MULTIPACTING SIMULATION FOR MUON COLLIDER CAVITY*

Lixin Ge[1], Zenghai Li, Cho-Kuen Ng, Kwok Ko, SLAC, Menlo Park, California, U.S.A.
Rober B. Palmer, BNL, Upton, Long Island, Ner York, U.S.A.
Derun Li, LBNL, Berkeley, California, U.S.A.

Abstract

The muon cooling cavity for the Muon Collider works under strong external magnetic fields. It has been observed that the presence of external magnetic fields can enhance multipacting activities and dark current heating. As part of a broad effort to optimize external magnetic field map and cavity shape for minimal dark current and multipacting, we use SLAC's 3D parallel particle tracking code Track3P for the analysis. Track3P is a parallel finite-element tracking code which provides unprecedented capabilities for modelling complex structures with fast turn-around times. It has been successfully used to predict multipacting phenomena in many accelerator components such as the ILC ICHIRO cavity. In this paper, we present the comprehensive multipacting simulations for both 200MHz and 805MHz single-cell Muon Collider cavities.

INTRODUCTION

High gradient RF cavities, in the frequency range of 200 MHz to 805 MHz, are required in muon cooling channels for the design of a muon collider. These cavities have to be installed inside superconducting magnet fields up to a few Tesla. Significant research efforts have been done in the past several years [1]. A pillbox-like geometry cavity design was theoretically and experimentally studied for understanding RF-related issues of muon cooling channels [2] [3]. While strong multipacting and/or dark current effects were measured during the processing in the presence of external magnetic fields, there have been comparatively less systematic numerical studies due to the problem complexity where large scale high performance computations are required.

In the past few years, SLAC has built a suite of 3D parallel codes based on the finite-element method. The finite-element grid with curved elements fitted to the curvature of a boundary allows high-fidelity modeling of the geometry. Track3P, a member of this suite, is a 3D parallel particle tracking code which has been extensively benchmarked against measurements for dark current and multipacting [4] [5] [6]. For example, it has been used to predict correctly the multipacting barriers in the ILC ICHIRO cavity [7].

We use Track3P to carry out simulations for both the 200 MHz and 805 MHz muon cooling cavities and investigate the effects of external magnetic fields on the occurrences of multipacting. This will help us understand how to optimize the external magnetic field map and cavity shape in order to minimize multipacting and dark current effects.

MULTIPACTING ANALYSIS

The correct treatment of surface physics for particle emissions is important for multipacitng and dark current simulations. Several emission models for thermal, field and secondary emissions have been implemented in Track3P. It can trace particle trajectories in structures excited by resonant modes, steady state or transient fields, which are taken as input obtained by other high-accuracy field solvers built in the finite-element code suite.

In a typical multipacting simulation, electrons are launched from specific surfaces at different phases over a full rf period. The initial launched electrons follow the electromagnetic fields in the structure and eventually hit the boundary, where secondary electrons are emitted based on the secondary emission yield (SEY) of the surface material. The tracing of electrons will continue for a specified number of RF cycles, after which resonant trajectories are identified. Not all of these resonant trajectories contribute to multipacting. Only those with successive impact energies within the right range for SEY bigger than unity will be treated as multipacting events. In this paper, the SEY curve is based on that of cooper (Fig. 1). To identify the types of multipacting events, we use the multipacting order and type, which are defined as the number of cycles per impact and the number of impacts per multipacting cycle, respectively.

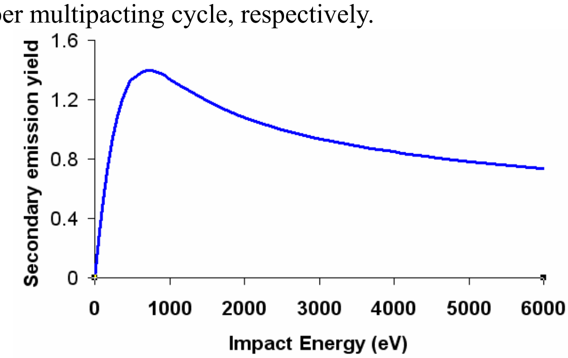

Figure 1: Secondary emission yield for cooper.

SIMULATION OF 200 MHZ PILLBOX CAVITY

The multipacting simulation for 200 MHz pillbox cavity was studied for different cases with/without external magnetic field. In this simulation, the average

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[1]lge@slac.stanford.edu

field gradient is scanned up to 10 MV/M with a 0.1MV/m interval.

(1) *Without external magnetic field*. Fig. 2 shows that there are no multipacting barriers. Although resonant trajectories are present at some field levels, the impact energy is either too low or too high. At low average field gradient between 1 MV/m to 2 MV/m, the impact energy is very high, which may cause dark current heating. Further dark current simulation will be carried out at field levels in this range.

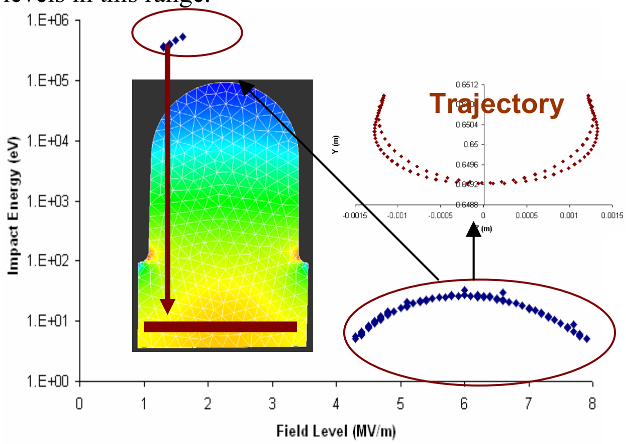

Figure 2: Impact energy vs. field level for the 201 MHz cavity without external magnetic field.

(2) *With external axial magnetic field of 2T.* Resonant trajectories are found with high impact energies, so multipacting is not a concern.

(3) *With external transverse magnetic field of 2T*. There are two types of resonant trajectories: one is between upper and lower irises, and the other between upper and lower cavity walls. The impact energies are too high for both cases, so there are no multipacting events. By monitoring the impact energies for those particles continually emitted in one period at several surface locations, we found that when these particles hit the wall, they may generate enough heat and cause RF breakdown (Fig. 3).

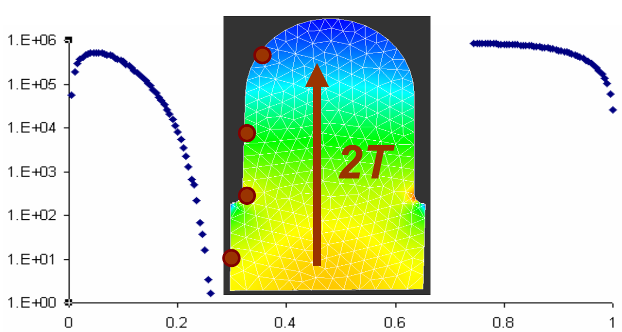

Figure 3: Distribution of impact energy in one RF period. Four example locations (red spots) are selected for monitoring the impact energy.

(4) *With tilted transverse magnetic field of 2T*. When the magnetic field makes a small angle of a few degrees with the vertical axis, multipacting barriers are present at low field gradients. Fig. 4 shows the impact energy as a function of the field gradient for resonant particles in a uniform external magnetic field at 10 degrees with the vertical axis. Two kinds of multipacting events are present at low field levels: one point multipacting at the upper wall and two points multipacting at the beampipe.

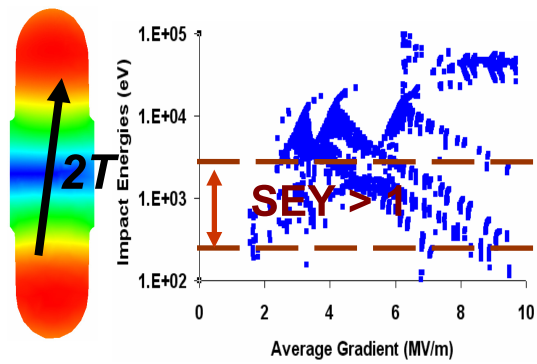

Figure 4: Multipacting barriers in a uniform external magnetic field at 10 degree with vertical axis

SIMULATION OF 805 MHZ PILLBOX CAVITY

The 805 MHz cavity design uses cylindrically symmetrical pillbox geometry, and the detail of the cavity design and fabrication has been reported in [8]. High-power RF tests both with and without magnetic fields showed that severe surface damage could occur, especially in the presence of a strong solenoid magnetic field. Large dark currents and x-ray intensities were measured during the tests. To reduce multipacting and dark current, we studied the modified magnetic insulated 805 MHz cavity as shown in Fig. 5. The magnet is operated in the solenoid mode at a field strength of 3 T.

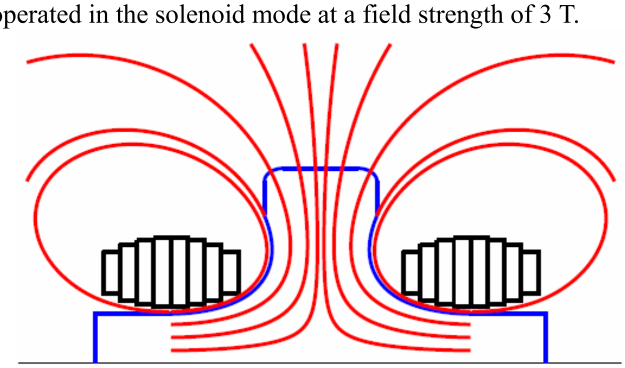

Figure 5: Magnetic insulated cavity where cavity surface is designed to follow external magnetic field lines.

To identify possible multipacting barriers, we scan the average field gradient up to 50 MV/M with 1MV/m interval. Numerical results show that at low field level of 6 MV/m, there are resonant trajectories at the top of the cavity. Due to external magnetic field effects, the particles are confined near the wall. The resonant particles hit the wall once in three periods, with impact energies in the range of 150 keV to 300 keV at different impact positions.

The impact energies are too high to produce multipacting barriers.

After the average field gradient reaches 14MV/m and above up to 50 MV/m, resonant trajectories are present at the beampipe region, with impact energies in the range of 150 eV to 20 keV (Fig. 6). The type of resonant particles changes from hitting once in three periods to once in one period. These are potential multipacting barriers as the impact energies fall in the region of the copper SEY curve that is greater than unity.

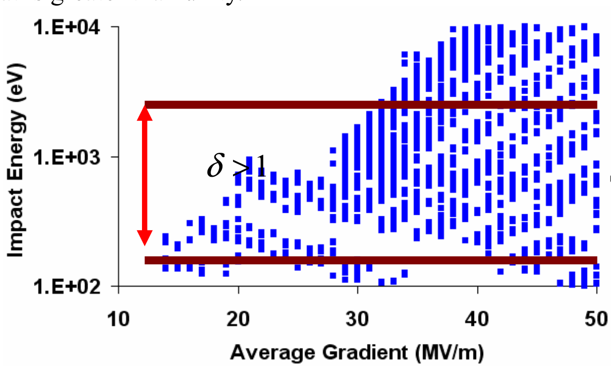

Figure 6: Impact energy vs. average field gradient from 10 MV/m to 50 MV/m.

Two snapshots of the particle distribution at 28 MV/m are shown in Fig. 7. Initial particles are emitted on all surfaces. When non-resonant particles disappear after several cycles, multipacting particles are found in the beampipe region. A detailed particle trajectory between two impacts is shown in Fig. 8. Most resonant particles at this field level hit the wall once in two periods, and the impact energies vary from 170 eV to 600 eV at different beampipe locations.

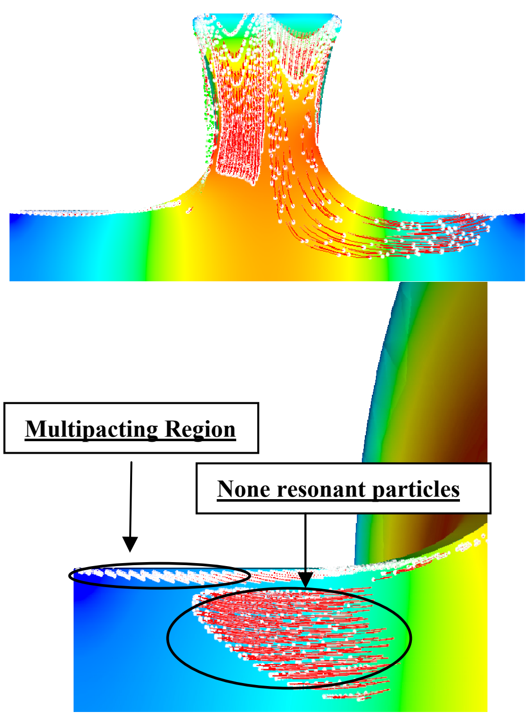

Figure 7: Snapshots of particles distribution at 28 MV/m.

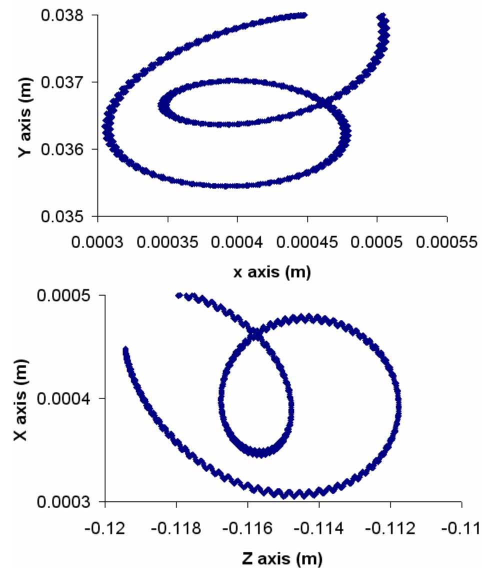

Figure 8. One multipacting particle trajectory in x-y space (up) and x-z space (down) at 28 MV/m in the beampipe region. The impact energy is 535 eV. The time between two impacts is two periods.

CONCLUSION

Track3P is a fast and efficient particle tracking tool to simulate multipacting and dark current. Our multipacting simulation on 200 MHz and 805 MHz muon cooling cavities helps understand RF heating and breakdown occurred in these cavities. Simulation results show no multipacting activities inside the 805 MHz magnetic insulated cavity. However, potential multipacting trajectories were found in the beampipe region. Further multipacting and dark current simulations will be carried out to improve cavity design and to optimize external magnetic field profile.

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