PROGRESS ON THE MICE 201 MHz RF CAVITY AT LBNL*

Tianhuan Luo†, Don Summers, University of Mississippi, University, MS 38677, USA
Allan DeMello, Derun Li, Chris Redding, Steve Virostek,
Michael Zisman, LBNL, Berkeley, CA 94720, USA

Abstract

The international Muon Ionization Cooling Experiment (MICE) aims at demonstrating transverse cooling of muon beams by ionization. The ionization cooling channel of MICE requires eight 201 MHz normal conducting RF cavities to compensate the longitudinal beam energy loss in the cooling channel. In this paper, we present the recent progress on the electropolishing work on MICE RF cavity at LBNL, which is intended to improve the cavity performance in the presence of strong external magnetic field, and the RF simulation with SLAC's ACE3P code to study the multipacting effects in the cavity and at the coupler regions with the influence from the external magnetic field.

INTRODUCTION

The international Muon Ionization Cooling Experiment (MICE) [1] aims at demonstrating transverse cooling of muon beams by ionization. To achieve 10% transverse emittance cooling in MICE, the voltage gradient is needed to approach 16 MV/m. Previous experiments have shown that this gradient is easy to achieve without an external B field. But once operated at multi Tesla level field, the break down voltage drops significantly [2]. Thus the cavity R&D is focused on understanding the breakdown mechanism and achieving the required gradient.

ELECTROPOLISHING

Several proposed mechanisms of the cavity breakdown [2] in strong B field are associated, though in different ways, with the field emission electrons. Electropolishing (EP) has been widely used in superconducting RF community to smooth the cavity surface and suppress the field emission. A prototype of 201 MHz cavity has been EPed at JLab and showed significant performance improvement. Thus EP is planned for ten MICE 201 MHz cavity at LBNL, eight for the MICE beam line and two spares.

EP Process

At the time of this report, EP is being carried out in the LBNL plating shop. The chemical process is based on the EP R&D with the prototype cavity at JLab. Due to the large size and unique shape, the cavity is filled with electrolyte and rotates during EP, with a U-shape cathode immersed in the electrolyte. The cavity body is electrically grounded, serving as the anode. A rotation mechanism is mounted to the cavity, driving it at about 1 turn/min, as shown in Figure 1. The electrolyte is an industrial product called Power Klein 500, whose chemical composition is similar to the homemade electrolyte used at JLab.

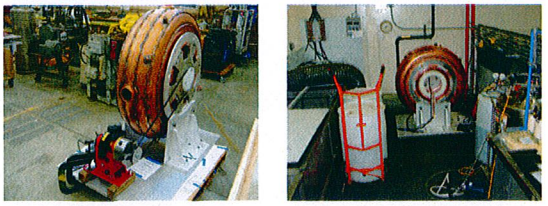

Figure 1: EP Setup. The left figure shows the ventilation side of EP setup, with the pulley, driving belt and rotating motor. It is covered by a ventilation hood during EP. The right fiugre shows the whole EP setup in the LBNL plating shop.

Safety Issue

The major safety issue for EP is the hydrogen gas generated during the chemical process, which has a wide range of the explosive density in the air (4%-75%). A rough worst-case estimation gives a hydrogen gas generation rate of 0.2 CFM [3]. Also the chemical reaction in the cavity might generate the chemical mist. Thus we need to ventilate the hydrogen gas and chemical mist in a controlled manner. A cone shape hood is placed closely at the ventilation side of the cavity to collect the mixture of hydrogen gas and chemical mist. To prevent a hydrogen explosion, the air flow in the ventilation system should be at least 50 CFM, which dilutes the hydrogen density to below 0.4%. Also, a compressed air purge is setup at the upper part in the cavity to prevent the hydrogen gas accumulation. Some safety precautions are shown in Figure 2. The hydrogen density and the gas face velocity measured by EH&S on both the prototype hood and the final EP setup have confirmed the effectiveness of these safety precautions.

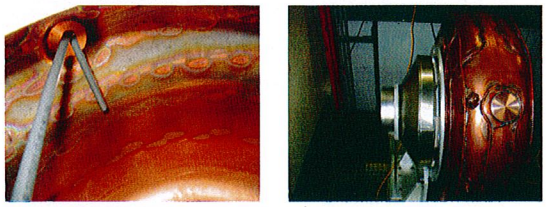

Figure 2: EP Safety Controls. The left figure shows the compressed air purge at the upper part inside the cavity, to prevent the hydrogen gas accumulation. The right figure shows a customized cone shape ventilation hood.

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† tluo@lbl.gov

EP Results

Before starting EP on the cavity, we carried out a sample test, as shown in Figure 3. We have tested 3 OFHC polishing techniques: hand polish (HP), hand polish then EP, and hand polish then "bright dip" (BD), which is a light chemical buffer process. The surface finishing of each sample is characterized by profilometer measurements and the results are shown in Table 1. For the HP with EP sample, we delay the rinsing process by 5 minutes to simulate the time window to pump out the electrolyte in the real EP process. The surface finishing deteriorates significantly during this period. Thus we need a post-ep chemical cleaning, which is essentially a bright dip, to recover the surface smoothness.

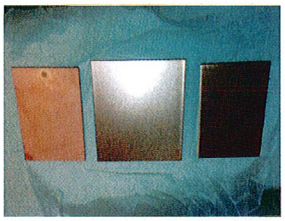

Figure 3: The sample test of EP. The left one is HP with EP, the middle one is just HP and the right one is HP with BD.

Table 1: Profilometer Measurements of the Roughness Average (RA) of OFHC Sample Plates

Sample	Just HP	HP with EP	HP with BD
RA (μm)	0.140	0.537	0.108

During the first week in May 2012, we finished the EP on the first cavity. The final surface finishing is shown in Figure 4, which is very smooth and shining. For the EP of the next cavity, we have planned several improvements, including stabilizing the electric current, using fresh electrolyte and applying more thorough post EP chemical cleaning. We are expecting an even better surface finishing after all these improvements.

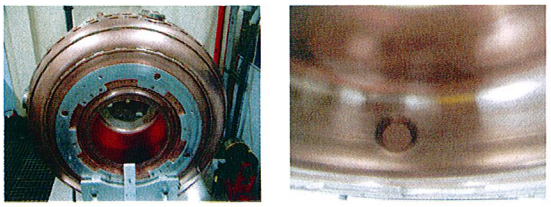

Figure 4: The cavity surface finishing after EP.

ACE3P RF SIMULATION

ACE3P is an accelerator simulation suite developed by SLAC ACD group [4]. For the MICE 201 MHz RF cavity, we used Omega3p to calculate the cavity RF parameters and Track3p to study the multipacting effects in the cavity and at the coupling region.

RF Calculation With Omega3P

The simulation model is built from the imported CAD drawing. Compared to previous simplified simulations, the curvatures of the beryllium windows and the extruding ports are included in the model, as shown in Figure 5. The calculated RF parameters are summarized in Table 2. Due to the asymmetric windows, the E field along the beam path is no longer uniform. The calculation shows that the field on the intruding surface is about 2 times higher than the extruding surface.

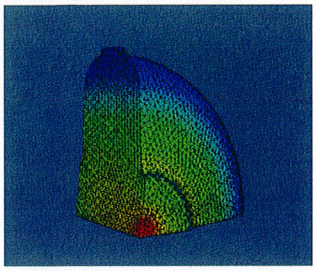

Figure 5: The cavity RF calculation in ACE3P

Table 2: RF Calculation of MICE Cavity

Model	Without Port	With Port	Be Window
f_0 (MHz)	202.041	201.923	201.923
Q_0	52631	52536	52119

Multipacting Study with Track3P

The Second Emission Yield (SEY) depends on the surface condition. In this report, we assumes the impact energy range where SEY>1 is from 100 eV to 2000 eV,which covers several different copper surfaces. The multipacting of the 201 MHz cavity has been studied with Track3P in [5] with a simplified symmetric pillbox model. Here we report the results based on the more realistic asymmetric model.

The multipacting spectrum in the cavity without external magnetic field is shown in Figure 6. At 2 MV/m, there are a few electron resonance orbits with impact energy larger than 100 eV. Their impacting locations are near the cavity equator. All other resonance orbits have too low impact energy to induce multipacting. Compared with the results in [5], we find the same resonance orbits near the cavity equator. But we didn't find any resonance orbit near the cavity center, where the curvature of beryllium window changes the field significantly.

We also calculate the strong external magnetic field case. With 3 Tesla magnetic field parallel to the beam path, all the resonance orbits have the impact energy higher than 2000 eV, which will not induce multipacting. This result is the same with [5].

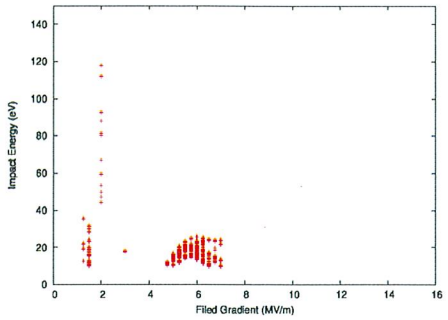

Figure 6: The sample test of EP. The left one is HP with EP, the middle one is just HP and the right one is HP with BD.

Besides in the cavity, we are also interested in the coupling region, where the low field and the small gaps make this region "pro-multipacting". Figure 7 shows the multipacting spectrum without external B field. It indicates that there is multipacting below 4 MV/m. The impacting location is show in Figure 9.

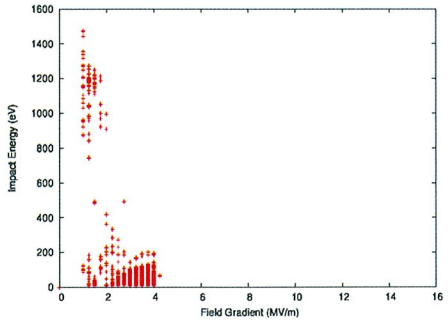

Figure 7: The multipacting spectrum near the coupling region, without external magnetic field.

We also study the multipacting with external magnetic field. Based on the magnetic field mapping in [2], we do a coarse approximation of the stray field by assuming B = (0, 1T, 1T) near the coupling region, where Z is the direction of beam path. The multipacting spectrum, as shown in Figure 8, indicates a multipacting effect from 12 MV/m to 16 MV/m. The impacting location is shown in Figure 9.

CONCLUSION

After building the fixtures and solving the safety issues, the first 201 MHz cavity has been EPed at LBNL.The surface finish is very smooth and shining. Several improvements are planned for the next cavity for an even better surface finish. RF simulation with curved beryllium window and extruded ports has been carried out in Omega3P. Track3P simulation has identified the possible multipacting both in the cavity and near the coupling region with or without external B field.

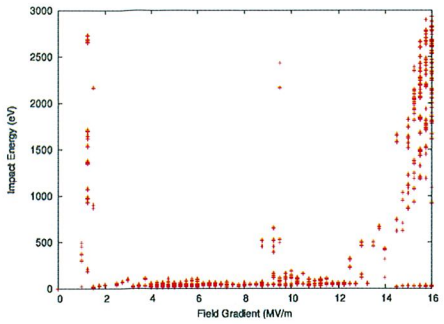

Figure 8: The multipacting spectrum near the coupling region, with external B field B = (0, 1T, 1T).

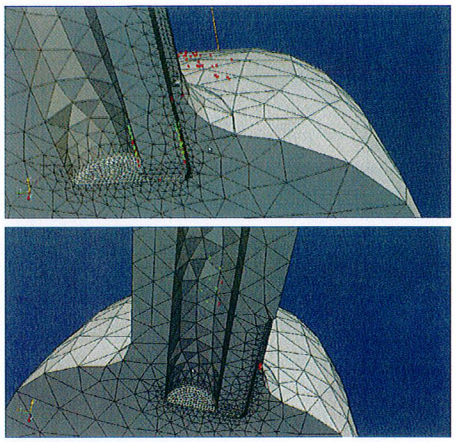

Figure 9: The impacting location of multipacting near the coupling region. The upper and lower figures are without and with external B field, respectively. The red dots are for the impacting energy between 100 to 1000 eV and the green dots are for 1000 to 2000 eV.

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