MULTIPACTING SIMULATION OF MICE 201 MHz RF CAVITY*

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Abstract

In this report we present a preliminary study of multipacting (MP) effects on the MICE [1] 201 MHz cavity. The RF model is built in CUBIT [2] from a CAD drawing, including the features of curved Beryllium windows, port extrusion and loop coupler. The RF field is calculated by Omega3P [3], and the MP is studied by the charged particle tracking code Track3P [4]. We survey the possible MP in the coaxial waveguide, in the cavity body and at the coupler region, with and without the solenoid field from the MICE cooling channel. This procedure can be applied to study the MP of the cavity in different solenoid fields.

INTRODUCTION

The international Muon Ionization Cooling Experiment (MICE) aims at demonstrating transverse cooling of muon beams by the ionization process. The ionization cooling channel of MICE requires eight 201 MHz normal conducting RF cavities to compensate the longitudinal beam energy loss. The cavities are of rounded pillbox shape, with curved beryllium windows covering the iris at both ends. They will be operated in the solenoid field of the MICE cooling channel. Multipacting (MP) is a phenomenon in RF devices when secondary electron emission in resonance with an alternating EM field leads to exponential electron multiplication. If not suppressed, it can cause RF breakdown or possibly permanent damage on the cavity surface, and therefore limit the achievable RF gradient.

In this report, we present a preliminary study of MP effects on MICE 201 MHz cavity, with and without the solenoid field in the cooling channel. There are four cavities in one Coupling Coil (CC) module and each cavity experiences different solenoid fields. In addition, there are two operating modes for the MICE cooling channel: solenoid mode and flipped mode. Here we only study one cavity in solenoid mode for the 240 MeV/c muon beam. The method can be applied to other cavities in other magnetic field configurations.

OMEGA3P SIMULATION OF CAVITY RF FIELD

To study the MP, we need to have the RF field distribution in the cavity. An RF simulation model is built using CUBIT from the 3D CAD drawings used for the MICE cavity fabrication. The model includes curved beryllium windows, RF loop coupler and coaxial waveguide, as shown in Figure 1. With the symmetry of the geometry, we only need to calculate half of the cavity. The RF field is solved numerically with Omega3P as shown in Figure 2.

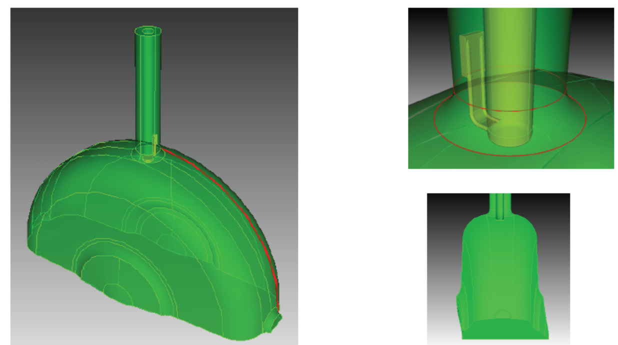

Figure 1: The RF model of MICE 201 MHz cavity, built from the CAD drawing. The left figure shows the half cavity geometry that we simulate, the upper right shows the RF coupler region and lower right features the curved Be windows on both sides.

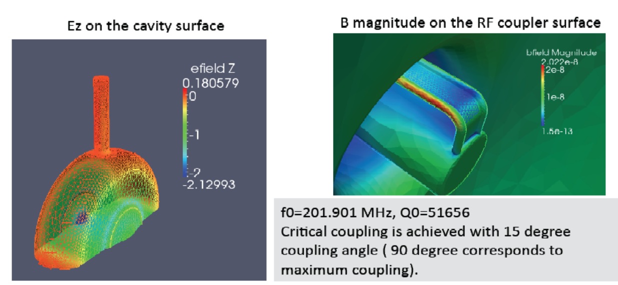

Figure 2: Omega3P simulation results: the left figure shows the E_z field on the cavity surface, and the right figure shows the B field in the coupler region, where the peak B field is located.

MAGNETIC FIELD MAPPING OF MICE COOLING CHANNEL

The 201 MHz cavity will be operated in the solenoid field of the MICE cooling channel. Along the central beam path, the B field can go up to 2 T. This external B field will strongly affect the trajectories of emitted electrons. To study the multipacting effect with an external B field, we

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need to include the solenoid field distribution in the calculation.

The solenoid field in the MICE cooling channel is calculated by OPERA [5], including all the magnets in the Spectrometer Solenoid (SS) modules, Absorber Focusing Coil (AFC) modules and RF Coupling Coil (RFCC) modules. With the azimuthal symmetry, the 2D OPERA magnetic field calculation result is shown in Figure 3.

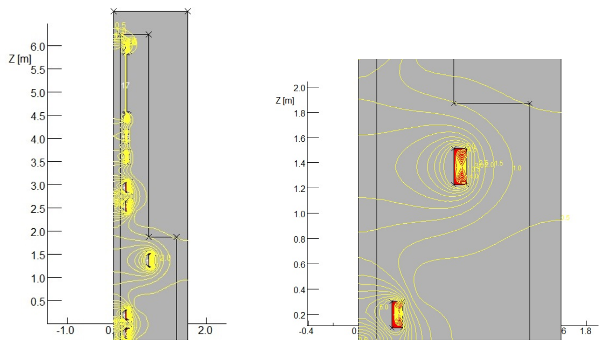

Figure 3: The magnitude contour plot of the magnetic field of solenoid mode in the MICE cooling channel. The left figure shows the field mapping in half of the whole channel. The right figure is a close-up view of the magnetic field distribution in the RFCC module, where the RF cavities are to be installed.

The magnetic field vector component B_r and B_z in the RFCC module are plotted in Figure 4, which shows the B field varies a lot at different radii in the cavity, thus there is no way to approximate the real solenoid field with a homogeneous B field background. In this paper, we only study one cavity which is located at $z = 1.77$ m in Figure 4. The other three cavities can be studied in the same way.

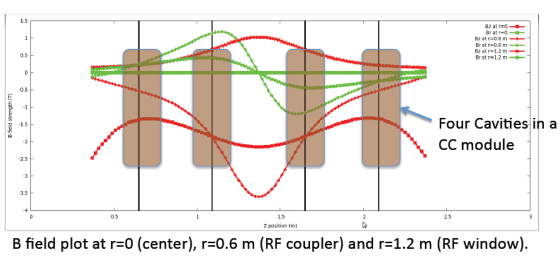

Figure 4: Magnetic field vector component B_r and B_z plot in CC module.

TRACK3P SIMULATION OF CAVITY MULTIPACTING

Besides the RF field and external solenoid field, another important input parameter for the MP calculation is the Secondary Emission Yield (SEY) coefficient of the surface material. It is defined as the number of secondary electrons emitted per incident particle and strongly depends on the surface material and treatment. Multipacting occurs at an impact energy level where the SEY is larger than 1. In this cavity, there are two kinds of surface: electropolished copper and TiN coated beryllium. The SEY coefficient of copper that we used in the MP simulations is in Figure 5, which shows its MP impact energy ranges from tens of eV to 3000 eV, with peak at 200-700 eV, depending on the surface treatment. For simplicity, the TiN coated Be surface is treated as an absorber surface where there are no secondary emitted electrons [7].

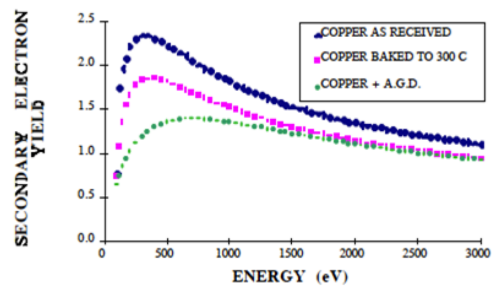

Figure 5: The SEY data of different copper surfaces [6].

In Track3P, at each accelerating field gradient level, primary electrons are released from the cavity surface at different RF phases in the first RF cycle and tracked through several RF cycles. The impact energies and locations, as well as the electron trajectories are recorded. They are used to identify the MP electrons later in the post-processing. In this report, we have studied the MP with primary electrons emitted in the coaxial waveguide, in the cavity body and at the coupler region. The field gradient is scanned from 0.5 MV/m to 16 MV/m and the impact energy at which the secondary electron can emit is from 10 to 3000 eV.

MP in coaxial waveguide

Figure 6 shows the MP result in the coaxial waveguide with and without external B field. Without the external B field, MP can happen at field gradient from 2 MV/m to 2.5 MV/m. With the external B field, MP can happen from 2 MV/m to 4 MV/m. MP is mostly caused by the resonant electrons bouncing between the inner and outer conductor.

MP in the cavity body

Figure 7 shows the MP result in the cavity body with and without external B field. Without external B field, the MP has a narrow band from 2 MV/m to 3 MV/m, and the impact locations are all at the port extrusion. Inside the cavity, there is no MP. With the external B field, the MP band expands from 1.5 MV/m up to 15 MV/m. The impact locations are at the cap of the extrusion port and along the equator inside the cavity. Compared with the results without external B field, the cooling channel solenoid field makes the cavity much more vulnerable to MP effects over a wide range of field gradients.

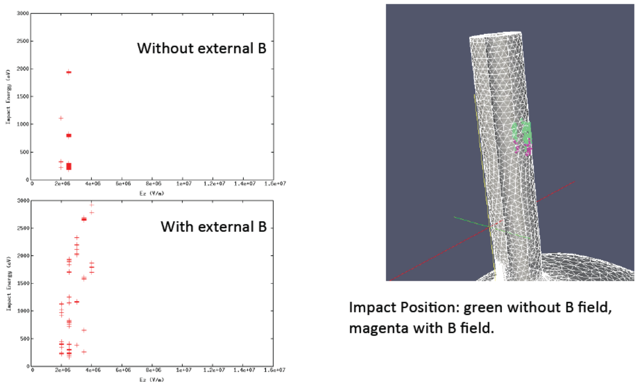

Figure 6: The MP in the coaxial waveguide with and without external B field. The left two figures show the MP spectrum and the right figures shows the MP impact positions.

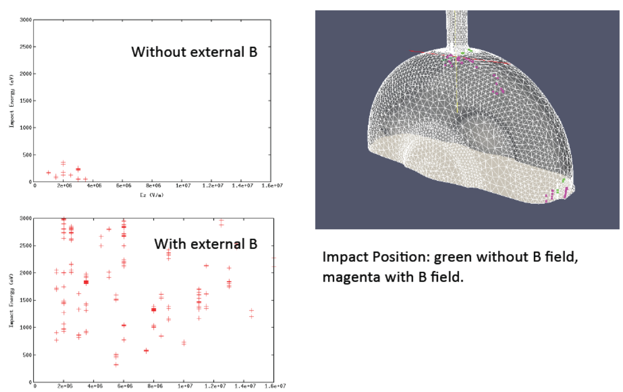

Figure 7: The MP in the cavity body.

MP at the coupler region

Figure 8 shows the MP result in the cavity coupler region with and without external B field. Without a solenoid field, the MP can happen from 1 MV/m to 4.5 MV/m and at around 6.5 MV/m. After being emitted from the coupler region, some electrons can drift back into the the waveguide and build up MP there. There are also resonant electrons bouncing between the coupler strip and the cavity wall which can cause MP. With external B field, the MP can happen from 1 MV/m to 7 MV/m and at around 15 MV/m. Due to the focusing effect of the B field, there are no more electrons drifting into the waveguide. The impact locations are all around the coupler region, either on the coupling loop, the inner conductor or the cavity walls nearby.

CONCLUSION

In this report, we present a preliminary study of MP effects in the MICE 201 MHz cavity. The cavity model is built from the CAD drawing and the RF simulation is carried out with Omega3P. MP study with Track3P shows that solenoid field from the MICE cooling channel has a significant effect on the MP pattern. Especially, it induces extra MP along the cavity equator over a wide field gradient range, which could be alerting and requires more thorough study. TiN-coating on the above areas, in particular at the coupler region, will help to suppress the MP and will be considered. Although here we only study with one particular solenoid field, the method can be easily applied to the cavities in other magnetic field backgrounds.

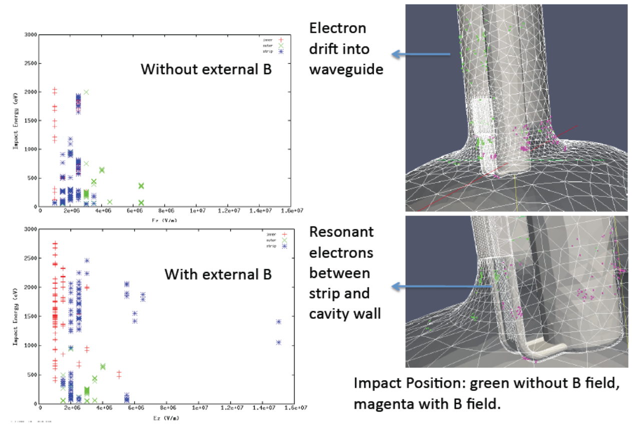

Figure 8: The MP at the coupler region

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