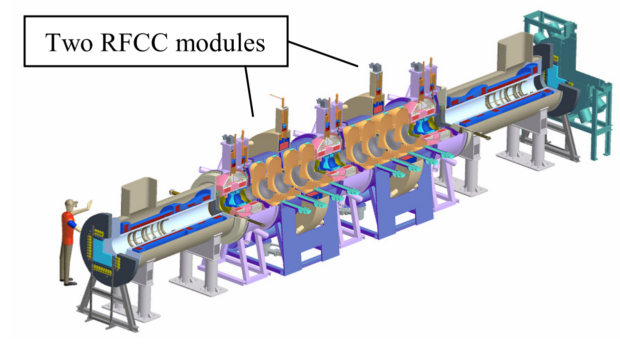

Figure 1: International MICE cooling channel—three AFC (Absorber and Focusing Coil) and two RFCC modules.

Previous RF testing has indicated that conditioning and operating an RF cavity in a strong magnetic field is a challenging task. The achievable accelerating gradient degrades with increasing external magnetic field [2]. The MICE RF cavity will be operated at 1-Hz repetition rate, 1-ms pulse length, and a modest gradient of 8 MV/m; this is due to a limitation on available RF power.

This paper reports recent progress on the design and fabrication of the MICE RF cavities

201-MHz CAVITY FOR MICE

The cavity design, fabrication techniques and post-processing are based on the successful prototype cavity for the US MuCool program [3, 4, 5]. Unlike the prototype, the MICE cavity will be installed in a vacuum vessel; there is no differential pressure on either the cavity body or the beryllium windows. Significant progress has been made in engineering the interface of the RF cavity with the RF power coupler, cavity tuners, support structure, and superconducting coupling coils. The cavity design and fabrication plans went through two reviews in 2008. The engineering design of the cavity is complete.

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Contracts for the cavity fabrication were awarded early this year.

Cavity Design

The MICE cavity design adopts a round pillbox profile (similar to the MuCool prototype cavity) with low peak electric surface field; and the conventional open irises are terminated by curved 0.38-mm thick and 42-cm diameter beryllium windows. The main parameters of the cavity are listed in Table 1. For the nominal neutrino factory parameter of ~16 MV/m, up to 4.6 MW peak RF power is needed in each cavity.

Table 1: Main design parameters of the 201-MHz cavity

Parameter	Value	Units
Frequency	201.25	MHz
Shunt Impedance	22	MΩ/m
Cavity diameter	121.7	cm
Beam iris (diameter)	42.0	cm
Cavity gap (length)	42.0	cm
Quality factor Q	53,500	

A 3-dimensional parameterized CST MWS model was built (as shown in Fig. 2) to simulate RF fields and cavity geometry optimization. Frequency shifts due to the four RF ports and curved beryllium windows are included in the model analysis. Good agreement was achieved between the simulation results and measurements of the MuCool prototype cavity.

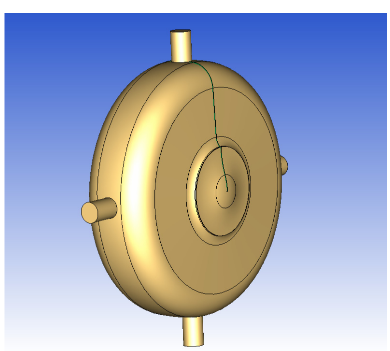

Figure 2: CST MWS model for MICE 201-MHz cavity.

ANSYS has also been used to simulate RF fields, and to study thermal and mechanical designs (see Fig. 3) [6]. The simulated RF fields provide the RF power heating density distribution of the cavity for thermal analysis. The thermal solution gives the temperature distribution throughout the cavity and its beryllium windows. We found that the heat fluxes on inward curving windows are 60% higher than for outward curving windows (with a correspondingly higher temperature rise). Peak temperature rise occurs at center of the inwardly curved beryllium window (~86°C) using "Nominal Neutrino Factory" parameters [4]; for MICE, the temperature rise is 4 times lower.

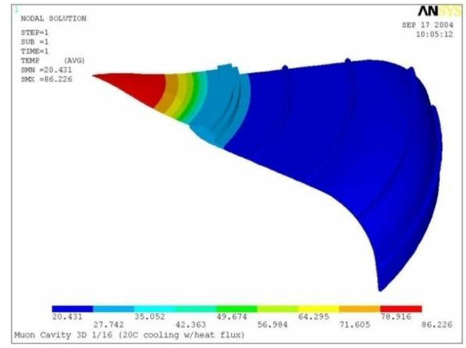

Figure 3: ANSYS modelling to perform RF, thermal and structural cavity analyses.

Cavity Body Fabrication

Similar to the MuCool prototype cavity, the cavity body will be spun against a pre-designed and machined mold (from 6-mm flat copper sheets). The mold used for the prototype cavity will be re-used for MICE cavities, but with a slight reduction in diameter to raise the cavity frequency. Two spun half-shells will be joined by e-beam welding. We need four ports at the cavity equator for RF power couplers, vacuum and RF probes. These ports will be formed by pulling a die through a pilot hole cut across the equator weld (extruding), a technique developed and successfully used for the MuCool prototype cavity. Water cooling tubes will be externally TIG brazed to the cavity body. Two curved, thin beryllium windows will be bolted onto the cavity aperture. Figure 4 is an exploded view of the cavity showing the details of the cavity concept.

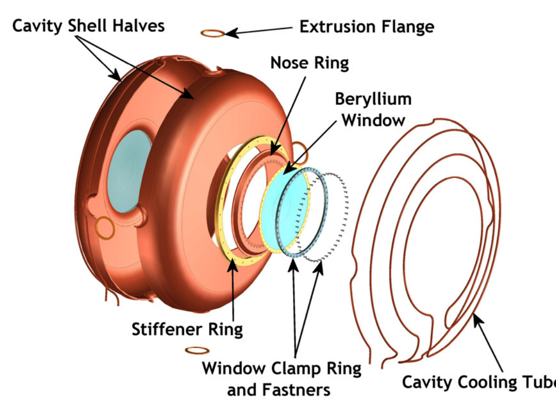

Figure 4: 201-MHz MICE cavity fabrication concept.

The cavity body spinning will be conducted at Acme Metal Spinning Company in Minneapolis. The copper sheets will be pre-polished before spinning and possibly polished again, if necessary, after spinning. The spun half-shells will then be shipped to Applied Fusion Company in Hayward, California to complete e-beam welding and port extruding. The cavities will then be shipped to LBNL for surface inspection or to be further cleaned both mechanically (if necessary) and chemically before electro-polishing (EP). Pre-assembly of the RFCC module will take place at LBNL, before shipping to RAL.

Curved and Thin Beryllium Windows

Each cavity has a pair of curved, thin beryllium windows with TiN coating. The window has a double-curved shape and is 0.38-mm thick and 42-cm diameter. The window profile and thickness were designed and determined in consideration of mechanical and thermal stresses caused by RF heating. The window (foil) shape is formed at a high temperature against a die with the designed profile. Copper frames are brazed onto the windows after forming. To minimize cavity frequency shifts, the windows are mounted in the cavity in such a way that one curves out and the other curves in. The beryllium windows for the MuCool prototype were made at Brush-Wellman Company in California. The MICE cavity will use the same window design. A purchase order for the beryllium windows has been placed.

RF Power Coupler

There are two loop couplers at critical coupling for each cavity. Fabrication of the coupler uses standard off-the-shelf copper coaxial components. The coupling loop has integrated water cooling lines. Each coupler uses one SNS-style ceramic RF window manufactured by Toshiba Company. Figure 5 shows two photos of the RF loop coupler (right) and the SNS ceramic RF window (left) for the MuCool prototype cavity. It may not be necessary to use two couplers for the MICE cavity, as the available peak RF power for each cavity is only 1 MW. Nevertheless, with the two couplers we have the possibility to test the MICE cavity at high gradient by feeding all available RF power into one or two cavities.

Figure 5: SNS Ceramic RF window (left) and loop RF coupler for MuCool prototype cavity.

Cavity Tuners

It is difficult to reach the design frequency of 201.25 MHz accurately using spinning fabrication techniques. RF tuners are required to adjust the cavity frequency. The cavity will be tuned in two steps, coarse tuning and fine tuning. The coarse tuning will be realized by deforming the cavity body using the stiffener rings (if this becomes necessary after fabrication to bring the cavity frequency within the dynamic tuning range of the fine tuners). Fine tuning employs six dynamic tuners, evenly spaced on each cavity as shown in Fig. 6, to provide a tuning range of –230 kHz to +230 kHz with a sensitivity of +230 kHz/mm per side. The tuners touch the cavity, and apply loads, *only* on the stiffener ring (see Fig. 4). The tuners will work both in push-in and pull-out modes.

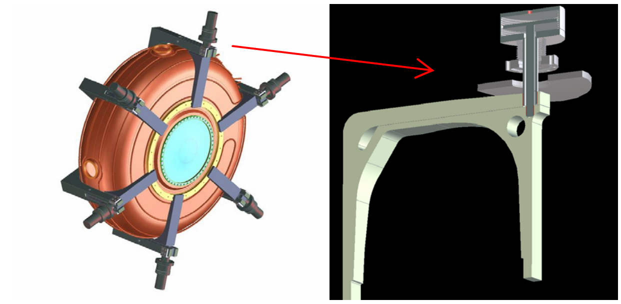

Figure 6: Six tuners on each cavity (left) and enlarged view of one tuner (right) showing the actuator and pivot point.

FABRICATION SCHEDULE

Cavity fabrication has begun, and the first five cavities will be delivered to LBNL by the end of calendar year 2009. Significant progress has been made in integrating the RF cavities into the overall RFCC module containing the coupling coil magnets, which will be fabricated at Harbin Institute of Technology, China, in collaboration with LBNL [7].

SUMMARY

The 201-MHz cavity design for MICE is complete and the fabricated has begun. Eight 201-MHz RF cavities are needed for MICE; and the first five cavities will be delivered to LBNL by end of 2009.

REFERENCES

[1] Latest information on MICE and the collaboration can be found at http://www.mice.iit.edu.

[2] R. Palmer, *et al.*, "RF breakdown with external magnetic fields in 201 and 805 MHz cavities," PRST: Accelerators and Beams, **12**,031002 (2009).

[3] D. Li. *et al.*, "A 201-MHz normal conducting rf cavity for the international MICE experiment," EPAC-2008 Proceedings, Genoa, Italy, 23-27 June 2008, pp 784-486.

[4] D. Li, *et al.*, "Progress on RF Coupling Module Design for the MICE Channel," PAC 2005; D. Li, *et al.*, "201 MHz Cavity R&D for MuCool and MICE", PAC 2007 Proceedings, Albuquerque, New Mexico

[5] R. Rimmer, *et al.*, "Fabrication of the prototype 201.25 MHz cavity for a muon ionization cooling experiment," PAC 2005 Proceedings, Knoxville, Tennessee, pp 2080-2082

[6] S. Virostek and D. Li, "RF, Thermal and Structural Analysis of the 201.25 MHz Muon Ionization Cooling Cavity," PAC 2005 Proceedings, Knoxville, Tennessee, pp 2119-2121

[7] L. Wang, *et al.*, "Progress on the MuCool and MICE Coupling Coils", PAC-2009 Proceedings