MULTIPACTING STUDY FOR THE RF TEST OF THE MICE 201 MHz RF CAVITY AT FERMILAB MTA*

T. Luo†, D. Summers, University of Mississippi, University, Mississippi, USA
A. DeMello, D. Li, H. Pan, S. Virostek, M. Zisman, LBNL, Berkeley, California, USA

Abstract

In this paper, we present a study of multipacting effects for the high power RF test, to be done at Fermilab's Mucool Test Area, of the 201 MHz RF cavity for the Muon Ionization Cooling Experiment. We show how the fringe field of the Lab_G magnet affects the cavity performance due to multipacting and predict the possible multipacting bands in the high power RF test with different magnetic field strengths.

INTRODUCTION

One cavity for the international Muon Ionization Cooling Experiment (MICE) [1], after being manufactured and electro-polished at LBNL, has been shipped to the Fermilab Mucool Test Area (MTA) for the single cavity test. To study the cavity performance in a strong magnetic field, this cavity will be tested in the fringe field of the 5-T Lab_G magnet before the MICE Coupling Coil is ready for operation.

In this paper, we study multipacting (MP) effects for the single cavity with and without the Lab_G magnet fringe field. We show possible MP bands with different magnetic field strengths expected in the high power RF test. The Lab_G magnetic field is calculated by ANSYS, the cavity RF field by S3p [2] and the MP effect by Track3p [3].

MAGNETIC FIELD OF THE LAB_G MAGNET

The magnetic field of the Lab_G magnet has been mapped both experimentally and numerically [4, 5]. However, none of the previous mappings cover the full region where the 201 MHz cavity will be placed. Thus we used ANSYS to recalculate the magnetic field. The field along the central axis is compared with previous mapping and shows good agreement, as shown in Fig. 1. Due to the uniqueness of the solution of Poisson equation, the ANSYS result should also give the correct field everywhere in space, including the fringe field region where the cavity will be placed, which is about 1.0 m away from the Lab_G magnet (center-to-center) if the Single Cavity Vessel is located as closely as possible to the Lab_G magnet.

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† tluo@lbl.gov

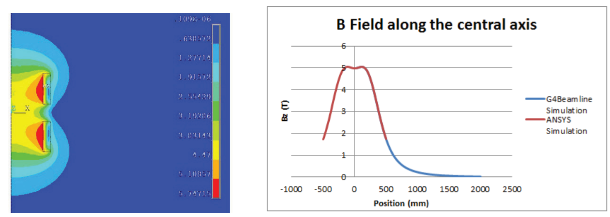

Figure 1: The ANSYS magnetic field calculation of the Lab_G magnet. The left figure is the contour plot of the field magnitude. The right figure is the comparison of magnetic fields from ANSYS with previous G4Beamline results [5] along the central axis.

RF FIELD IN THE 201 MHz CAVITY

The cavity model is built from its CAD drawing, including the curved beryllium windows, the coaxial waveguide and the loop coupler. To build an RF field with power propagating into the cavity and dissipating on the cavity walls, we use S3p with a "waveguide" boundary condition (BC) at the coaxial port and " impedance " BC on the cavity wall. The orientation of the coupler is adjusted to achieve critical coupling ($\beta \approx 1$), with coupling angle at about 17°. The E and B fields in the cavity are shown in Fig. 2.

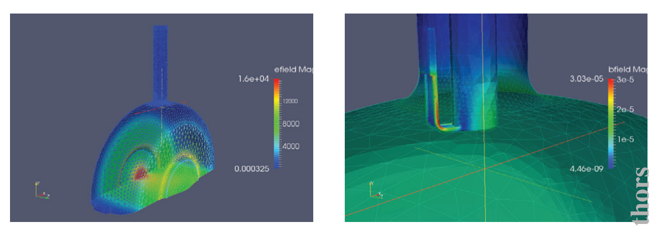

Figure 2: RF field of the cavity. The left figure shows the E field magnitude in the cavity. The right figure shows the maximum B field in the cavity on the coupler loop, where sufficient cooling should be supplied.

MULTIPACTING EFFECT ON 201 MHz CAVITY WITH LAB_G MAGNET

The MP effect is evaluated by the Enhancement Counter (EC) in the Track3P code. The electron is launched from its primary emission surface and tracked for 50 RF cycles, until its energy is too high or too low for MP, or until it hits the absorber surface. Every time it hits the second emission surface, the probability η to generate a secondary electron, which depends on impact energy and surface material, is

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recorded. After 50 RF cycles, the enhancement counter:

$$EC = \Pi_{i=1}^{N} \eta_1 \cdot \eta_2 \ldots \eta_N ,$$

when $EC > 1$, it indicates a possible MP case. The larger the EC, the more likely the MP will happen. The SEY data of copper we used in this paper are for the Argon Glow Discharge (AGD) treated copper [6]. Since Be windows will be TiN coated, we treat these as an absorber surface.

According to its geometry, the cavity is divided into three parts: the coaxial waveguide, the coupler and the cavity body. We study the MP with different magnetic field strengths: $\mathrm{B_{max}} = 0$ T, 1.25 T, 2.5 T, 3.75 T and 5 T on the central axis.

The required cavity field gradient for the neutrino factory is 16 MV/m, which corresponds to about 2.8 MW input power per port. Thus we will study the MP from 10 kW up to 3 MW.

MP In the Coaxial Waveguide

Without B field, the MP in the coaxial waveguide can be solved analytically for low-order modes and has been studied thoroughly. With the fringe field of the Lab_G magnet, the MP pattern changes significantly.

- The EC spectrum is shown in Fig. 3. Without B field, there is a narrow MP band at low power from 40 kW to 70 kW. Beyond that, there is no more MP. The Lab_G magnet fringe field induces a resonant pattern at higher power. As the B field increases, more resonant patterns show up at high power but the EC is small compared to the MP at low power.

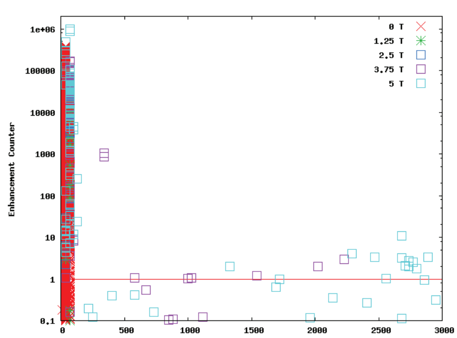

Figure 3: The EC spectrum in the coaxial waveguide.

- The MP impact location is shown in Fig. 4. With Lab_G B field, many resonant patters show up near the RF window with high EC. Most of them happen under 100 kW. Looking into the trajectories of these electrons, they are emitted near the RF window and build the resonance pattern bouncing between the inner and outer conductor of the waveguide. This may explain the copper deposition on the RF window observed in the previous test of the 201 MHz prototype cavity [7].

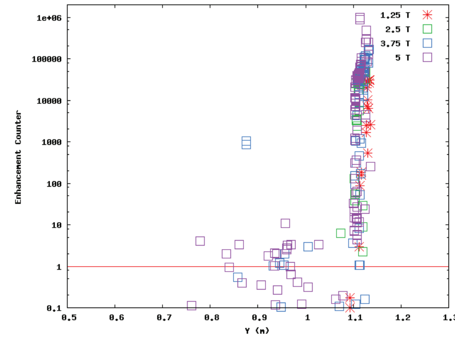

Figure 4: The MP impact location in the coaxial waveguide, where $Y = 1.1$ m is near the RF window.

MP In the Coupler Region

Due to the detailed geometry in the coupler region, the meshing at this area needs to be very dense to achieve an accurate RF field. The computation time would be too long if we carried out the MP calculation in the whole region. Therefore, we choose three typical locations in the upper, the middle and the bottom part of the couple and combine their results.

- The EC spectrum is shown in Fig. 5. Without external B field, MP happens only below 200 kW. As the Lab_G magnet increases its strength, the MP decreases in the low power region but shows up at higher power with smaller EC. No MP is observed above 750 kW.

- The MP impact location is shown in Fig. 6. Without external B field, the electrons emitted at the coupler region migrate up into the coaxial waveguide and build up a resonance there. When the external magnetic field is present, some electrons start to migrate into the cavity body and build up resonance along the curved torus. The stronger the external B field, the more resonance in the cavity.

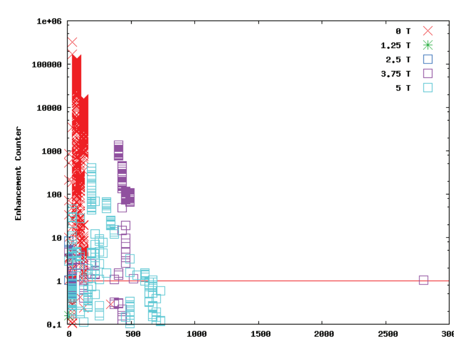

Figure 5: The EC spectrum in the coupler.

MP In the Cavity Body

When studying the MP in the cavity body, for simplicity, we study the cavity without the coaxial waveguide and

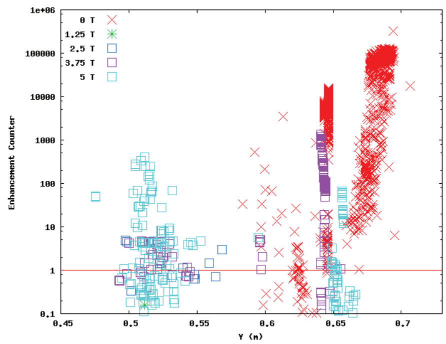

Figure 6: The MP impact location in the coupler. For reference, the extrusion transition between cavity and waveguide is from $Y = 0.601$ m to 0.627 m.

coupler. Without the power input port, we use the E field gradient instead of the input power in the MP EC spectrum.

- The EC spectrum is shown in Fig. 7. When the external B field is zero or small, there is no MP in the cavity. As the B field increases, MP starts to show up in the cavity. The maximum MP happens at around 2 MV/m.
- The MP impact location is shown in Fig. 8. Above 50% of the full field of Lab_G magnet, stong MP starts to show up on the cavity copper side walls around $x \approx \pm 0.4$ m.

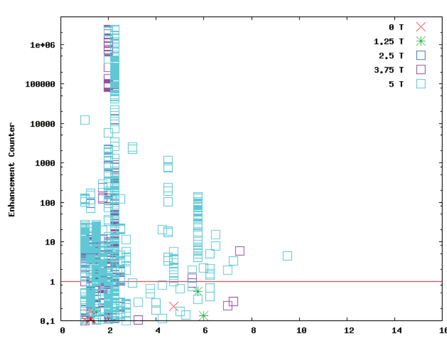

Figure 7: The EC spectrum in the cavity body.

CONCLUSION

In this paper we have studied the MP in the MICE 201 MHz cavity in the Lab_G magnet fringe field for the upcoming single cavity test at Fermilab MTA. Our study has shown that:

1. Without external magnetic field, in the coaxial waveguide, there is a narrow MP band at around 40-70 kW; in the coupler, some electrons migrate into the waveguide and build up MP there; no MP shows up in the cavity body.

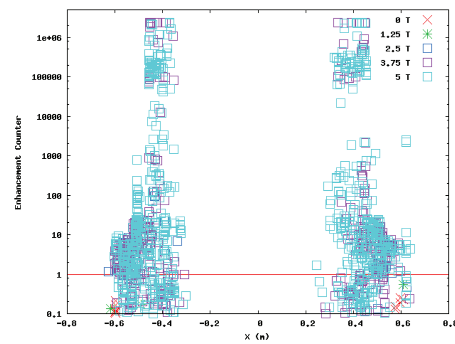

Figure 8: The MP impact location in the cavity body. For reference, the extrusion edge of the vacuum port and instrumentation port are at $X = -0.6$ m and 0.6 m, respectively.

2. The Lab_G magnet fringe field will change the MP, and its effects depend on the field strength. With the Lab_G field, simulation shows strong MP near the RF window in the waveguide, which might explain the copper deposition on the RF window seen in the previous test. In the coupler region, the B field guides the electrons into the cavity body and builds up MP along the curved torus. In the cavity body, when the Lab_G magnet operates above 50% of its full field, MP shows up on the copper side walls at low power.

We have applied several approximations in the simulations, such as ignoring other ferrite materials near the cavity, simplifying the loop coupler and RF window structure, using SEY data of AGD copper instead of electropolished copper, tuning the cavity to exact critical coupling, etc. All these factors will affect the MP results. Nonetheless this paper provides a qualitative, or semi-quantitative, description of the MP effect in the MICE 201 MHz cavity in the upcoming single cavity test.

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