PROGRESS ON THE MICE RF MODULE AT LBNL*

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Abstract

The international Muon Ionization Cooling Experiment aims to demonstrate the transverse cooling of a muon beam by ionization interaction with absorbers and re-acceleration in RF cavities. The final MICE cooling channel configuration has two RF modules, each housing a 201 MHz RF cavity to compensate the longitudinal energy loss in the absorbers. The RF modules will be assembled and tested at LBNL before being shipped to and installed at RAL. This paper reports the recent progress on the manufacturing and testing of the RF module components, as well as the preparation for the final module assembly.

INTRODUCTION

The international Muon Ionization Cooling Experiment (MICE) [1–3] aims to demonstrate the transverse cooling of a muon beam by ionization interaction with energy absorbers and re-acceleration in RF cavities [4, 5]. The final MICE cooling channel configuration, as shown in Figure 1, has two RF modules, each housing a 201 MHz RF cavity to compensate the longitudinal energy loss in absorbers [6]. A detail exploded view of RF module is shown in Figure 2.

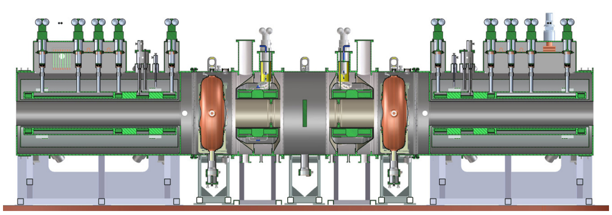

Figure 1: MICE beamline layout.

Lawrence Berkeley National Laboratory (LBNL) has made significant progress on the manufacturing and testing of the RF modules since the last report [7], including the RF couplers, the frequency tuning system and the vacuum vessel. Preparation for the RF module assembly is well underway; the vacuum vessels arrived at LBNL in late April 2016. This paper reports on recent progress.

RF COUPLER PRODUCTION AND TEST

The MICE RF coupler is a coax waveguide with a coupling loop at the end, magnetically coupling the RF power into the cavity. Two couplers are symmetrically placed on each side of the cavity, each delivering up to 1 MW peak

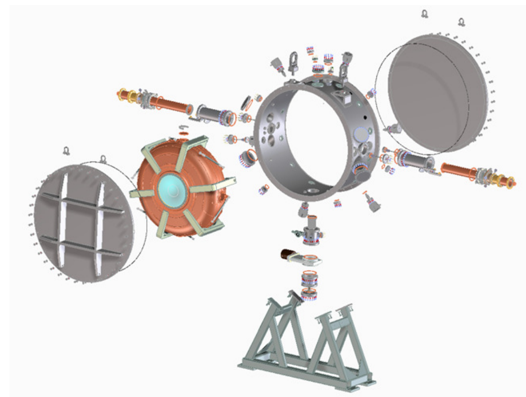

Figure 2: RF module exploded view.

power in the MICE experiment. To suppress the multipacting in the coupler, the inner surface of the coax waveguide outer conductor and the coupling loop are coated with TiN thin film, which has a smaller Secondary Electron Yield (SEY) than copper. The effectiveness of multipacting suppression by this method has been proven in the previous Single Cavity Module high power test at Fermilab [8]. The TiN thin film is generated by the sputtering deposition method by the LBNL Plasma Application Group. The quality of the resulting coating for the coax waveguide and coupling loop are shown in Figure 3 and 4 respectively. Both coatings passed the adhesive tape test.

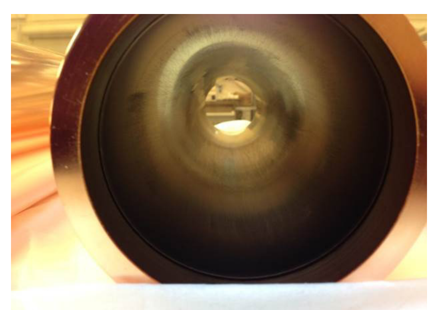

Figure 3: TiN coating of the inner suface of coax waveguide.

The assembly of the RF couplers was carried out at the LBNL main machine shop. All the parts, including the coax outer conductor, inner conductor, Toshiba RF window, adaptive bellows and coupling loop are put together following stringent procedure and with high precision, with several iterations of welding and cleaning during the process. The final assembled coupler is shown in Figure 5. After passing leak checks, two couplers were sent to the Fermilab MTA for high power RF testing.

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Figure 4: TiN coating of the coupling loop

Figure 5: The assembled RF coupler

At the Fermilab MTA, the RF couplers were installed in the Single Cavity Module and tested in February and March 2016, as shown in Figure 6. Stable operation was achieved at the MICE target gradient of 10.3 MV/m, both with and without the stray field of the MTA LabG magnet.

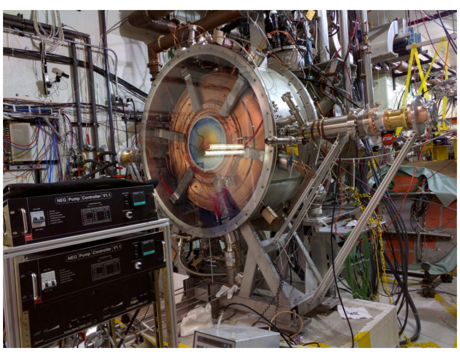

Figure 6: High power test of Single Cavity Module at MTA.

Besides the two couplers tested at the Fermilab MTA, four more couplers were fabricated for the two RF module assemblies at LBNL for use at MICE.

VACUUM VESSEL DESIGN AND PRODUCTION

The vacuum requirements of the RF module for MICE operation are as follows:

1. Interior RF cavity vacuum equal to or better than the order of 10^{-8} Torr.
2. Differential pressure on the beryllium windows less than 1.2 PSI.
3. Exterior vacuum equal to or better than the order of 10^{-6} Torr.

The vacuum vessel design of the RF module is based on the Single Cavity Module design, with the following major modifications to adapt to the MICE environment:

1. The RF cavity vacuum is isolated from the external channel vacuum.
2. The RF cavity interior is directly pumped on via the NEG pump.
3. A custom-designed differential pressure box is implemented to protect the beryllium windows in the event of pressure rise.

Two reviews of the vacuum vessel design were held in January and April 2015 at LBNL. The design was finalized and the contract for production of both vacuum vessels was awarded to Keller Technology Corp in Buffalo, NY. The vessels were delivered to LBNL in late April 2016, as shown in Figure 7.

Figure 7: Vacuum vessels arrived at LBNL.

FREQUENCY TUNING SYSTEM FABRICATION AND TEST

For the MICE cavity, the frequency is tuned by six tuner arms around the cavity body. Each tuner arm is squeezed by a pressurized actuator to deform the cavity shape.

A total of 25 tuners arms were manufactured by the University of Mississippi and shipped to LBNL. Two sets of six arms were machined to fit the measured distance between the mounting points of the two cavities which had been preselected for having close natural frequency. Twelve arms were UHV cleaned and are ready for assembly, as shown in Figure 8. Custom shims were made to help positioning during the assembly.

The actuator was re-designed from the Single Cavity Module design to avoid nitrogen gas leakage problems. Functional and lifetime tests were carried out on a prototype unit. The actuator functional test measured the relationship between the deflection and the applied pressure. The test result, as shown in Figure 9, was consistent with previous tests at Fermilab [9] and validates its functionality.

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Figure 8: Tuner arm after UHV cleaning.

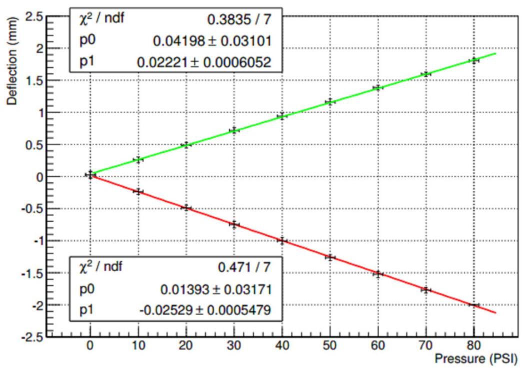

Figure 9: Actuator functional test: Deflection vs Applied pressure.

In the lifetime test, as shown in Figure 10, the actuator was operated under different base pressures for 10000 cycles over 40 hours. The operation went smoothly and no hystersis behavior was observed.

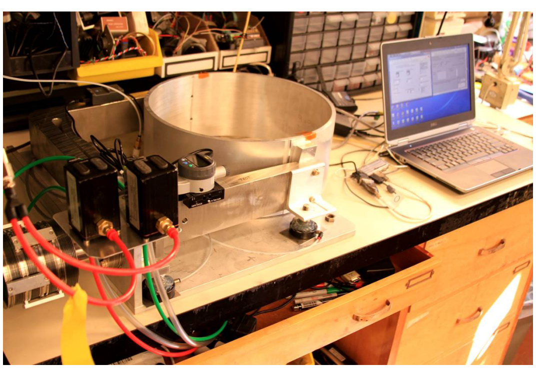

Figure 10: Actuator lifetime test.

After the success of both tests, twelve actuators plus four spares were fabricated, cleaned and ready for assembly.

FUTURE PLAN

Before cavity installation and final assembly, each vessel undergoes vacuum leak checking and mechanical inspection. Once qualified, the vessels are cleaned as necessary and brought into a clean tent for assembly. A custom alignment fixture is used to pre-align the hexapod strut system that holds the RF cavity within the vacuum vessel; this step is key as it aligns the RF coupler ports, actuator ports, and vacuum port, making the eventual dressed RF cavity installation much easier. Once the cavity is installed, the RF couplers, actuators, RF pickups, diagnostics and vacuum system components are installed. The final step of the assembly process will be the fitting of the beryllium windows, after which the RF vacuum vessel is sealed. Vacuum system testing and RF tuning system testing then commences. Target vacuum for the cavity is 10^{-8} Torr, for the outer vacuum it is 10^{-6} Torr. The tuning system should show a frequency tuning capability of +/- 200 kHz. After these systems are qualified, the RF modules are packaged and shipped to RAL for the MICE experiment. The target date for the first RF module shipment is late August to early September 2016, with the second module to follow approximately one month after.

CONCLUSION

This paper reports the recent progress on the MICE RF module at LBNL. Six RF couplers were manufactured at LBNL. Two were tested successfully at Fermilab MTA, while the remaining four will be installed on the RF module. The actuator prototype unit passed the functional and lifetime tests. Twelve production units plus four spares were made. The tuner arms were machined to fit the selected cavities and UHV cleaned. Modifications were made on the vacuum vessel design for the MICE operation requirement. Two vessels finished the production and were shipped to LBNL at the end of April 2016. The final assembly of two RF modules is in progress.

ACKNOWLEDGMENT

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