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PROGRESS ON THE MICE 201 MHz CAVITIES 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 in energy absorbers. The final MICE cooling channel configuration has two RF modules, each housing a 201 MHz RF cavity used to compensate the longitudinal energy loss in the absorbers. The LBNL team has designed and fabricated all of the MICE RF cavities. The cavities will be post-processed and RF measured before being installed in the RF modules. We present the recent progress on this work, including the low level RF measurement on cavity body and Be windows, the electro-polishing (EP) on the cavity surface, the numerical simulation on cavity Be window detuning, and the ongoing mechanical designing work of cavity components.

INTRODUCTION

The international Muon Ionization Cooling Experiment (MICE) [1] aims to demonstrate the transverse cooling of a muon beam by ionization in energy absorbers. The final MICE cooling channel configuration has two RF modules, each housing a 201 MHz RF cavity to compensate the longitudinal energy loss in absorbers [2]. Recently a lot of work has been done at LBNL on the cavity production, including the characteristic frequencies measurement of cavity bodies and beryllium windows, electro-polishing of cavity inner surface, simulation of frequency detuning due to Be windows, modification of cavity coupler design, actuator design and prototype test, etc. In this paper, we will report these progresses.

CAVITY BODY AND BE WINDOW FREQUENCY MEASUREMENT

The MICE cavity is composed of a copper cavity body and two Be windows. Due to the production process, each cavity body and window has slightly different characteristic frequency. Under the first order approximation, the cavity frequency can be decomposed into the linear combination of cavity body frequency f_b and each window frequency f_{w1} and f_{w2}:

$$f_c = f_b \pm f_{w1} \pm f_{w2},$$

where the "+" corresponds to the curved-out window and "-" the curved-in. Once we know all the f_b and f_w, we can predict the cavity frequency with any combination of cavity body and Be windows without assembling one. The accuracy of this prediction is proved to be within 5kHz by Omega3P [3] simulation.

To measure the characteristic frequencies, we assemble a cavity, flip the direction of the Be windows one at a time and measure the cavity frequency for each assembly. With the linear approximation:

$$\begin{aligned} f_{c1} &= f_b - f_{w1} - f_{w2}, \\ f_{c2} &= f_b - f_{w1} + f_{w2}, \\ f_{c3} &= f_0 + f_{w1} - f_{w2} \end{aligned}$$

, and with the measured f_{c1}, f_{c2} and f_{c3}, we can calculate f_b, f_{w1} and f_{w2}. The measurement set up and the S11 measurement on a Network Analyzer are shown in Figure 1. The frequency results are shown in Table 1. After the electropolishing, we will select the two cavities bodies with the best surface condition, then pick up a pair of Be windows for each body to achieve the desired cavity frequency.

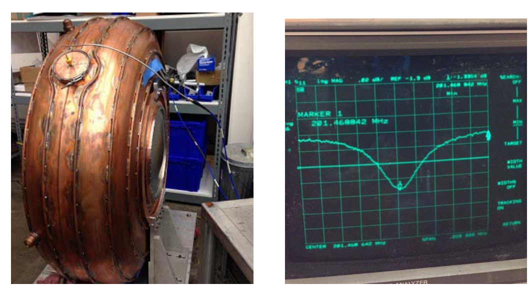

Figure 1: Cavity frequency measurement Left: Set up; Right: S11 measurement on Network Analyzer.

Table 1: Characteristic Frequency of Cavity Body and Be Window

Cavity #	Frequency (MHz)	Window #	Frequency (MHz)
5	201.510	1	0.674
6	200.976	2	0.581
7	200.675	3	0.640
8	200.874	4	0.537
9	200.970	5	0.517
10	200.999	6	0.557
		7	0.541
		8	0.623
		9	0.623
		10	0.663

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ELECTROPOLISHING OF CAVITY SURFACE

The purpose of electro-pollishing of the cavity inner surface is to suppress field emission and reduce mulitpacting. One cavity has been electropolished at LBNL in 2012 [4], and later been used in the Single Cavity Module. It shows good performance in the high power test at Mucool Test Area (MTA) at Fermilab, achieving the target gradient within short conditioning time. Based on this experience, we decide to carry out electropolishing on four more cavities, two for MICE beam line and two as spares.

The EP process follows almost the same procedure as what we did in 2012, except a few improvements:

1. The electric contact between the cavity body and the EP fixture is improved by extra graphite pads. Thus the current and the voltage are more stable during the EP process.

2. A plastic lip ring is added to the cavity body to better contain the electrolyte during the rotation.

3. The cavity rotation fixture provided by Fermilab, as shown in Figure 2, simplifies the cavity handling significantly.

Figure 2: Cavity on the fixture before EP. Left: Rotation fixture from Fermilab; Right: EP fixture.

The cavity inner surface after EP is shown in Figure 3. All four cavities show a almost-mirror-like results like the cavity we did in 2012.

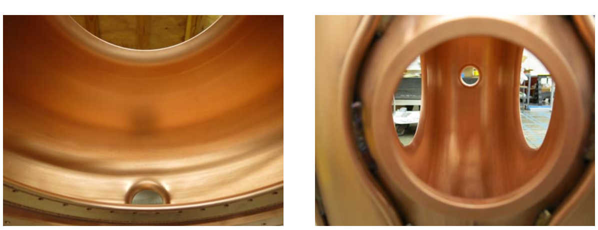

Figure 3: Cavity inner surface after EP.

THERMAL AND LORENTZ FORCE DETUNING ANALYSIS OF BE WINDOWS

Due to the RF heating, the Be windows on the cavity will experience thermal expansion in the same direction. Due to the curvature, the curved-in window will heat up more and expand more than the curved-out window, thus the distance between the Be windows will change and the cavity resonant frequency will be detuned. With the distance between two Be windows decreasing, the effective capacitance increases and the frequency is shifted down.

Lorentz force on the Be window is another detuning mechanism. The electromagnetic field in the cavity exerts an effective pressure on the cavity inner surface $p = 1/4(\mu_0 H^2 - \epsilon_0 E^2)$. This effect is usually negligible for the normal conducting cavity. But for MICE cavity with thin Be windows (0.38 mm) and high Q ($Q_0 \approx 50000$), the Lorentz force might become a concern.

Both detuning process are simulated by TEM3p [3]. The detuning frequencies as a function of input power are shown in Figure 4 and 5.

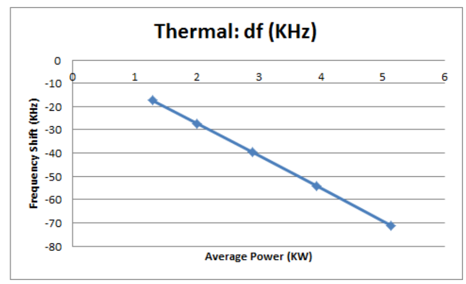

Figure 4: Frequency detuning due to thermal expansion.

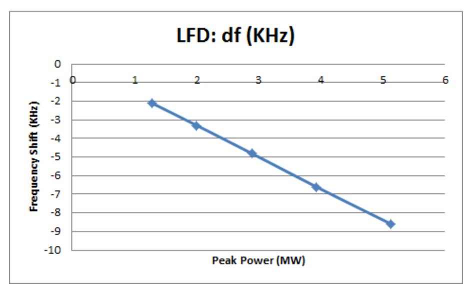

Figure 5: Frequency detuning due to Lorentz force.

MODIFIED DESIGN AND TEST OF CAVITY COUPLER

Based on the test at MTA for the Single Cavity Module, we carried out the following improvement in the cavity coupler design:

1. The loop coupler has been moved up by 40 mm. The critical coupling angle has been increased from 15 degree to 48 degree and the coupling is less sensitive to the coupling angle. It will make the coupler adjustment much easier. The Omega3p simulation has been carried out to calculate the new position, as shown in Figure 6.

2. The new lip design on the coupler flange will allow it to be rotated without falling away from the cavity. Extra support of the coupler arm is added at the windows.

3. The slots on the outer conductor where the cooling tubes go through have been sealed. The test at MTA

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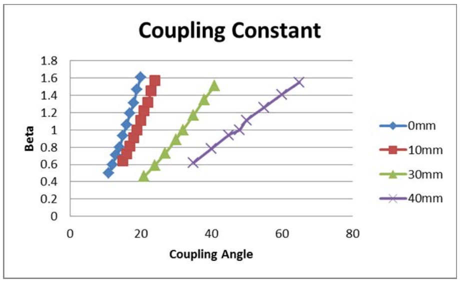

Figure 6: Omega3p simulation results: the coupling constant as a function of coupling angle with difference coupler loop positions.

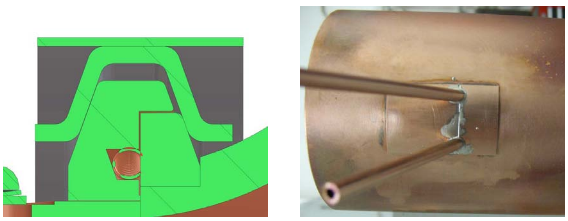

Figure 7: Left:the lip at the coupler flange; right: Slot welding test.

shows the gas load from the slots is significant and prevent the cavity from achieving the desired vacuum level.An extra copper pad will be welded to sealed the slots. Th welding test of the copper pad has been successfully carried out at LBNL.

MODIFIED ACTUATOR DESIGN AND TEST

To simplify the fabrication, the actuator design has been modified from the one used in Single Cavity Module test, and a prototype has been built and are currently under tests at LBNL, as shown in Figure 8. The functional test shows the similar performance as the previous design, as shown in Figure 9. The life time test will start soon.

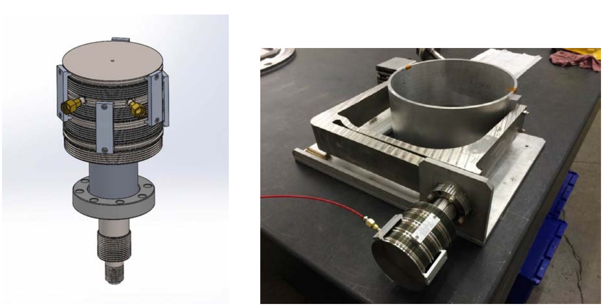

Figure 8: Left:the modified actuator design; right: the actuator functional test set up.

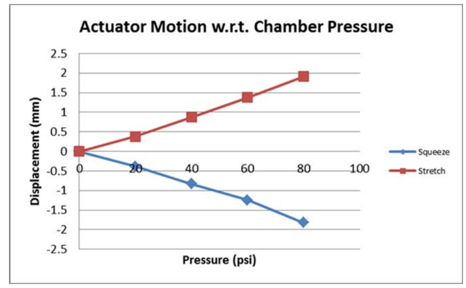

Figure 9: Functional test results of the modified actuator prototype.

CONCLUSION

In this paper we have reported the recent progress on the MICE cavity at LBNL. The characteristic frequencies of 6 cavity bodies and 10 Be windows have been measured. Four cavities with the best inner surface condition have been electropolished, all achieving almost-mirror-like surface condition. We have also simulated the frequency detuning due to the thermal expansion and Lorentz force on the Be windows. Several modifications have been made on the coupler design for easier coupling adjustment and better cavity vacuum. The actuator design has also been modified and the test of the prototype is in progress.

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