MULTIPACTING SIMULATIONS OF SSR2 CAVITY AT FNAL*

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Abstract

SSR2 is the second family of single spoke resonator under development at Fermi National Accelerator Laboratory (FNAL). These cavities will be placed in Project X front-end after SSR1 spoke resonators, which have already been built and tested and FNAL. Spoke cavities are affected by multipacting and the nature of their 3D geometry does not allow simulating the multipactor process using 2D tools. 3D tracking simulations, of electrons inside the cavity volume, have been carried out using CST Particle Studio. Different Secondary Emission Coefficients have been applied to the cavity walls in order to understand how strongly the multipacting depends on material properties. The power levels used in simulations cover the whole operating gradient range of SSR2 cavity. Results of these simulations are compared to the one given by SSR1 model, which demonstrated good agreement with experimental data. The purposes of this paper are to present the results gotten from the tracking solver, to give a prediction of what will be the multipacting scenario for SSR2 cavity and if there will be any dangerous zone for operation.

INTRODUCTION

Multipacting affects SRF cavities from high energy elliptical cavities to coaxial resonators for low-beta application. This work is focused on multipacting in low-beta structures; the main aim is to present the results of SSR2 cavity for Project X. SSR2 is a spoke resonator in development for Project X at Fermilab [1], it operates at 325 MHz and its optimal beta is 0.51. The design has been finalized recently it was necessary to understand at what level this resonator is affected by multipacting (MP), what the critical gradients are and where the MP develops in the cavity geometry. The software used for MP simulations is CST Particle Studio which provides a particle tracking solver that uses the field from the eigen-mode solver of Microwave Studio. The figure of merit chosen as a final result of tracking simulations is the growth rate, which gives information on how fast the number of particles increase with time. Simulation of MP in SSR2 cavity have been run for three different niobium secondary emission yields (SEY): in CST environment the highest emission for niobium is given by the wet treated material, a bake out model gives the intermediate one and the lowest yield is given by the discharge cleaned niobium. The growth rate has been calculated in a wide range of gradients and the MP locations have been identified for the major MP barriers. The experience of Fermilab with MP in low-beta structure started with SSR1, which is the lower optimal beta spoke resonator for Project X, operating at 325 MHz as well. Multipacting in SSR1 cavity has been simulated, using the same approach as for SSR2, and these results have been compared with experimental data from multipacting barriers found during the vertical test of SSR1 cavity [2], [3]. All this has been done in order to compare SSR1 and SSR2 multipacting simulations, and to understand how reliable and accurate the results of these simulations are.

SIMULATION SET UP

In order to simulate multipacting using CST particle studio it is necessary to create a shell all around the cavity volume to have an emitting material. The outer layer has been grown from the outside of the vacuum volume of the cavity, without interfering with the inner ideal surface. Figure 1(a) shows the geometry of SSR2 used for multipacting simulations in the x-y cut plane view. Once created the emitter shell the primary particle sources needed to be built. They were placed on the geometry taking advantage of the symmetry of the spoke resonator. Figure 1(b) shows the particle sources chosen for SSR2 MP simulations; red surfaces indicate sources of primary electrons. This set up has been used for SSR1 simulations as well; it has been previously described in [4] when the first multipacting simulations of SSR1 cavity were done.

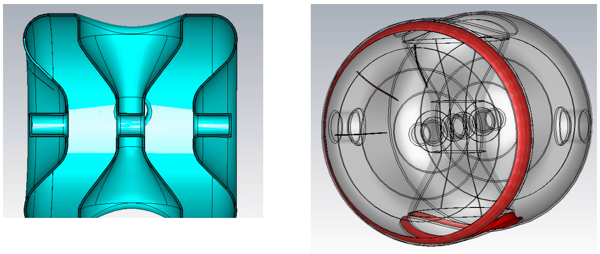
(a) (b)

Figure 1: (a) outer shell built around SSR2 geometry x-y plane view, (b) particle sources are highlighted by red surfaces.

Primary particles were launched from the sources with an initial energy ranging from 2 to 6 eV, the angle was chosen randomly by the solver to get an isotropic electron emission. When simulating multipacting it is extremely important to have the mesh dense enough in the locations where the MP happens, the multipacting spatial scale is much smaller than the cavity dimensions. Multipacting occurs in regions where the electric field is not high, compared to the accelerating field, and the magnetic field bends the trajectories in a way that they satisfy the resonant condition. Electron trajectories could be very small compared to the cavity radius or length especially for complicated shapes like spoke resonators; thus a very fine mesh is required to get accurate EM field calculation

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and reliable particle tracking in the multipacting regions. The emission model used is by Particle Studio is the Furman probabilistic model, which takes into account elastic backscattered, re-diffused and true electrons. The last ones are the responsible for electron growth since the backscattered and the re-diffused do not produce secondary particles. The available settings of secondary emission yield for niobium are three and all of them have been used in simulations, to understand how strongly the multipacting depends on the material property. Figure 2 compares the three SEY curves used, the plot is meant for a primary particle hitting the material perpendicularly to the surface.

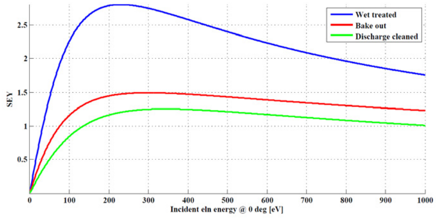
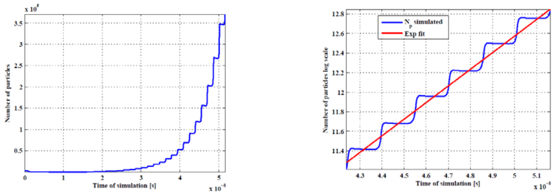


Figure 2: SEY of Nb as a function of the incident electron energy.

GROWTH RATE CALCULATION

A typical output from a multipacting simulation consists in a plot of the number of particles versus time of simulation. When multipacting occurs this curve can be approximated using an exponential function of time, the growth rate (GR) is the exponential coefficient that multiplies the time; after the MP is started the number of particles can be expressed by: $N(t) = N_0 e^{\alpha(t-t_0)}$. Where α is the growth rate, usually expressed in ns^{-1}, and N_0 is the number of particles at $t = t_0$, the time at which the MP process starts.



(a) (b)

Figure 3: (a) exponential particle growth vs. time, (b) last 3 RF periods of simulation time, particle number and its exponential fit.

Figure 3(a) shows the growth of particle with simulation time, usually the multipacting does not start immediately but it needs few RF periods to be engaged. Figure 3(b) shows the particle number and its approximation, y axis has been put in logarithmic scale; the figure shows the last 3 RF periods of simulation time, the one used to evaluate the growth rate value. From figure 3(b) it is clear that the resonant condition has been reached since the number of particles is increasing every half RF period, six steps appear over a simulation time of 3 RF cycles. The optimal number of RF periods to use for growth rate calculation has been chosen by looking at the GR values dependence on the RF cycles used for interpolation. Figure 4 shows the GR for number of RF periods going from 1 to 5, the optimal amount is considered to be around 3.

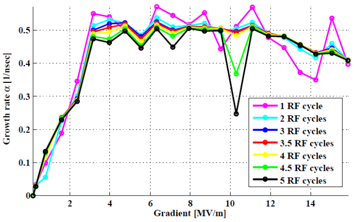


Figure 4: GR dependence on RF cycles used for the exponential fit.

The definition of gradient used in this paper is in agreement with the one used in Project X documents and it is based on a definition of effective length of the cavity expressed by $L_{eff} = \beta_{opt}\lambda$; the gradient is therefore $E_{acc} = \Delta W_{max}/L_{eff}$, where ΔW_{max} is the energy gain for a particle traveling at optimal beta through the cavity with zero synchronous phase.

SSR2 MP SIMULATIONS

SSR2 growth rate has been calculated for E_{acc} ranging from approximately 1 to 15 MV/m; the maximum energy gain for the cavity in Project X lattice is currently 5 MeV, which corresponds to $E_{acc} \simeq 10.6$ MV/m [5]. The growth rate summary plot is presented in figure 5, it includes all three different material used in simulations.

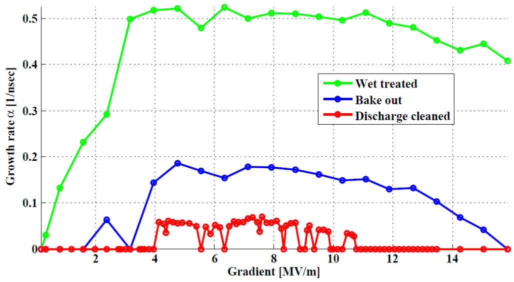


Figure 5: SSR2 GR vs. gradient summary.

The wet treated emission model has been allowing multipacting throughout the whole gradient range, so it did not give any information about particular barriers proper of the cavity geometry. Bake out SEY has helped in reducing the high number of secondary electrons generated, lowering the overall growth rate and some low gradient MP disappeared. The discharge cleaned material has allowed seeing different MP barriers in the medium-high gradient range, low and high power multipacting have not been observed. The number of points on the red curve has been increased to enhance its resolution and not to miss small barriers. Multipacting locations have been observed looking at the particle trajectory plots, in order to understand why and how the MP locations move from one spot to another it is fundamental to know the field distribution in the cavity. To increase the gradient means to increase the fields, electric and magnetic, the electrons move accordingly with field amplitude which can satisfy the resonant condition. When the gradient is increasing linearly, MP moves to lower field areas to find the same field levels as for lower gradients. Figure 6 shows the field distribution is SSR2 (a) electric and (b) magnetic. Looking at fig. 7, which shows MP locations at different E_{acc} values, it seems that MP affects SSR2 cavity in the corners of the outer cavity wall. The MP spots move from the spoke vertical position, at low E_{acc}, to almost horizontal position on the corners, at higher gradients.

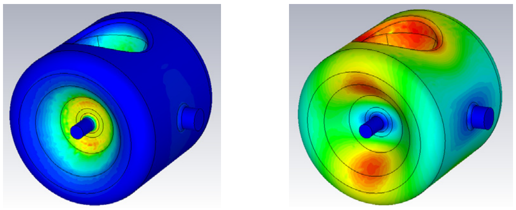
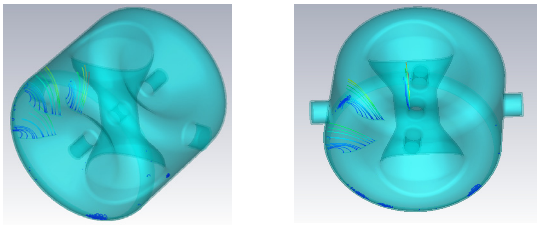

(a) (b)

Figure 6: SSR2 field distribution, (a) electric and (b) magnetic.


(a) $E_{acc} = 4.4$ MV/m (b) $E_{acc} = 6.6$ MV/m

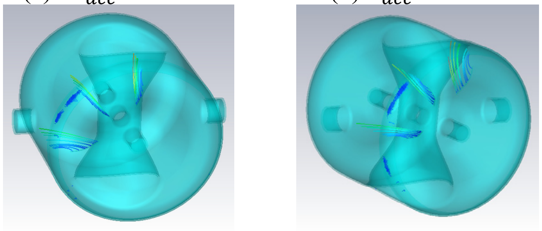

(c) $E_{acc} = 8.7$ MV/m (d) $E_{acc} = 10.4$ MV/m

Figure 7: multipacting locations at different gradients.

SSR1 MP SIMULATIONS

Since several SSR1 resonators have been tested and multipacting barriers have been experimentally observed; the results of multipacting simulations of SSR1 have been compared with the data collected during the vertical tests of the cavities. Comparing the simulation results with the experimental data helps in understanding how accurate the simulations are, and how far from reality the model is. SSR1 simulations have been compared with experimental data and then with SSR2 MP, to see if the new cavity will have multipacting barriers whether softer or harder than the one observed during the tests of SSR1. The growth rate values of SSR1 and SSR2 are plotted in figure 8, the graph shows the data related to the lowest SEY model, since it is the only one the allows to see different MP barriers. SSR2 cavity shows harder multipacting barrier having higher growth rate values, the MP seems to occur for a wider power range as well. SSR1 has two main MP barriers according to simulations: the first ranges from 4 MV/m to 6 MV/m, the higher barrier starts at 6 MV/m and ends around 8 MV/m.

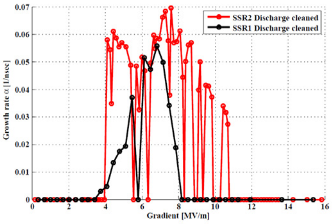


Figure 8: SSR1 and SSR2 GR comparison, discharge cleaned material.

The cold test data of all the SSR1 cavities is compared to the simulated growth rate in figure 9, which shows the time spent on each barrier for processing: around 4.5 and 6.5 MV/m all the cavities tested needed several hours for the MP to be processed, the black line in the plot represents the sum, on all cavities, of the time spent for processing. The simulations predict the two main barriers which all the tested cavities are showing during cold tests. The multipacting in SSR1 needs several hours to be processed and overcome; since SSR2 MP simulations showed an even worse scenario, the cavity may be subject to geometry changes to mitigate this phenomenon.

Figure 9: SSR1 MP processing time and growth rate.

CONCLUSIONS

MP has been simulated in SSR2 and SSR1 cavities for Project X, the results of SSR1 simulations have been compared with experimental data and the agreement seems good. SSR2 shows MP barriers harder and wider than SSR1, in the future SSR2 design may be slightly adjusted to mitigate the multipacting. Since the MP locations have been found the modification would involve slightly rearrangements of the outer wall corner.

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