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MULTIPACTING SIMULATION AND ANALYSIS FOR THE FRIB β=0.085 QUARTER WAVE RESONATORS USING TRACK3P*

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Abstract

The driver linac for the Facility for Rare Isotope Beams (FRIB) utilizes several types of low-β superconducting resonators to accelerate the ion beams from 0.3MeV per nucleon to 200MeV per nucleon. Multipacting (MP) is an issue of concern for such superconducting resonators as they have unconventional shapes. We have used the parallel codes Track3P and Omega3P, developed at SLAC under the support of the DOE SciDAC program, to analyze the multipacting barriers of such resonators. In this paper, we will present the simulation results for the β(v/c) = 0.085 Quarter Wave Resonator (QWR) for the FRIB project. Experimental data will also be presented to benchmark with the simulation results.

INTRODUCTION

Figure 1 shows the CAD model and electric and magnetic field profiles of the 80.1 MHz β(v/c) = 0.085 Quarter Wave Resonator (QWR) cavity [1,2]. The cavity will operate at a maximum peak electric field of 30 MV/m. The corresponding accelerating voltage for a β = 0.085 beam is 1.5MV. Omega3P [3] was used to obtain the RF parameters and field maps for multipacting (MP) simulation. Track3P [4] was used to track the particles and identify resonant trajectories. Calculations were performed on the NERSC Franklin machine, which has 38,128 Opteron compute cores. We typically use a few hundred cores in each run.

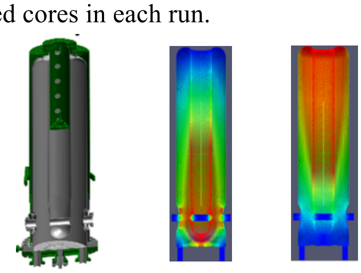

Figure 1: CAD model and field profiles of the β=0.085 superconducting quarter-wave resonator cavity for the FRIB.

Table 1: Electromagnetic Figure of Merit

Parameter	Value (Omega3P)
β_{opt}	0.085
Frequency	80.1MHz
Q	7745
Qexternal	1.35e9

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MULTIPACTING SIMULATION

Taking advantage of symmetry, one half of the QWR cavity was used in the multipacting simulation. The geometry was divided into three regions: top, middle and bottom (Figure 2 left) for ease of analysis. Seed particles were initiated on all the RF surfaces. The field level was scanned up to 1.5MV accelerating voltage with a 0.01MV interval. At each field level, 50 RF cycles were simulated for obtaining resonant trajectories. Several snapshots of particle tracking are shown in Figure 2 to illustrate MP resonances at 23kV accelerating voltage. The primary particles were emitted from all the surfaces (a); after a few RF cycles, some non-resonant particles were removed from the simulation (b); after more RF cycles, fewer particles survived (c); finally, after 50 RF cycles, only resonant particles which are considered potential MP particles remained (d). Both 2eV and 5eV were used as the initial energy for primary and secondary emissions to study its effect on MP. Typical niobium SEY curve shown in Fig. 3 was used to estimate the MP strength.

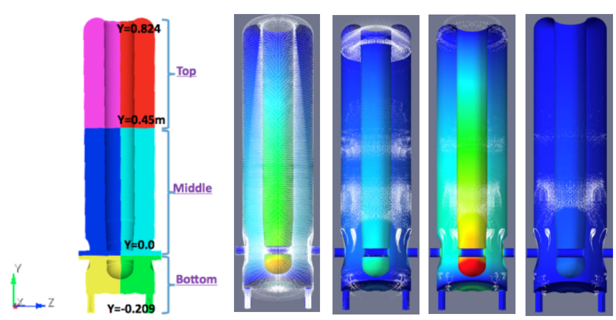

Figure 2: Left) MP simulation model. Right: a-d) Evolution of particles survived at increasing RF cycles. Particles survived a large number of RF cycles are considered potential MP particles.

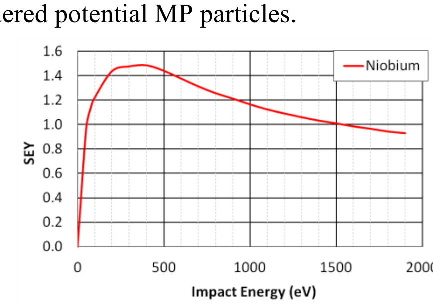

Figure 3: Impact energy dependence of SEY for Niobium. The peak SEY is around 150-700eV. Resonant particles with impact energies within this range likely contribute to MP.

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MULTIPACTING BANDS

Figure 4 shows the distribution of resonant particles identified using Track3P. There are two potential MP bands, one at low field levels with impact energies from tens of eV to about keV, and the other at high field levels from 360kV to 600kV accelerating voltage with low impact energies.

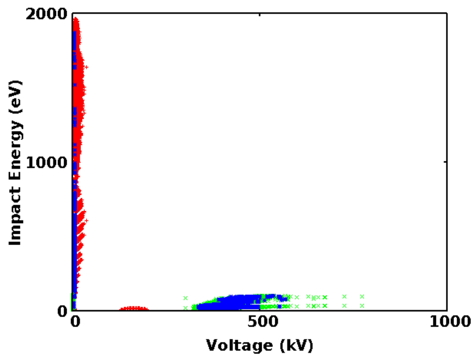

Figure 4: Impact energy vs. accelerating voltage for particles with resonant trajectories. Red color indicates resonant particles in the top region of cavity (see Figure 2), Green color is in the middle region, and Blue color is in the bottom region.

MP Band at Higher Field Level

The MP band at the higher field levels occurred in the beampipe region. Figure 5 shows the location and the impact energies of the resonant particles. The type of MP trajectories is of two point and second order. The resonant particle impacts at two positions on the beampipe surface, and takes two RF cycles to return to the original site. The impact energies are around 100eV, which are below the peak SEY energy for Nb (Fig. 3). Such a MP band is expected to be a soft barrier and could be processed through without many difficulties.

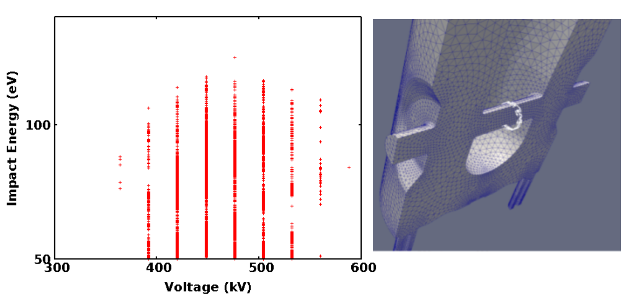

Figure 5: Left: Impact energy vs. accelerating voltage for particles with resonant trajectories at high accelerating voltage; Right: Impact positions.

MP Band at Low Field Level

The important MP resonances are at lower field levels. Figure 6 is an expanded plot around this MP band. There are two types of resonant trajectories in this band. The trajectories above 7.5kV accelerating voltage are of "unstable" type. Such particles impact the cavity wall multiple times and eventually drift away. These trajectories are located at the top region of the cavity.

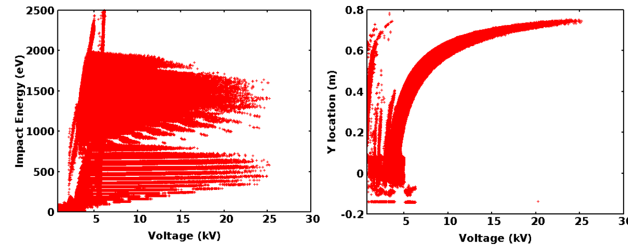

Figure 6: Multipacting activities at low accelerating voltage with initial particle energies 2eV. Left: Impact energies vs. accelerating voltage. Right: Impact location in y direction vs. accelerating voltage.

Stable resonant particles are observed at voltage levels from 800V to 7.5kV. Figure 7 shows the impact energies of the resonant particles within this MP band using 2eV for initial emission energy. The corresponding results for initial energy of 5eV are similar but with the impact energies slightly higher than those of the 2eV case. This MP band appears to be a relatively hard barrier as the impact energies of the particles are around the peak of the SEY curve (Fig. 3). This "stable" MP band agrees with the high power test data which showed processing barriers from 1.2kV -7.2kV accelerating voltage.

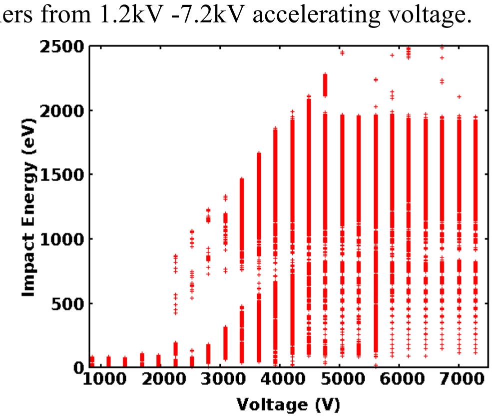

Figure 7: Resonant particle distribution for accelerating voltage between 800V - 7.5kV.

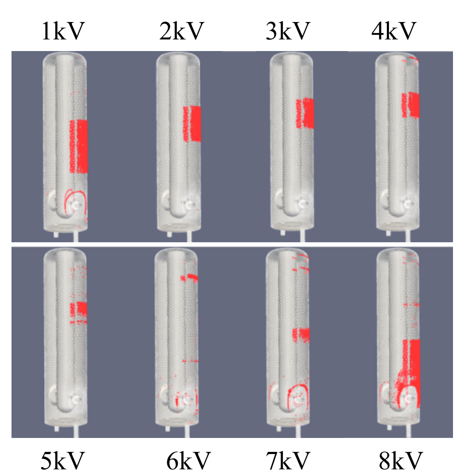

Figure 8: Impact positions of resonant particles at different accelerating voltage from 1kV to 8kV.

Resonant Trajectories at Low Field Level

Different types of resonant trajectories are observed at different locations and field levels. Figure 8 shows the impact positions of resonant particles at various field levels after 30 RF cycles. Figure 9 summarizes the locations in the y direction and impact energies at different field levels, which are represented by different colors. Most of the resonant trajectories are the type of two-point, and the particles impact on the inner and outer surfaces with different energies.

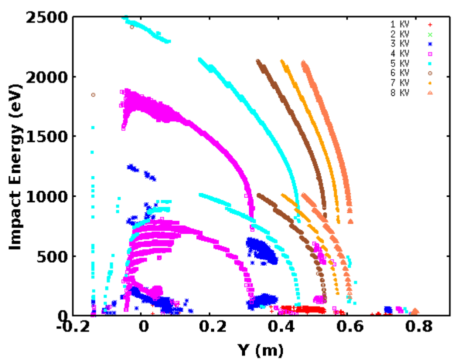

Figure 9: Impact energies vs. impact y locations at different accelerating voltage: 1kV - 8kV. The two energies at the same y location for a given field level are the impact energies on the inner and outer surfaces.

MP at 2kV Accelerating Voltage

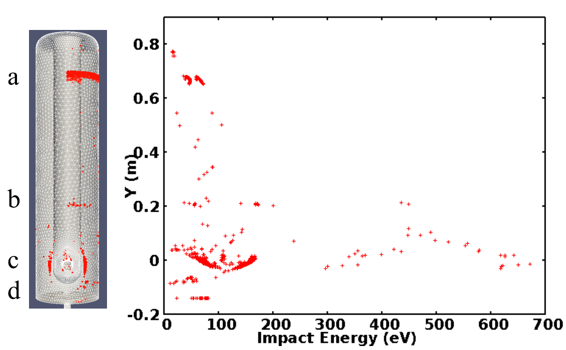

Figure 10: Resonant particle distribution at accelerating voltage 2kV.

We use the MP at 2kV as an example to show the MP characteristics of this MP band. At 2kV voltage, resonant particles are concentrated at four locations (Figure 10): a) In the upper portion of the cavity, the resonant trajectories are of the two point, fourth order with impact energies around 40eV(inner wall) and 60eV (outer wall); b) In the cavity middle region, the resonant trajectories are of the two point, sixth order with impact energies slightly higher than those in the upper portion of the cavity, although the range of RF phase that supports such resonances is quite narrow; c) In the beam port iris region, the resonant trajectories are of the one point, third order with impact energies around 140eV - 160eV; d) In the region between the bottom plate and the cavity wall, the resonant trajectories are of the two point, sixth order with impact energies around 50eV. A one-point, third order trajectory at around the beam port iris is shown in Figure 11.

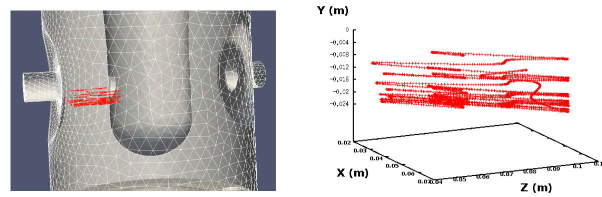

Figure 11: A resonant particle trajectory at accelerating voltage 2kV in the beam port region. It is one-point third-order MP with impact energies from 140eV to 160eV.

EXPERIMENTAL RESULTS

In RF testing of the QWRs, several low and medium field MP barriers were encountered in the Dewar tests of 5 β=0.085 QWRs. These are indicated in Fig. 12, where the MP barrier number is arbitrarily assigned to group together common multipacting barriers among the five cavities tested so far. The number of occurrences is indicated by the annotation near the points on the plot, e.g. MP barrier #3 was encountered 4 times among the 5 cavity tests.

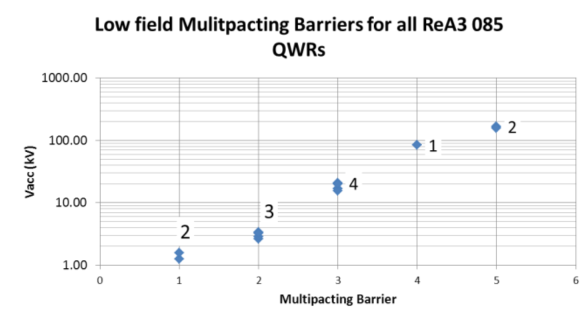

Figure 12: Multipacting barriers measured in QWRs.

SUMMARY

Track3P was used to analyze the MP bands in the QWR cavity. Different types of MP trajectories were found at different locations and field levels. Hard MP bands are found at low accelerating voltage levels from 800V to 7.5KV, which are in agreement with the experimental results observed at 1.2KV - 7.2KV.

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