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PROGRESS OF MICE RFCC MODULE*

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Abstract

Recent progress on the design and fabrication of the RFCC (RF and superconducting Coupling Coil) module for the international MICE (Muon Ionization Cooling Experiment) are reported. The MICE ionization cooling channel has two RFCC modules, each having four 201-MHz normal conducting RF cavities surrounded by one superconducting coupling coil (solenoid) magnet. The magnet is designed to be cooled by three cryocoolers. Fabrication of the RF cavities is complete; preparation for the cavity electro-polishing, low power RF measurements, and tuning are in progress at Lawrence Berkeley National Laboratory (LBNL). Fabrication of the cold mass of the first coupling coil magnet has been completed in China and the cold mass arrived at LBNL in late 2011. Preparations for testing the cold mass are currently under way at Fermilab. Plans for the RFCC module assembly and integration are being developed and are described.

INTRODUCTION

MICE is an international experiment aimed at the demonstration of 4-dimensional phase space cooling of muon beams through ionization. A schematic layout of the MICE experiment is shown in Figure 1, where there are two spectrometer solenoids and one section of ionization cooling channel that consists of three liquid hydrogen **A**bsorber-**F**ocus-**C**oil (AFC) modules and two RFCC modules. The momentum and position of incoming muons are measured by the first (upstream) spectrometer; muons lose momentum in absorbers and regain only the lost longitudinal momentum in RF cavities; the second (downstream) spectrometer measures the momentum and position of outgoing muons. The MICE cooling channel will produce about 10% transverse emittance reduction in the muon beam. The experiment is hosted at Rutherford Appleton Laboratory (RAL) in the UK. Institutions participating in the collaboration include national laboratories and universities in Europe, the U.S., China, and Japan. Successful demonstration of muon ionization cooling is essential to the success of a future Neutrino Factory or a Muon Collider.

More details of the MICE experiment, its status, progress and schedule can be found in [1], [2].

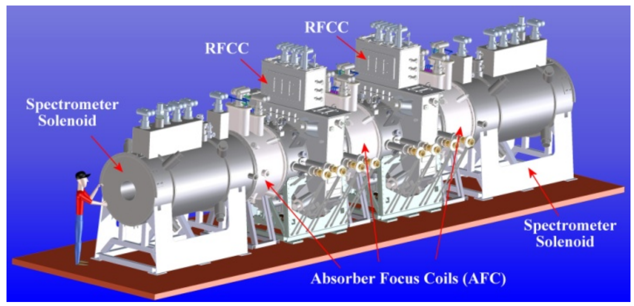

Figure 1: A schematic layout (3-dimensional CAD model) of the MICE experiment with major components.

PROGRESS OF THE RFCC MODULE

The RFCC module for the MICE cooling channel consists of a superconducting **C**oupling (solenoid) **C**oil (CC) magnet, four 201-MHz normal conducting RF cavities with thin beryllium windows to terminate conventional beam irises. Figure 2 shows a cut-away view of the 3-dimensional CAD model of the RFCC module.

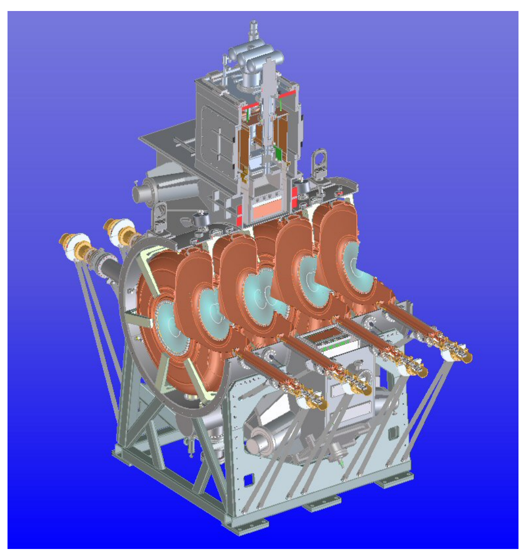

Figure 2: A cut-away view of the RFCC module of the MICE cooling channel: four 201-MHz normal conducting RF cavities with thin beryllium windows are installed in a vacuum vessel, surrounded by the CC magnet that is cooled by three crycoolers.

* This work was supported by the Office of Science, U.S. Department of Energy under DOE contract number DE-AC02-05CH11231, US Muon Accelerator Program and NSF MRI award: 0959000.
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The CC magnet

The CC magnet and its cryostat are designed by Harbin Institute of Technology (HIT), with the help of Shanghai Institute of Applied Physics (SINAP), in collaboration with LBNL. LBNL takes technical responsibility and oversees the design and fabrication. Main design parameters of the magnet are summarized in Table 1. The coil winding and cold-mass fabrication contract was awarded to Qi-Huan Corp. in Beijing in March 2010. Winding of the first coil was completed in December 2010; the aluminium cover plate welding was conducted at HIT in the summer of 2011. The cold-mass was shipped and arrived at LBNL in October 2011.

Table 1: Main design parameters of the CC magnet.

Parameters	**200 MeV/c, β=400 mm**	
Operation modes	Flip	Non-flip
Coil length (mm)	281	
Coil inner radius (mm)	750.5	
Coil thickness (mm)	104	
Number of layers	96	
Number of turns per layer	166	
Self inductance (H)	596	
Magnet J (A mm^{-2})	95.5	90.1
Magnet current (A)	175.1	165.2
Stored energy (MJ)	9.1	8.1
Peak induction (T)	6.231	5.879
Temperature margin (K)	~ 1.6	~ 1.8

A photo of the cold-mass is shown in Figure 3. The cold-mass will be tested at Fermilab this summer. Designs of quench protection, lead stabilization and cooling circuit are completed. Figure 4 shows the updated design of the cold-mass with its cooling circuit and quench protection circuit. Fabrication of necessary parts for the cold mass testing is currently in progress at LBNL. Welding of the aluminium pipes for LHe has started. The cold-mass is scheduled to ship to Fermilab by mid-June 2012.

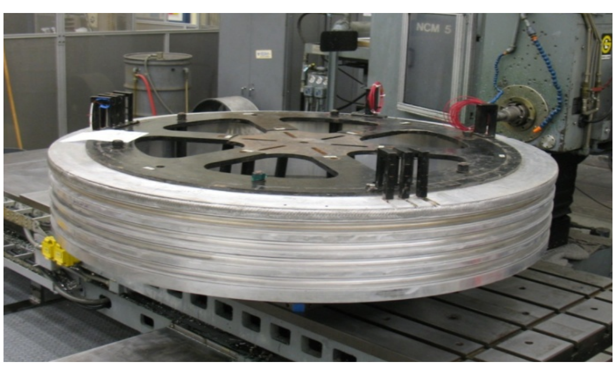

Figure 3: Cold-mass received from China, and currently at LBNL for welding of the LHe pipes and preparations for testing at Fermilab.

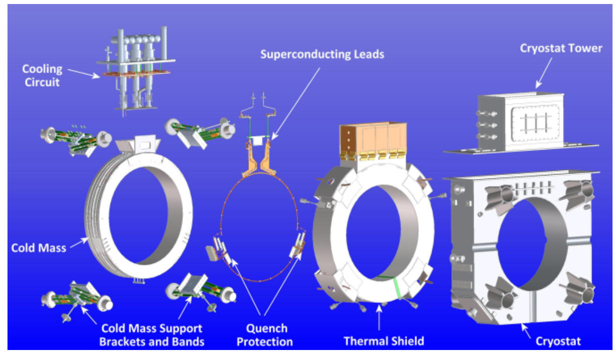

Figure 4: 3-dimensional CAD design model with exploded view of the cold-mass, quench protection circuit, lead stabilization, cooling circuit, cold-mass support and cryostat.

The RF Cavities

Fabrication of MICE cavities is complete. We have received ten cavities including two spares at LBNL; five of which have been measured with a CMM scan to verify the finished cavity profiles. Low power RF measurements were conducted using a given pair of curved thin beryllium windows to measure each cavity's frequency and quality factor, as shown in Figure 5, the cavity frequency is weakly dependent on the curved beryllium windows due to the fabricated window profile variations. The measurement results are shown in Table 2. The measured average center frequency from cavity #1 to #4 is 200.990 MHz; and the frequency variations among these cavities are less than ± 254 kHz (within our expectations and the tuner's tuning range). Q measurements of the first five MICE cavities (without any cleaning) are between 42,000 and 44,600, which is about 80% of the theoretical simulation results. The remaining five cavities will be measured later. The measurements agreed well with the design.

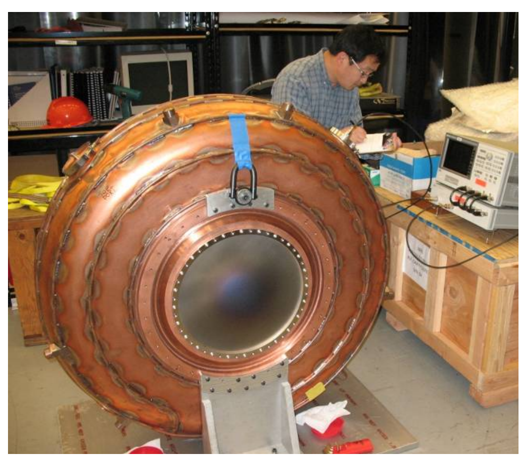

Figure 5: MICE RF cavity measurements with curved beryllium windows at LBNL.

Table 2: Frequency measurements of five MICE cavities

Cavity #	1	2	3	4	5 (spare)
f(MHz)	201.084	200.888	201.247	200.740	201.707

Beryllium windows:

Eleven thin beryllium windows and ten ceramic RF windows have been received at LBNL, as shown in Figure 6. The last two beryllium windows were delivered to LBNL in January 2012 with an improved brazing technique developed at Materion Electrofusion, Fremont, California that gives a much better control of the window profile after brazing.

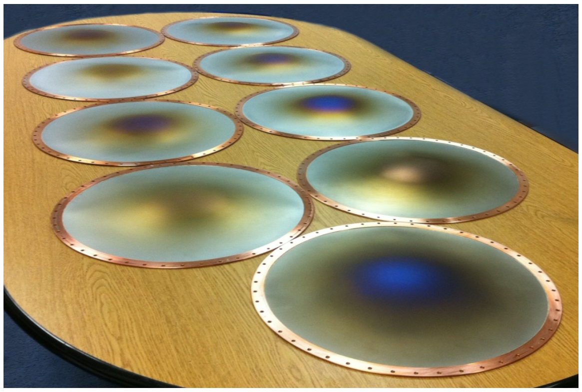

Figure 6: Beryllium windows for MICE RF cavities, the windows are TiN coated on both sides.

Tuner design is complete, and has been tested offline at LBNL. Six tuner arms are currently being fabricated at Fermilab, and six associated actuators have been ordered and will be delivered to LBNL soon. Figure 7 is a photo taken at the Fermilab machine shop showing the fabrication progress.

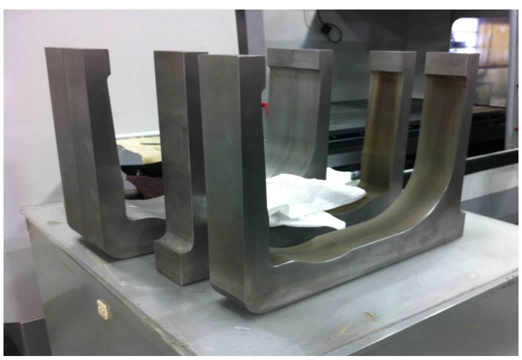

Figure 7: A photo showing the tuner arms that have been wire EDMed at the Fermilab machine shop.

Electro-Polishing:

Electro-polishing (EP) of the first MICE cavity started in early May 2012 upon receipt of ES&H approval at LBNL. Hydrogen generation during the EP process is the major safety concern; evaluation of hydrogen generation rate, ventilation system requirements to dilute the hydrogen gas concentration and its monitoring setup, and other related safety issues have been carefully reviewed and resolved [3]. Due to budget constraints in FY12, only one cavity has been electro-polished so far, as shown in Figure 8. The remaining cavities will be electro-polished later.

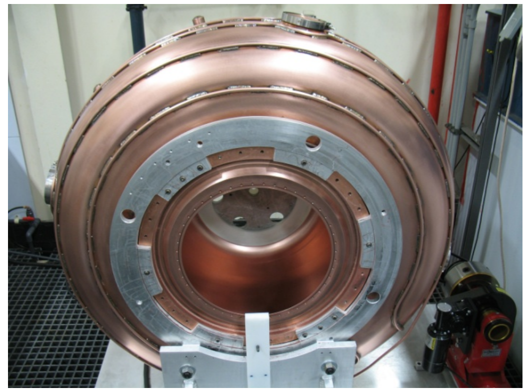

Figure 8: The first MICE cavity electro-polished at LBNL in May 2012.

Power Coupler:

The coupler design for the MICE RF cavities has been modified based on lessons learned from the high power RF testing of the 201-MHz prototype cavity at the Fermilab MTA. A complete drawing package has been delivered to Fermilab for fabrication. Initially two couplers will be fabricated and tested using a MICE cavity in a single cavity vacuum vessel.

Single Cavity Vacuum Vessel Design and Fabrication

A single cavity vacuum vessel has been designed and fabricated, as shown in Figure 9. The single cavity vessel design keeps the same dimensions and features as the RFCC vacuum vessel. It allows for testing of assembly, and for commissioning each MICE RF cavity in the configuration of the RFCC module.

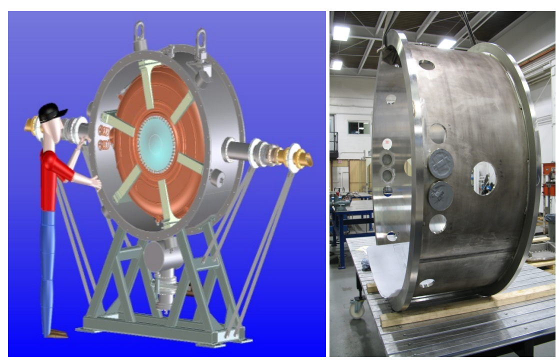

Figure 9: Single cavity vacuum vessel design (left); fabrication of the single cavity vessel at Keller Technology (right).

REFERENCES

[1] MICE web site: http://www.mice.iit.edu; M. Bogomilov et al., arXiv:1203.4089.

[2] A. Blondel, "The MICE Experiment", these proceedings.

[3] T. Luo et al., "Progress on the MICE 201 MHz RF cavity at LBNL," these proceedings.

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