FINAL ASSEMBLY AND TESTING OF 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. Two RF modules have been assembled and tested at LBNL. This paper reports the final assembly and testing work.

INTRODUCTION

The international Muon Ionization Cooling Experiment [1–3] aims to demonstrate the transverse cooling of a muon beam by ionization interaction with absorbers and re-acceleration in RF cavities [4,5]. 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 [6]. A detail exploded view of RF module is shown in Figure 1.

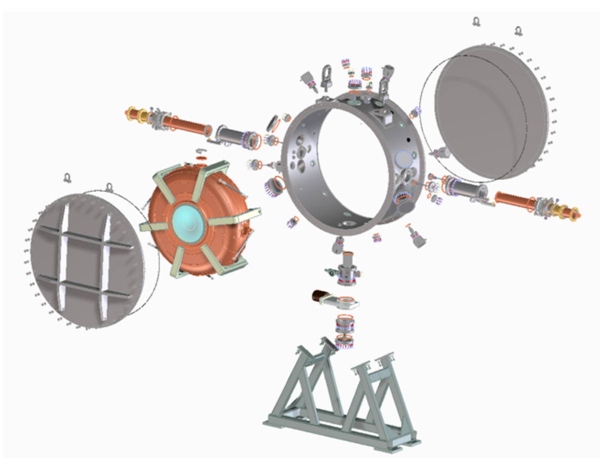

Figure 1: MICE RF module exploded view.

Lawrence Berkeley National Laboratory (LBNL) has made significant progress on the assembly and testing of the RF modules since the last report [7]. Both modules have been fully assembled. Vacuum test and low power RF test have been carried out successfully. The final packing and shipping preparation are currently underway. This paper reports on the final assembly and testing work at LBNL.

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RF MODULE ASSEMBLY

The MICE RF Module includes RF cavity, RF couplers, RF tuning system, vacuum system, vacuum vessel and numerous auxiliary parts. Meticulous planning has been carried out at the beginning. The cavity, vacuum vessel and assembly equipment have been dry ice snow-cleaned before being moved into the clean room.

Figure 2: Left: dry ice snow cleaning; right: half finished module on the short stand.

VACUUM TEST

The MICE RF modules contain two separate vacuum volumes, which is an effort to protect the thin beryllium window mounted on the RF cavity. There is a limited conductance between the two volumes, such that poor outer vacuum can negatively impact the interior vacuum and RF performance. During extended pump-down testing, the outer vacuum reached the low 1e-7 Torr range, and the inner vacuum reached the low 1e-8 Torr range; this is without bakeout.

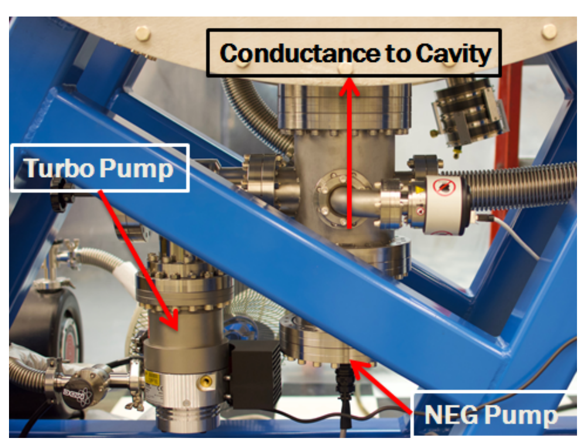

Figure 3: Vacuum test pumping system.

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In order to protect the beryllium window during pump-down, vent, and possible system failure, and differential pressure box was designed and constructed. This box contains check values, oriented to be gravity neutral, and allow gas exchange from one vacuum to the other. Any pressure differential exceeding 1 PSI opens these valves such that conductance for molecular and/or viscous flow is greatly increased, allowing pressures to equalize and avoid over-pressurization of one vacuum volume with respect to the other. Performance of the differential pressure box was extensively testing for both pump-down and venting. In addition, an auxiliary bypass line was installed with a manual valve, creating another large conductance path between the two volumes. During operation the bypass is closed, but it may be opened for pump-down and venting for additional protection.

LOW LEVEL RF TEST

The low level RF test of MICE RF module includes mainly three parts: the actuator test, the coupler adjustment for critical coupling and the pickup probe calibration. The measurement setup is shown in Figure 4. The frequencies of fundamental mode of two modules are different by 44 kHz, which is well within the tuning range. We also measured the Higher Order Mode (HOM) spectrum up to 500 MHz.

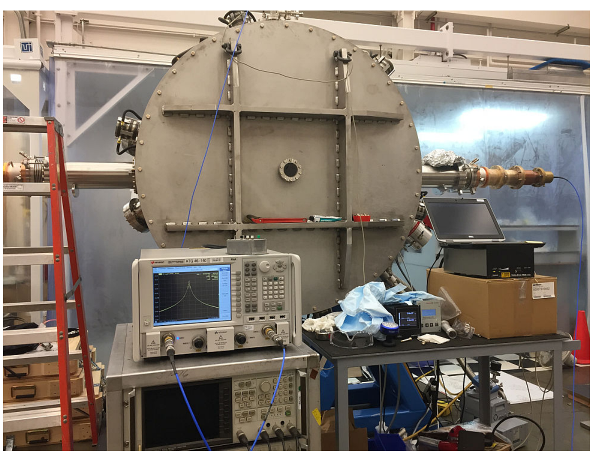

Figure 4: Low level RF test setup.

Actuator Test

The cavity frequency is adjusted by squeezing or stretching the cavity body. A prototype frequency tuning system has been tested and operated on the prototype MICE RF Module [8]. An updated actuator design has been tested offline [7] and installed on the cavity. In the test, starting from neutral position, we gradually stretch the cavity to 80 PSI, return to neutral, squeeze to 80 PSI, and return to neutral. The frequency change as a function of actuator pressure is shown in Figure 5.

The test on Module 1 shows that with 80 PSI, which is well within the stress limit, we achieve +258 kHz and -319 kHz frequency tuning range. The hysteresis character is as expected and consistent with previous measurement [9].

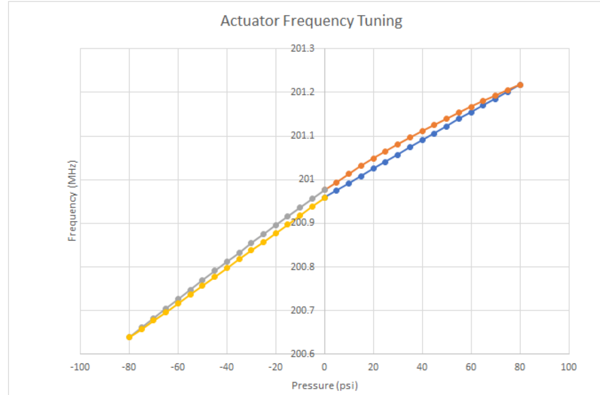

Figure 5: Actuator test on Module 1.

During the tuning, the vacuum level stays unchanged. The test on Module 2 shows similar results, with frequency tuning range of +258 kHz and -334 kHz at 85 PSI.

Coupler Adjustment For Critical Coupling

The cavity is powered by two coaxial loop coupler symmetrically placed on both sides. Since the beam loading is negligible, we aim for an overall critical coupling, leading to coupling constant $\beta = 0.5$, for each coupler. The adjustment procedure is as follows:

1. With Coupler 1 open, measure β on Coupler 2, and adjust the loop orientation to achieve $\beta \approx 0.5$.
2. With Coupler 2 open, measure β on Coupler 1, and adjust the loop orientation to achieve $\beta \approx 0.5$.
3. With Coupler 1 open, fine tune Coupler 2 to achieve $\beta = 0.5$.
4. With Coupler 2 open, fine tune Coupler 1 to achieve $\beta = 0.5$.

After the adjustment, the coupling constant of with each coupler is measured to be $\beta = 0.5$, as shown in Figure 6.

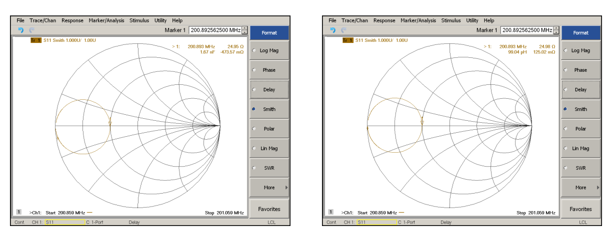

Figure 6: Coupling measurement of one coupler with the other coupler open.

To verify the coupling, we connect both couplers to Network Analyzer (NWA) with a splitter and drive them simultaneously, as the way in the high power operation. The measured smith chart shows a great critical coupling, with $S11 = -41$ dB and $\beta = 1.00$, as shown in Figure 7.

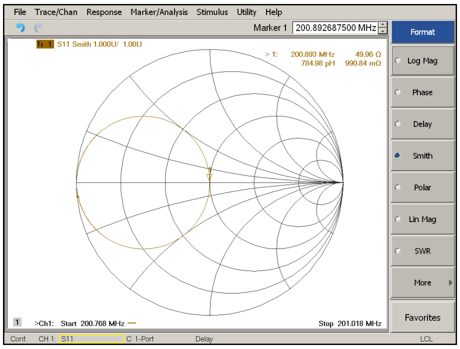

Figure 7: Coupling measurement with both couplers.

Pickup Calibration

With the couplers at critical coupling, the two pickup probes have been calibrated to be -48.22 dB and -50.18 dB. The loaded Q values measured from s21 are 20509 and 21204 respectively.

High Order Mode (HOM) Spectrum

As another important characterization of RF cavity, we measured the HOM spectrum up to 500 MHz, as shown in Figure 8. It is consistent with Omega3P numerical simulation results.

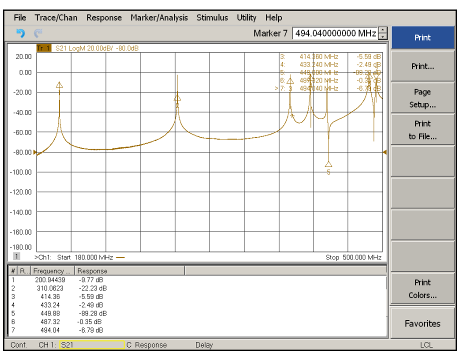

Figure 8: Resonant mode spectrum from 180 MHz to 500 MHz.

SUMMARY

The assembly of two MICE RF modules at LBNL has been finished. The vacuum test shows the vacuum in both vacuum volumes achieve the target level, and differential pressure box protects the beryllium windows as designed. In the low level RF test, the RF tuning system has been validated, the RF couplers adjusted to critical coupling, the pickup probes calibrated and HOM spectrum recorded. We are now working on the final packing.

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Figure 9: Final packing.

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