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Subashini De Silva
Old Dominion University, pdesilva@odu.edu

Jean R. Delayen
Old Dominion University, jdelayen@odu.edu

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MULTIPACTING ANALYSIS OF THE SUPERCONDUCTING PARALLEL-BAR CAVITY*

S.U. De Silva[1,2#], J.R. Delayen[1,2],
[1]Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA.
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, U.S.A.

Abstract

The superconducting parallel-bar cavity [1] is a deflecting/crabbing cavity with attractive properties, compared to other conventional designs, that is being considered for a number of applications. Multipacting can be a limiting factor to the performance of in any superconducting structure. In the parallel-bar cavity the main contribution to the deflection is due to the transverse deflecting voltage, between the parallel bars, making the design potentially prone to multipacting. This paper presents the results of analytical calculations and numerical simulations of multipacting in the parallel-bar cavity with resonant voltage, impact energies and corresponding particle trajectories.

INTRODUCTION

Multipacting is a complex phenomenon that limits the performance in any rf cavity, in which a large amount of secondary electrons are emitted from the cavity surface by the incident primary electrons. This becomes a critical condition if the primary electrons have localized and sustainable resonant trajectories with the cavity rf fields and the impact energies corresponds to a secondary emission yield (SEY) greater than one.

SEY shown in Fig. 1 varies for each material and also depends on the condition of the surface [2]. The impact energies of the primary electrons that generate secondary electrons are non-relativistic and relativistic electrons have no effect on multipacting.

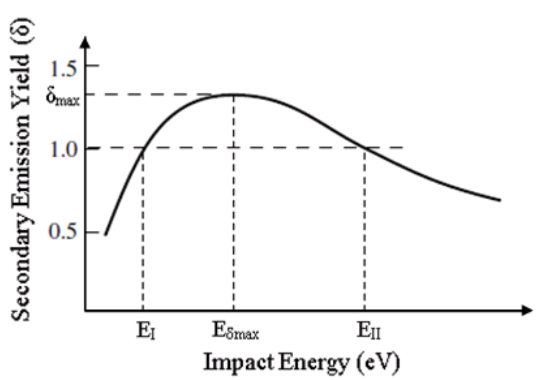

Figure 1: Secondary emission yield with impact energy.

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#sdesilva@jlab.org

More than one secondary electron can be emitted from the surface at a SEY>1. These electrons may further generate resonant electrons, building up a large amount of excess electrons near the surface. This continuous process can lead to a thermal breakdown of the rf cavity due to surface heating. The potential range of impact energies for Nb with a SEY>1 would be $E_I > 150\,eV$ and $E_{II} < 2000\,eV$.

The secondary particles absorb the rf power supplied to the cavity limiting the achievable gradient in the cavity. The soft barriers on the gradient can be eliminated by cavity processing and cleaning. However hard barriers may not be eliminated by processing and requires reoptimizing the cavity geometry.

MULTIPACTING ANALYSIS

A detailed multipacting analysis is performed on the 499 MHz cylindrical shaped parallel-bar geometry with curved bars [3] as shown in Fig 2. This geometry has improved properties compared to the rectangular shaped design with straight bars.

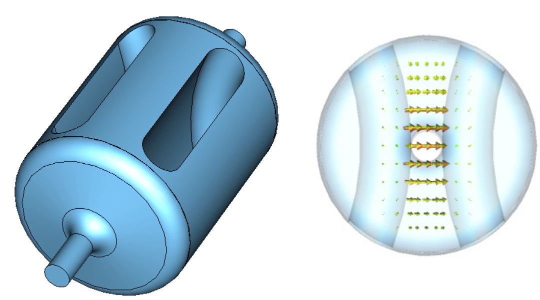

Figure 2: Cylindrical parallel-bar geometry (left) and transverse electric field between the bars (right).

The cylindrical parallel-bar cavity is susceptible to multipacting effects due to its geometry. The areas with parallel plate like geometry with the transverse electric field make the design more likely to have two-point multipacting present between the surfaces. In two-point multipacting the primary particle collides with each surface in every ½ rf period. The area between the cavity wall and the outer wall of the bars is very likely to have two-point multipacting at lower field levels.

For a parallel plate set-up with an alternating electric field, the resonant voltage and impact energy for two-point multipacting [4] are given by

$$V_n = \frac{m\omega^2 d^2}{(2n-1)\pi e} \qquad (1)$$

$$E_n = \frac{2m\omega^2 d^2}{(2n-1)^2 \pi^2} \quad (2)$$

where m is the mass of an electron, ω is the rf frequency of the cavity, d is the separation between the plates and n is the order of multipacting. Transverse electric field between the parallel bars is maximum at the center of the beam line with no magnetic field where the separation between the walls is 0.04m. At this gap for a two-point multipacting the 1st order impact energy is 18.1 keV with a resonance voltage of 28.5 kV. The first order impact energy corresponds to a secondary emission less than one compared to the potential impact energy range in the SEY curve for Nb. For higher orders of resonances the impact energy decreases resulting in a probable multipacting condition at lower field levels. However this analytical method cannot be applied to the complete cavity design due to its complexity in the geometry and rf fields. Therefore an advanced numerical code is used to identify probable multipacting conditions in the cylindrical parallel-bar cavity.

The 3D parallel tracking code Track3P from the ACE3P code suite developed by SLAC [5] is used to analyze the multipacting conditions in the cylindrical parallel-bar cavity. The code has been successfully used to determine multipacting conditions present in many complex cavity designs and components, and has been extensively benchmarked over measured data.

TRACK3P SIMULATION RESULTS

The electromagnetic fields required for Track3P is obtained from Omega3P, the eigenmode solver in the ACE3P code suite. The primary electrons for the simulations are emitted from the surface in the first full rf period where they follow the electromagnetic fields and may collide with the cavity surface generating secondary electrons based on the impact energy of the incident primary electron. Then the emitted secondary electrons are traced for a longer time (50 rf periods) to identify the resonant particles. The data from Track3P is used to determine the order and type of multipacting and the corresponding trajectories of resonant particles.

The resonant conditions were scanned for the fundamental deflecting mode up to a transverse voltage (V_T) level of 5 MV per cavity. This is equivalent to a field gradient of $E_z(x_0 = 5mm) = x_0 \frac{\omega}{c} \frac{V_T}{\lambda/2} = 0.87\, MV/m$ along the beam line at an offset of 5 mm; where $\lambda/2$ is the half wave length of 300 mm.

Based on the field orientations in the parallel-bar geometry, different potential areas are analyzed for multipacting up to a field gradient of 1 MV/m. Due to the symmetry of the fields the scanning areas can be simplified as shown in Fig. 3, (A) between the cavity wall and outer wall of the curved bar, (B) between the inner walls of the bars, (C) at the curved area near the beam aperture, and (D) near the curved outer edge of the cavity wall.

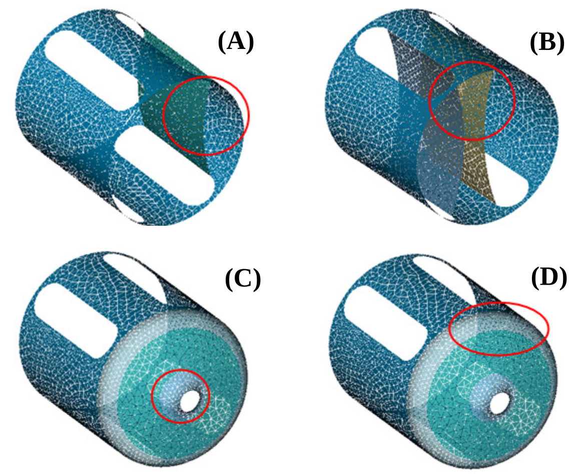

Figure 3: Potential areas scanned for multipacting the in the cylindrical shaped parallel-bar cavity.

In the area (A) it is likely to have multipacting condition present due to the low electric field between the cavity wall and the outer wall of the bar shown in Fig. 4. The data from the Track3P code shows two-point multipacting present in this area. The resonant particles are tracked over 50 rf periods where the corresponding impact energies are scanned for the field gradients up to 1 MV/m. The impact energies of the first 5 orders are shown in Fig. 5.

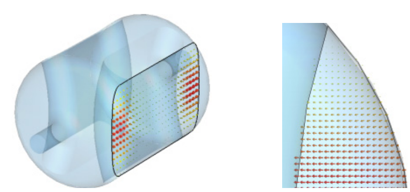

Figure 4: Transverse electric field between the cavity wall and outer wall of the curved bar.

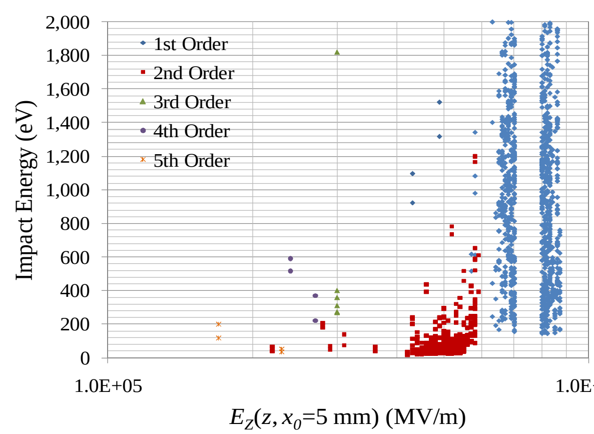

Figure 5: Impact energies for field gradient range of 10 kV/m to 1 MV/m for area (A).

Fewer resonant trajectories with low impact energies exist at low field gradients. At higher gradients the 1st order impact energies corresponds to a SEY>1. These resonant electrons may further lead to secondary electron emission, from the surface. The single particle trajectory plotted in Fig. 6 shows that particles may get trapped at the upper corner, between the surfaces. In order to prevent a buildup of excess electrons in this area the geometry can be reoptimized with curved edges.

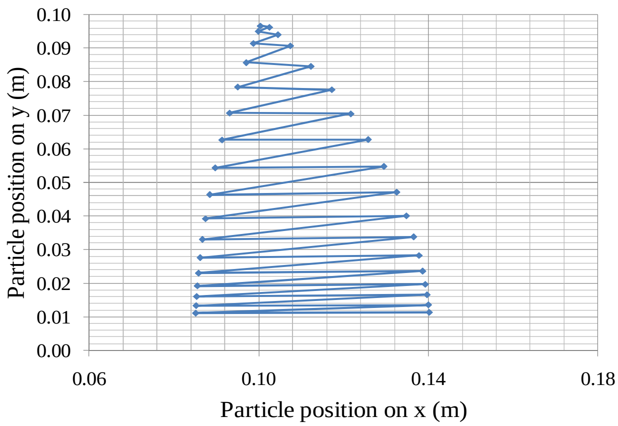

Figure 6: Trajectory of a single particle in (A) between the cavity wall and the outer wall of the bar.

In the areas of (B) and (C) the impact energies of most of the tracked resonant particles are below 200 eV. The resonant particles identified in (B) between the two inner walls of the bars mostly showed two-point multipacting where some of the trajectories showed collisions between the cavity wall and the inner wall of the bar as shown in Fig. 7. Fewer particles showed one-point multipacting.

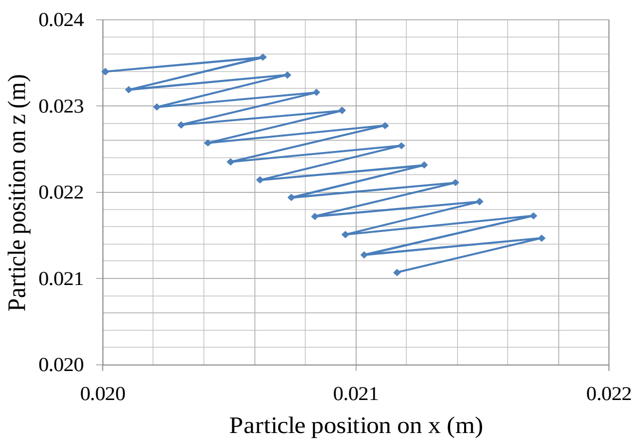

Figure 7: Trajectory of a single particle in (B) between the upper cavity wall and one of the inner walls of the bars.

In the area (D) near the curved outer edge of the cavity the magnetic field loops around the bars as shown in Fig. 8 that is likely to generate one-point multipacting conditions.

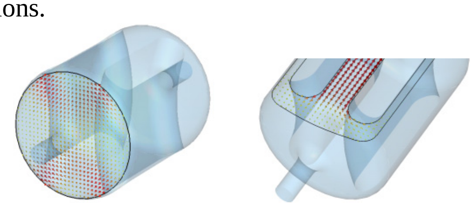

Figure 8: Magnetic field at a vertical cross section in front of the bars (left) and at a horizontal cross section near the cavity wall (right)

The data from Track3P code showed one-point multipacting for this area where the impact energies for the first 5 orders of multipacting are shown in Fig. 9. Higher orders of multipacting existed at lower gradients. At very high gradients there were considerably large amount of resonant particles of 1st order.

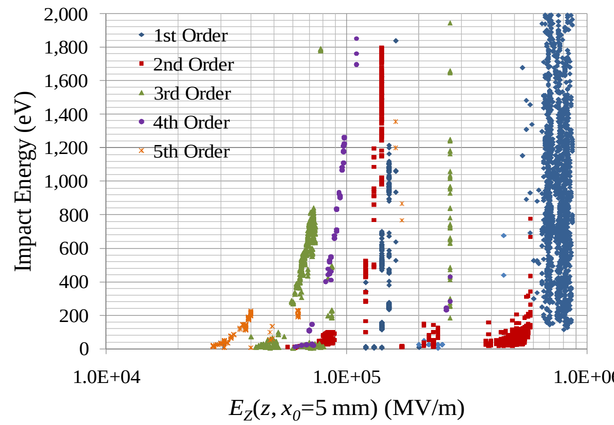

Figure 9: Impact energies for field gradient range of 10 kV/m to 1 MV/m for the area (D).

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CONCLUSION

Multipacting conditions are analyzed for the cylindrical shaped parallel-bar cavity using the Track3P code. At different field levels two potential areas of multipacting are identified. The area between the cavity wall and the outer wall of the curved bar, and also the area near the curved outer edge of the cavity showed resonant conditions with higher impact energies. All the resonant trajectories identified existed at field gradients above 0.1 MV/m that corresponds to a transverse voltage of 0.58 MV. Further analysis will be done to fully determine the resonant trajectories of the cylindrical shaped parallel-bar cavity and of similar geometries. Then further optimization will be carried out to eliminate potential multipacting conditions of these designs.

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