3D SIMULATIONS OF MULTIPACTING IN THE 56 MHz SRF CAVITY*

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Abstract

The 56 MHz SRF Quarter-Wave Resonator (QWR) is designed for RHIC as a storage cavity to improve the collider performance. 2D multipacting simulation has been done for the cavity alone. Ripples were added to the outer body of the cavity for multipacting suppression based on the simulation findings. During operation, there will be four higher order mode (HOM) couplers. All of these components will be exposed to high RF fields. In this paper we compare 2D and 3D codes simulation results for multipacting in the cavity. We also report 3D simulation results for multipacting simulation at the couplers.

INTRODUCTION

The 56 MHz superconducting quarter-wave resonator has been proposed for increasing the luminosity of the Relativistic Heavy Ion Collider (RHIC). The cavity will have 4 Higher Order Mode (HOM) loop couplers inserted into the rear end of the cavity. We will keep the cavity detuned and its fundamental mode damped during acceleration as it does not have enough tuning range to cover beam velocity change. When beam is at store, the cavity will be slowly put into resonance to build up the desired EM field. HOMs are damped in any case. Therefore, the cavity and its couplers will experience a large field variation at every injection. It is important to have a multipacting suppressed design and predict all possible multipacting field levels.

COMPARISON OF DIFFERENT CODES

2D multipacting simulations using MultiPac [1] have been completed for the initial design of the cavity [2]. From the 2D results, corrugations were added to the outer shell of the cavity to supress the multipacting. However, a 3D code is required to diagnose the multipacting in the vicinity of the couplers. To benchmark with the 2D code, we simulated a simple geometry as shown in Figure 1, which has been analyzed by MultiPac, with two different 3D codes, Particle Studio [3] and TRACK3P [4]. The multipacting simulation only focused on the front 20 cm as labeled in dark blue lines. Possible multipacting surface electric field levels from MultiPac are shown in Figure 2.

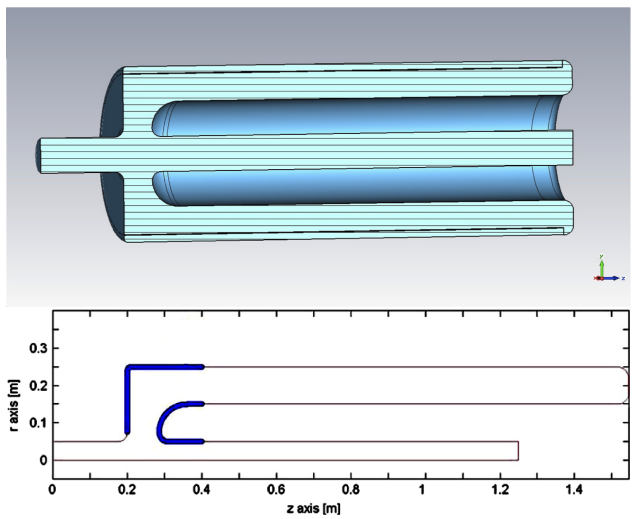

Figure 1: Simplified geometry of the 56MHz cavity for multipacting simulation. Top: Model for 3D simulations. Bottom: 2D outline used for Multipac simulation. Area labeled with dark blue lines is used for multipacting simulation.

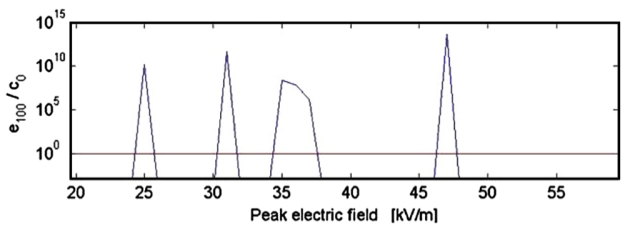

Figure 2: Multipac simulation results with peak electric field scan of 20 kV/m to 60 kV/m.

Figure 2 shows the simulation result from MultiPac. Enhanced counter function for 100 electron impacts showed that multipacting is possible at peak field level of 25 kV/m, 31 kV/m, 35-37 kV/m, and 47 kV/m.

For 3D simulations, the amount of computing effort increases exponentially. To obtain trustable results within a practical period of time, we limit the number of impacts to 40, and scanned through the same peak electric field range. Figure 3 shows the results from the two 3D codes. In Particle Studio simulation, the output is given in terms of final electron count at each field energy after 40 impacts. The numbers used for the plot has already subtracted the initial electrons. For TRACK3P simulation, every resonant particle has been recorded, but only electrons that survived

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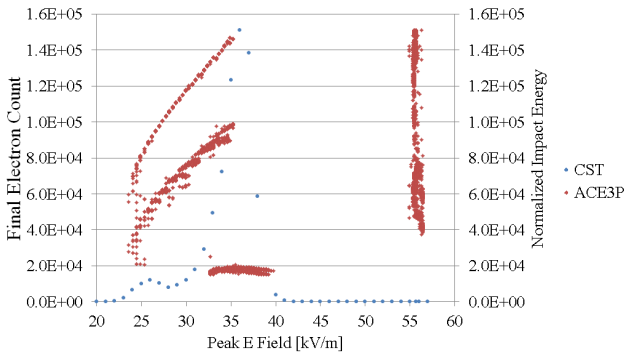

Figure 3: Multipacting results from Particle Studio and TRACK3P. Normallized for comparison.

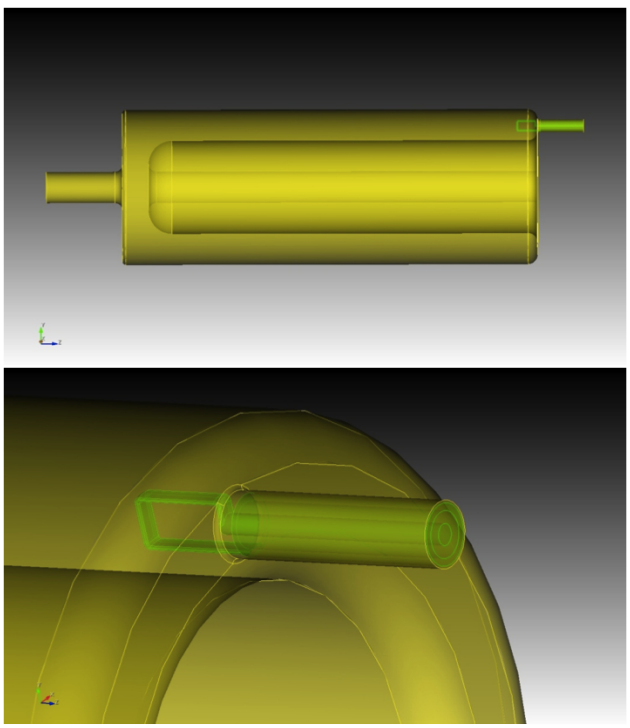

Figure 4: Simplified cavity model with HOM coupler inserted from the rear end.

40 impacts and with an impact energy that can create more than one secondary electron are being ploted in Figure 3. In order to show clearly the multipacting regions marked by two codes, we normalized the peak impact energy of the resonant particle from TRACK3P to the same level of the final electron count from Particle Studio.

The two 3D codes both show a possible multipacting peak electric field range from 25 kV/m to 40 kV/m. This range agrees with the prediction of the MultiPac. But the 47 kV/m predicted by MultiPac did not show in either 3D code results. Meanwhile, a very strong multipacting at 57 kV/m shown in the TRACK3P was not in the other two codes results.

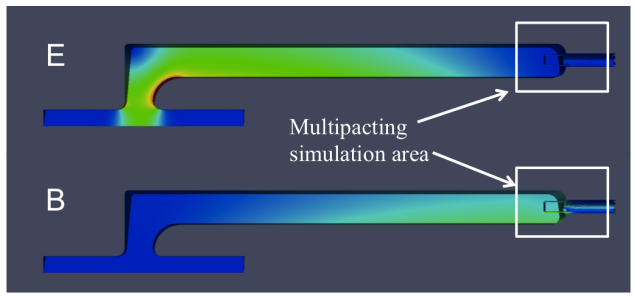

Figure 5: Electric (top) and magnetic (bottom) field of the HOM coupler multipacting simulation. The multipacting is focused in the vicinity of the coupler as shown in the white rectangle.

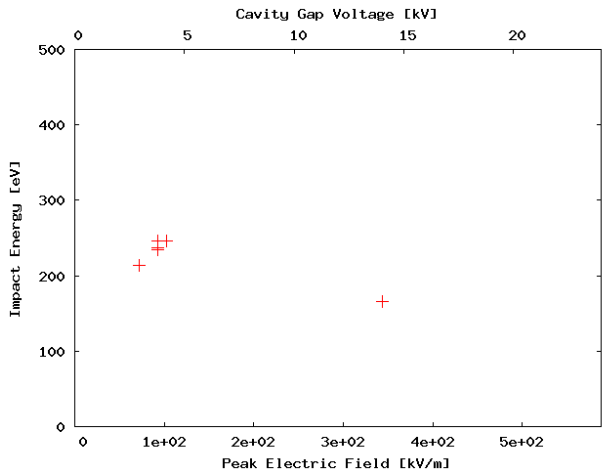

Figure 6: Multipacting results of the HOM coupler with TRACK3P.

MULTIPACTING AT THE COUPLER

For the HOM coupler multipacting study in the 56 MHz cavity, we chose TRACK3P for the advantage of using the NERSC cluster. To minimize the simulation time while still having reasonably fine mesh for the small geometries, we used the simple cavity model as shown in Figure 4. This does not effect the field distribution in the HOM coupler vicinity. One coupler is inserted through the rear end of the cavity with a boundary condition set to substitute the high-pass filter, which provides a total reflection to the fundamental mode. To further minimize the mesh number, we cut a 30 degree slice out of the cavity containing the coupler. With corresponding boundary conditions set up, the field in the slice is shown in Figure 5, and the multipacting simulation is focused on the coupler as shown in the figure.

The result of the simulation is shown in Figure 6. For impact energies in the range where SEY greater than 1 and for the impact number greater than 10, resonant particles were only recorded at 4 different peak electric field levels, 72 kV/m, 93 kV/m, 102 kV/m, and 344 kV/m. Most of the trajectories vanish after less than 20 impacts. This is

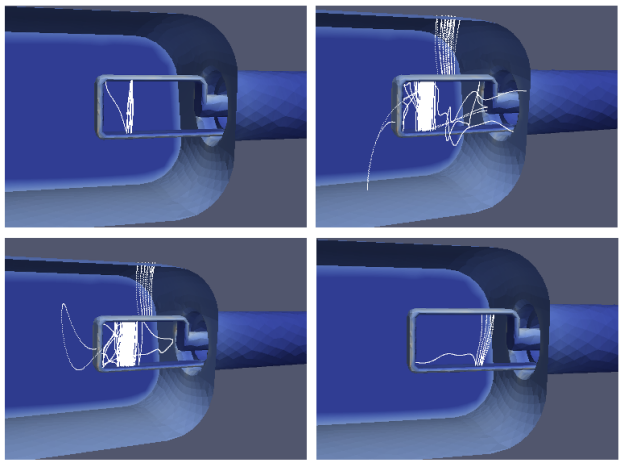

Figure 7: Resonant particle trajectories at the HOM coupler. Top-left: Epeak = 72 kV/m; Top-right: Epeak = 93 kV/m; Bottom-right: Epeak = 102 kV/m; Bottom-left: Epeak = 344 kV/m.

because the small variation of the field inside the HOM coupler loop pushes the electron trajectory slowly along the surfaces, and the resonant condition does not apply when it is out of phase. The trajectories of the resonante particle at each field level are shown in Figure 7.

If we assume the top and bottom surfaces of the coupler loop are infinitely large parallel plates, multipacting can be sustained in the voltage range between minimum and maximum values (in volts) calculated by the following equations [5]:

$$V_{g,min} = \frac{22480\,(fD)^2 - N\pi fD\sqrt{44960E_0}}{\sqrt{(N\pi)^2 + 4}}$$

$$V_{g,max} = \frac{22480}{N\pi}\,(fD)^2$$

where f is the frequency in GHz of the EM field, N is the order of the multipacting, D is the gap in cm, and E_0 is the energy in eV of the initial particle.

In our case, the separation of the two surfaces is 2.84cm, the order is mostly 2, and the frequecy of the cavity is 56.3 MHz. Therefore, the maximum and minimin multipacting voltage for our geometry and frequency would be

$$V_{g,min} = 42.2\text{V},\ V_{g,max} = 92.4\text{V}$$

At the predicted multipacting peak electric field level of 93 kV/m, the peak voltage vertically across the HOM coupler loop is shown in Figure 8. The voltage across the loop at the location where resonant particle trajectories are shown in Figure 7 is from 30 V to 90 V. The theoretical calculation agrees with the simulation qualitatively.

The difference between the actual field at the HOM coupler and infinitely large parallel plates brings the descrepancy of the results.

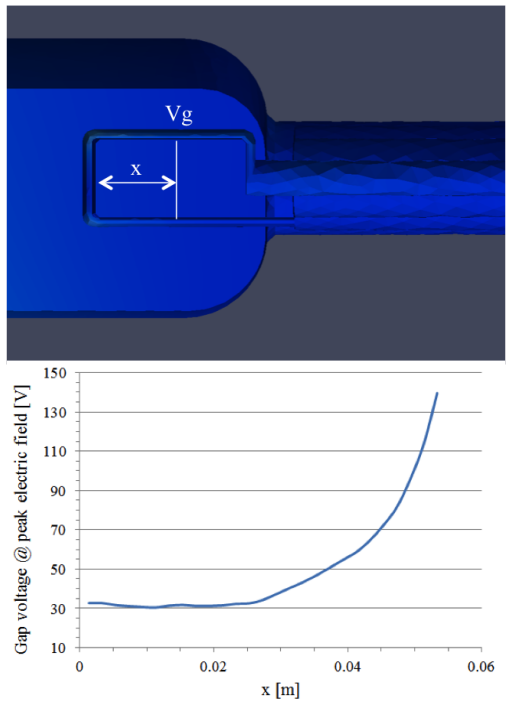

Figure 8: Voltage vertically across the HOM coupler loop at peak electric field level of 93 kV/m.

CONCLUSION

The multipacting simulation results from one 2D code (MultiPac) and two 3D codes (Particle Studio and TRACK3P) agree in most of the field levels, but there is some mismatch in the results. Further simulations of the real cavity with corrugations will be performed for the three codes, and later benchmarked with experiment.

The HOM coupler in the 56 MHz cavity did not show strong sign of multipacting at any field level. Resonant particle trajectories recorded by the simulation qualitatively agree will the theoretical estimation. This prediction will be verified during the upcoming vertical tests of the 56 MHz cavity.

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