FINAL COMMISSIONING OF THE MICE RF MODULE PROTOTYPE WITH PRODUCTION COUPLERS*

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Abstract

We report operational experience from the prototype RF module for the Muon Ionization Cooling Experiment (MICE) with final production couplers at Fermilab's MuCool Test Area. This is the last step in fully qualifying the RF modules for operation in the experiment at RAL.

INTRODUCTION

MICE has started [1] a program of multiple scattering, energy loss and emittance reduction measurements with a muon beam passing through various materials in a magnetic lattice [2] designed for ionization cooling. The final stage of the experiment [3] includes rf modules for demonstration of muon cooling with acceleration. The MICE RF Module prototype was assembled [4,5] at Fermilab with prototype rf couplers and operated [6] in the MuCool Test Area (MTA) facility demonstrating performance well beyond MICE requirements [7]. There were two mechanical issues with the prototype couplers related to coupling adjustment during installation and vacuum system performance. These were addressed without any changes to the rf design in the production couplers [8] which were assembled at LBNL and shipped to Fermilab in January 2016.

MECHANICAL ASSEMBLY

The main goals in this latest round of assembly work were to inspect the interior of the cavity and the prototype couplers, install a window spacer to shift the cavity frequency and replace the prototype couplers with the production units. Figure 1 shows the module in intermediate stages. One of the vessel cover plates was removed in order to reach the clamps attaching the couplers to the cavity body. Most of the vacuum system hardware is mounted on a flange plate on this cover plate and were taken off first. The experimental hall is kept relatively clean (class 1000-10000, ISO 6-7) but not to the standards required for this work. A portable clean room was brought over the vessel and the vessel exterior surfaces were cleaned before removing the vacuum system components. The flange plate was replaced by a temporary plate to block off the opening and the cavity was placed under nitrogen gas purge. Next, one of the beryllium windows was removed for inspection of the interior rf surfaces and replaced afterward with a temporary cover. The clean room was then moved away for lifting the cover plate with an overhead crane. A temporary transparent cover plate made of acrylic was installed on the vessel as soon as the cover plate was moved out of position to minimize the risk of contamination and the amount of time the vessel would be exposed to the air in the hall. The clean room was brought over the vessel and the exterior surfaces cleaned again before removing the temporary cover plate and proceeding with the rest of the assembly work. The same sequence was followed in reverse to reinstall the vacuum system. The clearance around the vessel inside the portable clean room is limited in all directions and this restricted the number of personnel who could work in the clean room at one time (only one for most tasks, no more than two) and the volume of parts that could be staged inside. Components to be installed were cleaned and bagged in a large clean room elsewhere on site (A0) and brought into the MTA hall.

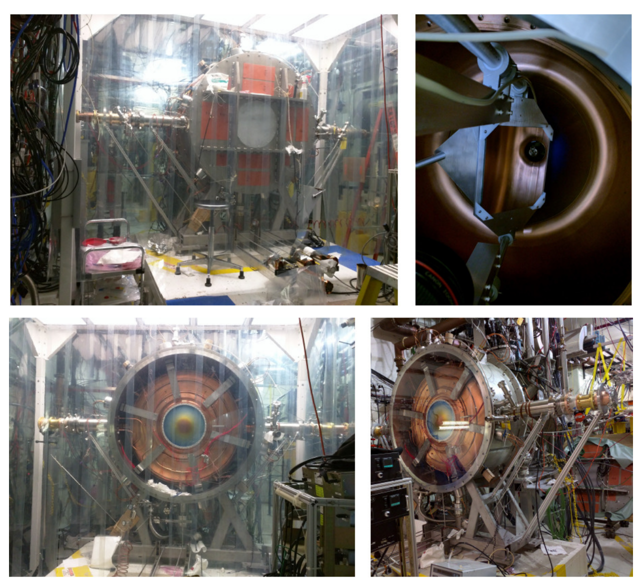

Figure 1: Stages of mechanical work – vacuum vessel under the portable clean room with flange plate replaced (top left); inspection of coupler loop through mirror (top right); vessel after coupler replacement (bottom, left); temporary transparent cover plate installed for protection during crane access (bottom, right).

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Inspection

The cavity and the prototype couplers had seen several million rf pulses, some at up to 14.5 MV/m gradient. Inspection of interior surfaces after the last run was a necessary step before moving to the final configuration. A custom mount built to hold a mirror and a camera was used to view the interior of the cavity as well as the prototype couplers. No new features were seen on the cavity (Be) windows or the vacuum side of the ceramic windows on the couplers. There was no evidence of significant damage on any of the cavity and coupler copper surfaces.

Spacer Installation

The MICE rf system specification for the resonant frequency is 201.25 MHz. The frequency of the cavity in the prototype (200.81 MHz at room temperature) was lower than this by more than the range of the mechanical tuner system (about -0.4/+0.3 MHz). A 10.3-mm thick spacer ring was fabricated out of copper and installed under one of the beryllium windows to increase the accelerating gap, reducing the capacitance. This resulted in a frequency of about 201.30 MHz, well within tuning range, with no loss in the quality factor.

Coupler Replacement

The production couplers were fully assembled at LBNL and shipped to Fermilab. They were partially disassembled, cleaned, re-assembled and vacuum leak checked at Fermilab. Adjustment of the rf coupling factor during installation, accomplished by rotating the entire coupler assembly, was challenging for the prototype units due to difficulty in alignment of the flat flanges which maintain contact between the cavity body and the coupler outer conductor. This problem was eliminated by modifying the outer conductor flange with a lip that captures the cavity flange. Adjustment of coupling after installation was much easier with the modified design which maintains alignment between the outer conductor flange and the cavity port. The overall coupling factor was set to within 2% of critical coupling and the two coupler arms were matched to within 2.7% of each other. The vacuum conductance for molecular flow between the inside and the outside of the cavity was higher than allowable to maintain operational vacuum pressure in the cavity when installed in the MICE cooling channel. The slots in the coupler outer conductor that provided most of this conductance were covered in the production design. Vacuum pressure inside the cavity volume improved as expected after the production couplers were installed.

HIGH-POWER OPERATION

Initial running with the new couplers was done in zero magnetic field. The gradient was kept below 1 MV/m for the first two days of operation and raised very slowly to keep vacuum pressure below a conservative limit. It was then raised to the 10.3 MV/m target over the next day and a half and held at this value for about 0.4M pulses at 5 Hz rep rate. The solenoid was turned on next with the central field setting at 4 T. The cavity was operated at very low power for about a day to process persistent multipacting. The gradient was raised again to 10.3 MV/m over half a day and kept there for about 0.5M pulses at 2 Hz rep rate to confirm stable operation. Up to that point, the system was operated in frequency tracking mode with the cavity tuners off and the rf source frequency updated to match the cavity resonant frequency. Operation of the tuning system was then verified again and the system switched to pressure tracking mode with the pneumatic actuators enabled to keep the cavity tuned to the fixed source frequency. The run configuration was modified to match MICE specifications as closely as possible. This involved raising the rep rate and gradient in order to compensate for the limited rf pulse width available so as to arrive at approximately the same average power. The resulting parameters are listed in Table 1. Over 1M pulses were collected in this configuration. Field emission electrons can generate X-rays while going through the cavity windows or the secondary absorbers in MICE. This X-ray flux leads to background hits in the scintillating fiber tracking detectors. The final portion of the run was dedicated to measuring the rate and spectrum of the photons from the cavity as a function of gradient and analysis of the data is in progress to evaluate the potential impact on track reconstruction.

Table 1: MTA Run Configuration vs. MICE

Parameter	MICE	MTA	Unit
Frequency	201.250	201.250	MHz
Peak gradient	10.3	10.6	MV/m
Average power	1.6	1.9	kW
Rf pulse width	1	1/6	ms
Rf rep rate	1	5	Hz
Tuner rep rate	1	1	Hz

CONCLUSION

Testing of the prototype MICE RF Module at Fermilab is complete. Successful operation at MICE specifications was demonstrated using the production couplers. Operational validation of the system through high power testing has given us confidence in final performance of the production modules in the experiment. Production units will be assembled at LBNL taking advantage of fixtures and techniques already used in the assembly of the prototype at Fermilab. They will be shipped to Rutherford Appleton Laboratory (RAL) for testing with the rf amplifier system there [9] before installation in the beamline.

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