RIPPLE STRUCTURE IN A 56 MHz QUARTER WAVE RESONATOR FOR MULTIPACTING SUPRESSION

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Abstract

A beam-excited 56 MHz RF niobium quarter wave resonator has been proposed to enhance RHIC (Relativistic Heavy Ion Collider) beam luminosity and bunching. As multipacting is expected, an extensive study was carried out with Multipac 2.1 2D code, looking for a way to suppress it. Simulation revealed both one-point and two-point multipacting with a tendency to move towards the closed end of the cavity. These are favoured up to a peak surface electric field of 50 kV/m. The wall of the cavity was rippled where multipacting was severe and it completely eliminated multipacting.

INTRODUCTION

Multipacting, is an electron avalanche phenomenon caused by resonating electron multiplication due to secondary emission [1, 2]. Starting from the walls or inside the cavity, the electrons gain energy from the RF field and follow a repetitive path. As the electrons hit the cavity wall, and depending on the secondary yield of the wall's material, they accumulate in greater numbers thus creating an electron cloud. The cloud absorbs much of the power pumped into the system and prevents the structure from functioning at its full capacity. The impacts of the electrons on the cavity wall raise its temperature; this is important for superconducting material as it may quench the superconductivity. Symmetry in RF structures also increases the probability of multipacting. The 56 MHz quarter wave resonator (QWR) [3], (shown in Fig. 1) has a symmetrical structure, made up of the superconducting material niobium, and thereby susceptible to severe multipacting [2]. A brief simulation of multipacting in the cavity was therefore carried out with both 2D and 3D codes. However, at first, simulation was carried out without coupler and dampers in the cavity with Multipac 2.1 2D code [4]. The present article discusses the results and a method to suppress multipacting in this cavity.

Figure 1: Outline of the 56 MHz RF Quarter Wave Resonator in 2-Dimension without coupler and dampers.

SIMULATION CODE FEATURES

The Linux-based Multipac 2.1 2D code, works for axially symmetric RF structures. Without coupler and dampers, the cavity has an axially symmetric geometry. Based on a finite element method field solver, the code calculates the time harmonic electromagnetic field. Thereafter it locates multipacting field levels aided by the secondary yield of the cavity material. Fig.2 shows the secondary yield from niobium. Finally, it details the resonant trajectories of the electrons.

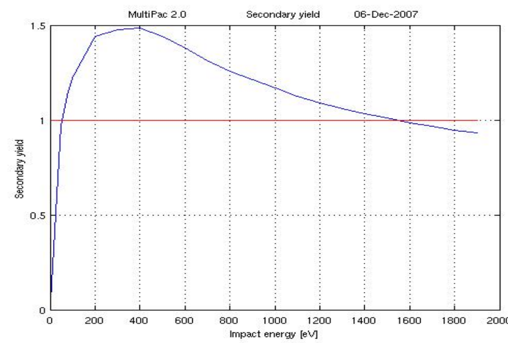

Figure 2: Secondary yield for niobium as a function of the electron impact energy in eV.

The representation of the multipacting is derived mainly from the secondary electrons generated during the process. Multipac called this the enhanced counter function, e_N/C_0, which is ratio of the total number of secondary electrons after N impacts (e_N) to the initial number of electrons (C_0). The understanding is that if the enhanced counter function for 20 impacts is greater than 1, then multipacting is probable at that field level. We adopted 100 impacts with $e_{100}/C_0 \geq 10^5$ as a significant multipacting level for the present study.

SIMULATION

In the cavity, the peak surface electric and magnetic fields are 44.19 MV/m and 1054 gauss respectively with the maximum electric field at the gap and the magnetic field at end of the cavity (Fig. 3) for 2.5 MV accelerating

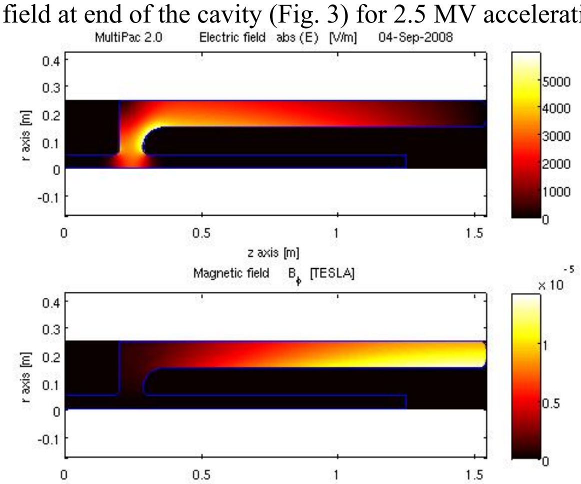

Figure 3: Electric and magnetic field distribution inside 56 MHz QWR cavity.

voltage across the gap. With 2 eV initial electron energy, 5 degree RF phase interval and 1 kV/m electric field step the simulation was carried out for the entire geometry. The cavity length is 154.57 cm and the outer radius is 25 cm. With these parameters, the cavity volume is large for a single simulation run. The full geometry was scanned in a number of runs, taking a small portion of the cavity at a time.

The results show both single-point and two-point multipacting. For high electric field area, 20-40 cm, above the acceleration gap, both types of multipacting occur. The simulation outputs' are shown in Fig. 4. The highlighted zone in Fig. 4a is the location where the seed electrons are emitted with energy 2 eV, phase 0-360

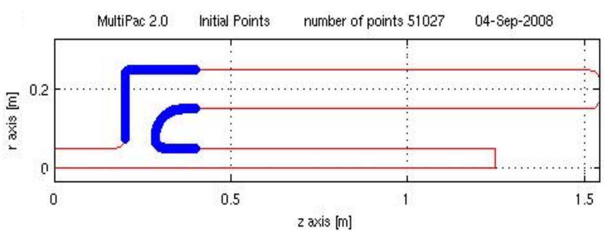

Figure 4a: Points between 20-40 cm where initial electrons were generated to cause multipacting.

degree and the full range of the field. Fig. 4b shows the enhanced counter function for 100 impacts. Multipacting occurs at peak surface electric field level 25, 31, 35-37 and 47 kV/m. At 25 (Fig. 4c) and 47 kV/m single-point multipacting takes place on the outer conductor whereas

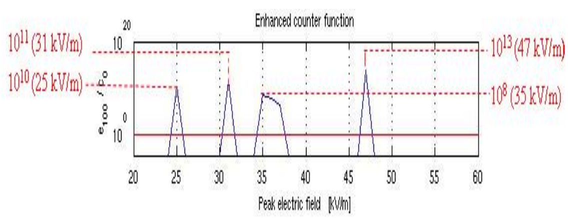

Figure 4b: Enhanced counter function for 100 electron impacts for the zone 20-40cm of the cavity.

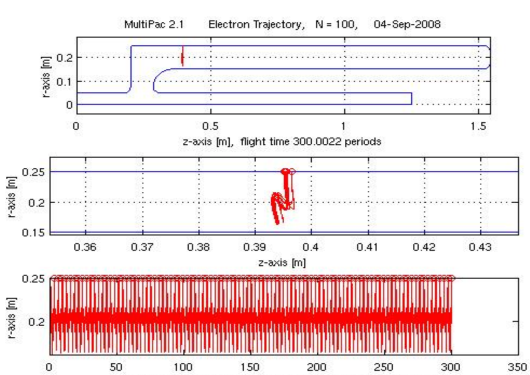

Figure 4c: Electron trajectory in single-point multipacting at 25 kV/m. The top figure represents the trajectory of the electron in (*r, z*) coordinates, the middle one is an expanded plot of a part of the top one, and the bottom plot illustrates the electron trajectory in (*r, t*) coordinates where *t* is the time in rf periods. The circles indicate the impacts on the walls of the cavity.

for the 31 kV/m two-point multipacting concentrates on the top corner of the cavity. However, for 35 kV/m the trajectories are two-point multipacting touching both inner and outer conductors, moving away from the gap zone and towards the end of the cavity.

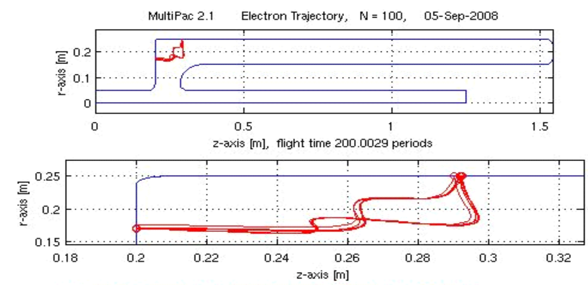

Figure 4d: Electron trajectory in two-point multipacting at 31 kV/m.

The electrons generated from both inner and outer conductors are capable of multipacting. They impact on the outer conductor in single-point multipacting, and on inner and outer conductors in two-point multipacting. In both cases they keep moving towards the high magnetic field end of the cavity. The electron trajectories cover up to 101 cm (including the beam pipe) which is 81 cm from the beam gap end of the outer conductor Fig. 5. Peak surface electric field up to 50 kV/m favor these trajectories.

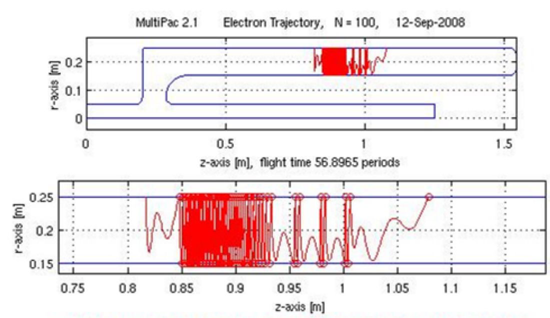

Figure 5: Electron trajectories for a peak surface electric field of 50 kV/m.

To assess the severity, the simulation was continued for more than 100 electron impacts and with some electron trajectories continued for 500, 1000 or more times. A significant increase in enhanced counter function indicated an intense electron cloud in the cavity.

SUPPRESSION

The cavity operates in a storage ring when generating such a large number of electrons, so multipacting must be suppressed. We reasoned that the most effective way to do so is by breaking the electron's stable resonant trajectory, thereby preventing further multiplication regardless of the cleanliness of the niobium surface. While there are several approaches to control multipacting from outside of the cavity (for example; by applying a DC electric field) [2], (due to the complexity of the system and a cryostat surrounding the cavity) they are not practical. As a useful alternative, we considered structurally modifying the cavity. Various structures such as a bigger radius of the outer conductor, and ripples pointing upward and downward in the outer conductor were considered. Incorporating ripples pointing upward direction seems to be the most promising (Fig.6) approach.

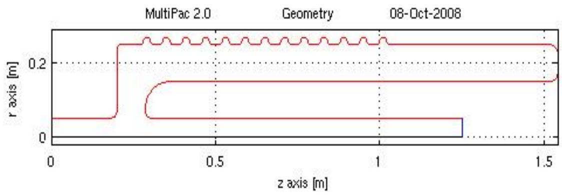

Figure 6: Ripples pointing in upward direction.

To reduce manufacturing costs, the ripples are optimized to a customary depth, width, and ensure they are sufficiently separated. Also, ripples must leave sufficient space for a coupler and dampers at the end of the cavity. Ripple depths up to 2 cm were considered for widths 1-3 cm, with the maximum possible separation. The simulation revealed that for a depth of 1 cm, electrons have resonant trajectories in the ripple zone, moving further and further, and multiplying electrons. Constraints on the material's curvature also prohibit shallow ripples. However, ripples of 2 cm depth are found to be most effective. The ripple width also is critical. A 1 cm wide ripple is not satisfactory as electrons can emerge from it, whereas they undergo resonant oscillation inside a 3 cm ripple, and are trapped there (Fig. 7).

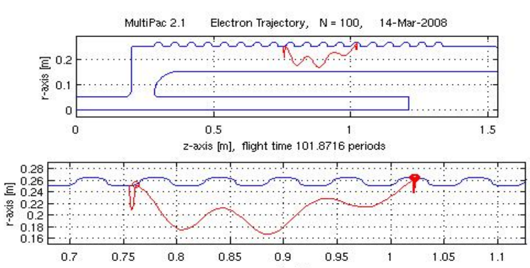

Figure 7: Stable trajectories of electrons inside a 3 cm wide ripple.

Though the energy of the electrons inside the 3 cm wide ripple are only few eV less to have secondary electron yield (δ) greater than 1 (δ > 1 at 55 eV), a little impurity in the niobium, may lead to multipacting. Hence, 3 cm width should be avoided. However, 2 cm wide ripples are a good choice. Likewise it is essential to determine the gap between the ripples. The stable trajectory of the electron is favored by having gaps bigger than 2 cm. Fig. 8 depicts the stable electron trajectories for a gap of 4 cm between the ripples, whereas Fig. 9 details the break in trajectory with 2 cm gap, even for 20 impacts [5].

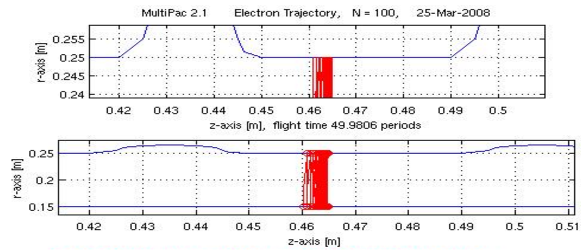

Figure 8: Multipacting trajectory with 4 cm gap between the ripples.

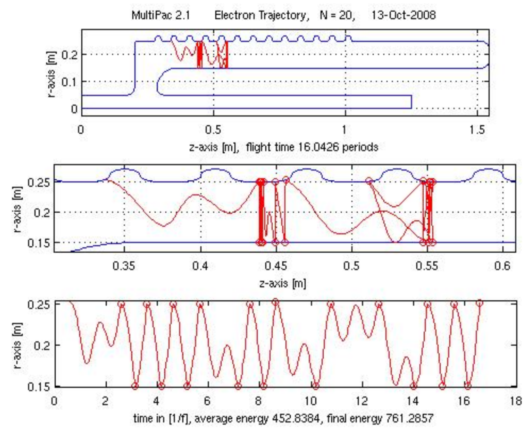

Figure 9: Discontinuities in the resonant electron's trajectory with gap 2 cm between ripples, even for only 20 impacts.

CONCLUSION

2D simulations revealed multipacting in a 56 MHz QWR is a severe low field phenomenon; however, they also showed that multipacting can be eliminated by structurally modifying the cavity. Since the cavity is equipped with a coupler and dampers, omitted in this simulation, a further complete simulation is being carried out with a suitable 3D code to confirm the parameters for a multipacting free cavity revealed by the 2D code.

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