MULTIPACTING SIMULATION AND ANALYSIS FOR THE FRIB SUPERCONDUCTING RESONATORS USING TRACK3P*

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Abstract

In the driver linac of the Facility for Rare Isotope Beams (FRIB), multipacting is an issue of concern for the superconducting resonators, which must accelerate the ion beams from 0.3 MeV per nucleon to 200 MeV per nucleon. While most of the multipacting bands can be conditioned and eliminated with RF, hard multipacting barriers may prevent the resonators from reaching the design voltage. Using the ACE3P code suite, multipacting bands can be computed and analyzed with the Track3P module to identify potential problems in the resonator design. This paper will present simulation results for multipacting in half-wave resonators for the FRIB driver linac.

INTRODUCTION

The driver linac for the Facility for Rare Isotope Beams (FRIB) [1] will use superconducting cavities to accelerate the heavy-ion beam to a minimum energy of 200 MeV/u. The first part of the driver linac utilizes two types of Quarter Wave Resonator (QWR) accelerating cavities operating at a frequency of 80.5 MHz to increase the beam energy to 17.5 MeV/u. The second part of the driver linac uses two types of Half Wave Resonators (HWR) cavities operating at a frequency of 322 MHz, with β= 0.285 and 0.53 respectively, to accelerate the beam to the final energy of 200 MeV/u.

Multipacting (MP) is an issue of concern for superconducting resonators which may cause prolonged processing time or limit the achievable design gradient. While most of the MP bands may be conditioned and eliminated with RF, hard multipacting barriers may prevent the resonators from reaching the design voltage. Elimination of potential MP conditions in the cavity design could significantly reduce time and cost of conditioning and commissioning the driver linac. We have utilized the Track3P code, a module of ACE3P code suite, to analyze and identify the potential MP bands in the QWR and HWR cavities for the FRIB linacs. Due to space limitations, we will present the simulation results for the beta53 HWR cavity in this paper. The MP study for the QWR cavity will be presented in a different report. High power testing of these cavities is being carried out and will be compared with simulation when data are available.

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HWR CAVITY FOR FRIB

Figure 1 shows the niobium prototype of the 322 MHz beta=0.53 HWR cavity [2]. The cavity has a 40 mm aperture in the drift tube and a 42 mm beam tube internal diameter. There are two ports perpendicular to the beam ports in the mid plane. One of the ports will be used for RF coupling. The other will be used as the field pickup port. Four rinse ports are on the top shorting plate for ease of cavity processing. Plungers are inserted into those rinse ports to minimize magnetic field enhancement at the port. These plungers can also be used as fine frequency tuners as needed. The cavity will operate at a peak electric field of 31.5 MV/m, which provides an accelerating voltage of 3.7 MV to the beam.

Figure 1. Beta 0.53 superconducting half-wave resonator cavity for the FRIB. Left: schematics of the HWR cavity; Right: Niobium prototype of the HWR cavity.

MP SIMULATION USING TRACK3P

Simulations of multipacting for the HWR cavity were carried out using Track3P. Track3P is a 3D particle tracking code in electro-magnetic fields using the finite-element method [3,4,5,6]. The finite element grid with curved elements fitted to the curvature of the boundary allows high-fidelity modeling of the geometry and, in the case of particle tracking, correct emission angles for particles with respect to the surface curvature. The Track3P can trace particle trajectories in structures excited by resonant modes obtained using eigensolver Omega3P, steady state or transient fields obtained using S-Parameter simulation code S3P or time domain code T3P. All of these codes are part of the ACE3P suite of finite element codes. The Track3P simulations have been benchmarked with various measurements and showed remarkable agreement [6,7]. As an example, it has been used to predict correctly the multipacting barriers in the ILC ICHIRO cavity [6].

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. The tracing of electrons will continue for a specified number of RF cycles, after which resonant trajectories are identified. Those with successive impact energies within the right range for secondary emission yield bigger than unity will be considered multipacting events. One then uses the secondary emission yield (SEY) curve of the surface material to estimate the MP strength. In Figure 2 are shown typical SEY curves for niobium and copper. The postprocessing tool in Track3P extracts these events and determines the MP type (order: # of RF cycles to return to original site; point: # of sites per MP cycle).

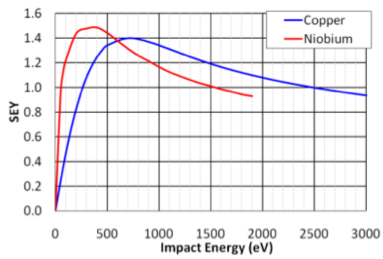

Figure 2. SEY curve for Niobium.

For the HWR multipacting simulation, initial particles were distributed on the whole cavity surface. Regions that support resonant trajectories were then identified and further analyzed. The field level was scanned up to 35 MV/m in peak surface electric field (4.1 MV accelerating voltage) with a 0.5 MV/m interval. At each field level, 50 RF cycles were simulated for obtaining resonant trajectories. In the following, we will present simulation results on different regions of cavity that may support resonant trajectories.

MULTIPACTING ON CAVITY SHORTING PLATE

Resonant trajectories were found at the top and bottom shorting plates at field levels from 13.5MV/m to 19.5MV/m of Epeak (1.6-2.2 MV accelerating voltage). These are of two-point first-order MP as shown in Figure 3 for a typical trajectory at 17 MV/m peak surface field. The impact energies of the trajectories are all below 50eV, and are not at the peak SEY for Niobium. Such a MP band is similar to that in a typical elliptical accelerating cavity, which can normally be processed through without much difficulty.

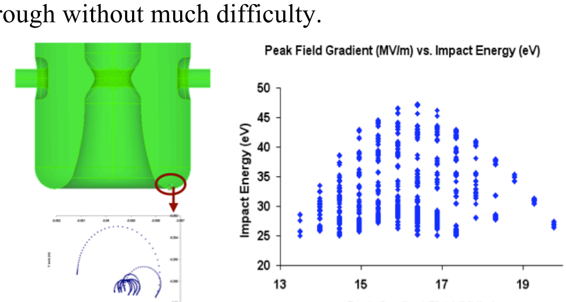

Figure 3. Two point first-order resonant trajectories at the shorting plates. The impact energies are all below 50 eV.

MULTIPACTING ON RINSE PORT

The rinse port with a plunger of 0 mm insertion was simulated. One-point first-order resonant particles were found on the plunger tip at Epeak between 6.5MV/m to 8 MV/m. Figure 4 shows the distribution of the resonant trajectories and the map of impact energy versus field level (Red for 0 mm plunger insertion). All the impacts are on the flat surface on the tip of plunger. The impact energies range from 100 eV to 550 eV, which are around the peak of the SEY of Niobium. These resonant conditions could potentially present significant multipacting. Since the area that supports these MP trajectories is small, it may not pose a strong barrier.

Different plunger insertions were simulated to understand the sensitivity of MP versus the plunger position. In Figure 4 are also shown the MP maps for 3-mm insertion (black), 5-mm retraction (blue) and 10-mm retraction (green). The MP bands shifted toward higher peak surface field as the plunger retracted from the cavity. It appears that the MP band is strongest at the 0 mm intrusion.

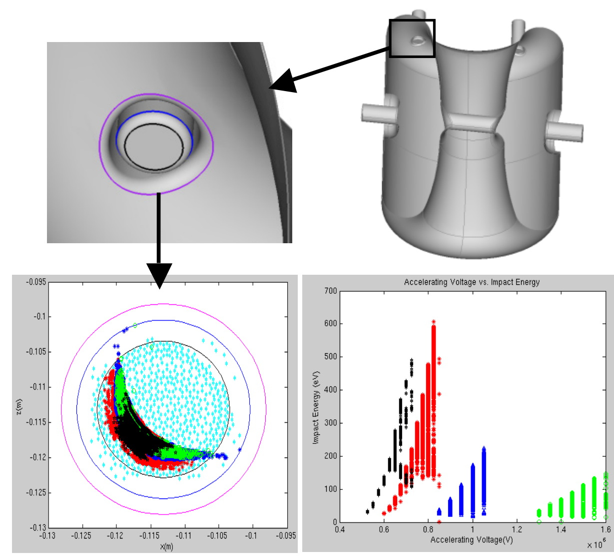

Figure 4. Left: resonant trajectory distribution; Right: Impact energy vs field level. Cyan: initial electron distribution; Red 0 mm plunger insertion; Black: 3 mm insertion; Blue: 5 mm retraction; Green: 10 mm retraction.

RINSE PORT MULTIPACTING MITIGATION

The impact energy of the resonant trajectories on the tip of the plunger is well around the peak of Niobium SEY. It is desirable in the design to minimize such resonant conditions to avoid potential strong multipacting.

Full Radiused Plunger Tip to Suppress MP

A straightforward way to alter the resonance condition is to introduce more curved surfaces in the tip region. Figure 5 shows MP maps with different tip rounding radii. With a larger rounding radius, the MP band moves to a lower field level, the MP area shrinks and the impact energy gets lower. With a full radius rounding, Magenta in Figure 5, no significant MP trajectories were identified.

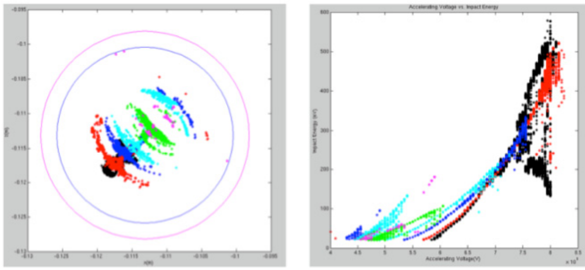

Figure 5. MP vs. plunger tip rounding: left) MP particle distribution; right) impact energy versus field level. Rounding radius - Black: 3mm, Red: 5mm, Blue: 8mm, Cyan: 10mm, Green: 12mm, Magenta: 12.7mm (full rounding)

Plunger Removed to Suppress MP

The main reason to have a plunger inserted into the rinse port is to reduce the field enhancement around the opening of the port. As shown in Figure 4 that multipacting diminishes as the plunger is retracted from the cavity. A fully retracted plunger would totally eliminate the MP in the rinse port region. However, removing the plunger may result in higher magnetic field on the rinse port. To compensate this effect, the rounding of the rinse port is increased such that the magnetic field on the port reduces to lower than the peak magnetic field on the cavity wall. Figure 6 shows the magnetic field enhancement as functions of rinse port radii, with and without plunger. The green line is the max magnetic field on the cavity wall. To lower the magnetic field on the rinse port to below the peak field on the cavity wall, a rounding radius larger than 12-mm is needed.

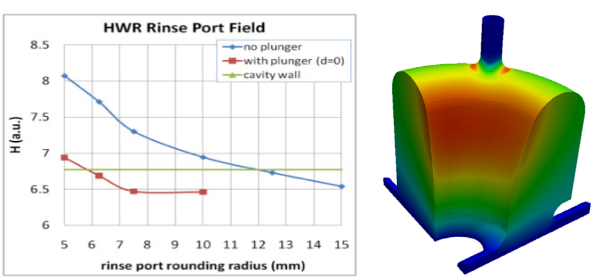

Figure 6. Magnetic field enhancement at the rinse port.

MULTIPACTING AT FPC PORT

Resonant particles are observed in the power coupler region. These resonant trajectories are two-points second-order between the inner and outer conductor of the coupler coax. There are no resonant trajectories found at the opening of the coupler port. Figure 7 shows the MP map and a trajectory in the coupler tip region at peak electric field of 28.5 MV/m. There appears to be a significant MP band at field level from 25 MV/m to 35 MV/m. Consider that the coupler inner conductor will be made with copper, those impact energies are on the lower end of the SEY curve (Figure 2).

It is worth to point out that simulations performed here are for the case of coupling beta=1. In the real cavity operation under full beam loading, the coupling beta is 6. The RF field in the coupler will be a combination of traveling and standing waves. A full FPC coupler MP simulation under such a operation condition is in progress.

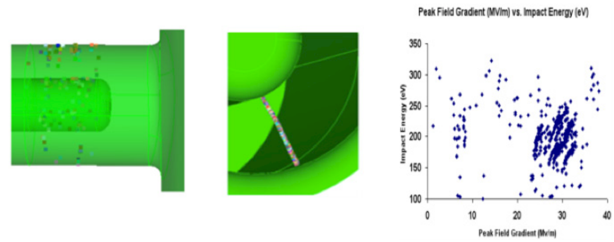

Figure 7. Resonant trajectory and MP map at the FPC coupler port.

SUMMARY

Track3P was used to analyze the MP bands in the HWR cavity. MP trajectories were found in the rinse port plunger region at various plunger insertions. Two ways to mitigate the MP at the rinse port were studied: one is to use a fully rounded plunger tip to suppress MP resonant trajectories, and the other is to remove the plunger which eliminates the resonant trajectories. For the later case, rinse port rounding need to be increased to larger than 12 mm to minimize the magnetic field enhancement. Resonant trajectories were also found on the cavity shorting plates. The impact energies of such trajectories are in the low end of the SEY curve of niobium. No resonant trajectories found on the field pickup port, which is on the opposite of the FPC coupler. There are no resonant trajectories found at the opening of the FPC coupler. Multipacting simulation of the full coaxial FPC coupler under operating condition is in progress. The HWR is undergoing high power testing at MSU. Comparison between simulation and measurement is in progress.

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