

MULTIPACTING ANALYSIS FOR THE HALF-WAVE SPOKE RESONATOR CRAB CAVITY FOR LHC*

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Abstract

A compact 400-MHz half-wave spoke resonator (HWSR) superconducting crab cavity is being developed for the LHC upgrade. The cavity shape and the LOM/HOM couplers for such a design have been optimized to meet the space and beam dynamics requirements, and satisfactory RF parameters have been obtained. As it is known that multipacting is an issue of concern in a superconducting cavity which may limit the achievable gradient. Thus it is important in the cavity RF design to eliminate the potential MP conditions to save time and cost of cavity development. In this paper, we present the multipacting analysis for the HWSR crab cavity using the Track3P code developed at SLAC, and to discuss means to mitigate potential multipacting barriers.

INTRODUCTION

A crabbing scheme [1] has been adopted as the baseline tool for the LHC luminosity upgrade, HL-LHC. The nominal scheme for the HL-LHC is the local crabbing with the 400 MHz superconducting deflecting cavities. The luminosity increase due to the implementation of a crab cavity is expected to be up to 16% and 63% for nominal β^* of 55cm and upgrade β^* of 25cm respectively. In the local crabbing scheme, at IR5, the beam-beam separation at the locations of the crab cavity is 194-mm. With such a tight beam-to-beam separation, a conventional elliptical cavity of reasonable frequency would not fit. The design effort for the crab cavity is to develop a compact 400-MHz cavity that can be used for either the global (at IR4) or local (at IR5) schemes. Such a design offers more flexibility for the final upgrade installation options and save R&D cost. The transverse dimension of the cavity is thus determined by the beam separation at IR5, which can only be of 145-mm maximum in half size. To meet such a design constraints, we have developed a novel 400-MHz cavity design that is compact and RF efficient.

The 400-MHz design in consideration is a half-wave spoke resonator (HWSR) [2] as shown in Figure 1. The shape of the cavity can be considered as a half-wave segment of a coaxial line, with the coaxial axis in the vertical direction. The operating mode is the coaxial TE₁₁ mode. The beam pipe passes through the electric nodes of the TE₁₁ mode where the magnetic field is at maximum which provides transverse deflection to the beam. This design was optimized to minimize the surface fields so that it can operate at a required deflecting voltage. The Lower-order-mode (LOM) and Higher-order mode (HOM) couplers were designed to effectively damp the

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unwanted modes. The damping of the LOM and the vertical HOM is realized through a coax-to-coax coupler (two vertical couplers in Figure 1). The insertion of the beam pipe coax for the LOM/HOM-v coupler enhances coupling to the high R/Q modes. The horizontal HOMs are damped through a loop HOM coupler similar to the ILC cavity HOM coupler. The power coupler included a coax and coupling stub on the opposite side of the LOM/HOM-v coupler to eliminate cross coupling. The major RF parameters of this cavity design are shown in Table 1.

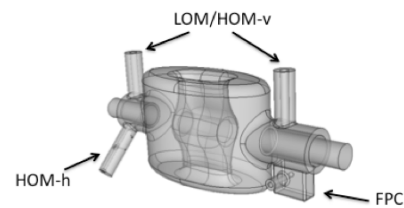


Figure 1: Half-wave spoke resonator crab cavity.

Table 1: Crab Cavity RF Parameters

Operating mode Frequency	400 MHz
Operating Mode	TE ₁₁ mode (coaxial)
LOM Frequency	336 MHz
Lowest HOM-v Frequency	810 MHz
Lowest HOM-h Frequency	628 MHz
Iris aperture (diameter)	84 mm
Transverse dimension	290 mm
Vertical dimension	391.5 mm
Longitudinal dimension	580 mm
(R/Q) _T	215 ohm/cavity
V _{deflect/cavity}	5 MV
B _{Peak}	100 mT
E _{Peak}	52 MV/m

Multipacting (MP) is an issue of concern for superconducting resonators that 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 MP 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. We have utilized the Track3P code, a module of ACE3P code suite, to analyze potential MP bands in the HWSR crab cavity. In this paper, we present the MP simulation results.

MP SIMULATION USING TRACK3P

Simulations of MP for the HWSR 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 modelling of the geometry. The Track3P can trace particle trajectories in structures excited by resonant modes obtained using the 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].

In a typical MP 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 MP trajectories are analyzed. There are two types of trajectories that are considered potential MP. The type-I MP involves particles with trajectories resonant with the RF. These particles will impact the surface at the same locations with constant energy. Those trajectories with successive impact energies within the right range for secondary emission yield bigger than unity will be considered MP 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).

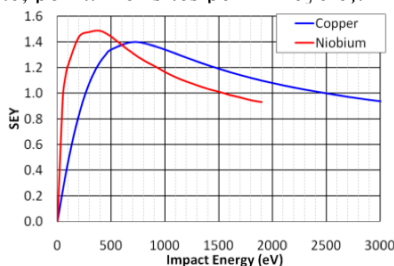


Figure 2: SEY curve for niobium and copper.

The type-II MP involves particles with run-away resonances. These particles start roughly resonant with the RF and slowly slip out of the resonant region and RF phase. The particles impact the surface numerous times with energies that could produce larger than 1 yield before decohere from the RF. For such trajectories, accumulative counter is calculated using a given SEY curve. The counter reaches a peak before the particle runs away from the resonance. We record the peak counter value as an indication of the MP strength. Run-away resonances with high counter peak values may cause observable multipacting activities in the RF processing.

HWSR MP SIMULATION RESULTS

For the HWSR MP 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 5 MV

of deflecting voltage with a 0.125 MV interval. At each field level, 50 RF cycles were simulated for obtaining the parameters of the resonant trajectories. In the following, we will present simulation results on different regions of cavity that may support resonant trajectories.

MP in the Cavity Region

Stable resonant trajectories were found at several locations in the cavity as shown in Figure 3 (Left). There are two MP bands. The first MP band is at the field levels from 0.1MV to 0.5MV. The resonant trajectories in this band are located on the cavity end-plates as well as on the center conductor outside of the beam pipe opening. The impact energies on the end-plate are below 50 eV. The energy on the center conductor is up to 160 eV. The second band is at the field level from 4.5MV-5MV, which is on the center conductor slightly inside of the beam pipe opening. In Figure 4 are shown the MP bands as a function of deflecting voltage and the z location.

Run-away resonances were identified in a broader area on the end-plate as shown in Figure 3 (Right). In Figure 5 are shown the enhancement counter of both stable and run-away resonant trajectories calculated for 50 RF cycles based on the SEY given in Figure 2 (counter maximum could be up to 50th power of respective SEY). The counter peaks are due to the stable resonances. The run-away resonances contributed much lower counter yields as a comparison and should not contribute to significant MP.

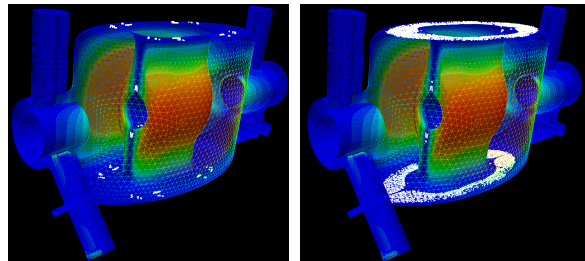


Figure 3: Left: Stable MP trajectories for all field levels. Right: distribution of run-away trajectories.

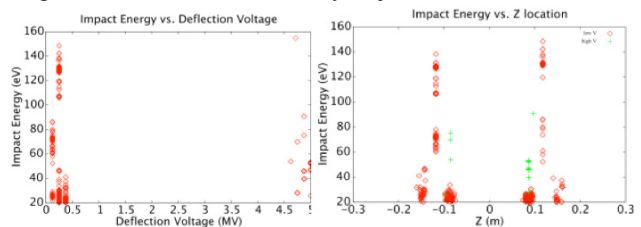


Figure 4: Stable MP bands vs. deflecting voltage and z position.

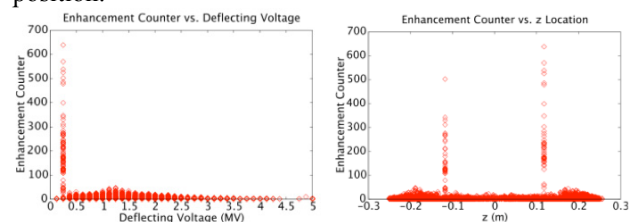


Figure 5: Enhancement counter vs. deflecting voltage z position.

MP in the Horizontal HOM Coupler

Stable resonant trajectories were found at the location close to the end cap of the HOM coupler at field levels around 2.8MV, 3.5MV and 4.5MV as shown in Figure 6 and 7. The MP impacts are on the outer tank. Some of the trajectories have impact energies that are in the range of high SEY for Nb thus may produce strong MP events. However, only a small area that would support such resonances.

Run-away resonances were identified in a broader area along the coupler on one side of the outer tank as well as around the beam pipe coax as shown in the right picture in Figure 6. The enhancement counter for 50 RF cycles is plotted in Figure 8, which shown three distinct MP bands at 1.7 MV, 3.5MV and 4.5MV distributed in 3 locations along the coupler. The most important band is at the far end of the HOM coupler due to the stable resonant trajectories. It is desirable to modify the local geometry to detune these resonant conditions.

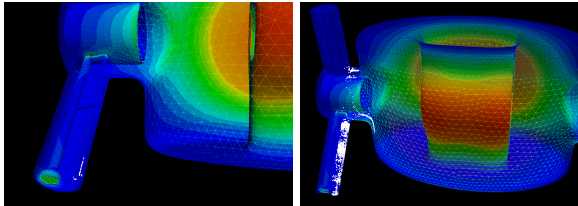


Figure 6: Left: Stable MP trajectories for all field levels; Right: distribution of run-away trajectories.

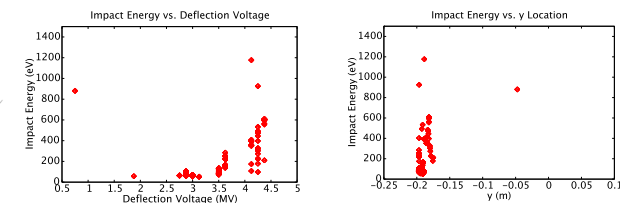


Figure 7: Stable MP bands vs. deflecting voltage and y position.

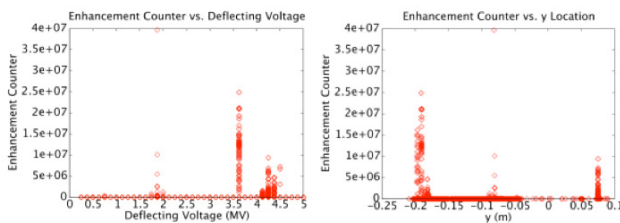


Figure 8: Enhancement counter vs. deflecting voltage and y position.

MP in Input Power Coupler

No resonant trajectories identified in the coupling stub and the coaxial beam pipe. Stable resonant trajectories were found in the coaxial region of the input power coupler. The first MP band is at field levels from 0.5MV to 2.2MV and the second band is from 4.5MV to 5MV. The MP band at the higher field level has lower impact energies and is expected to be “soft”. The enhancement counter of these resonances for 50 RF cycles is shown in Figure 9. The MP band at around 1MV has a relatively

high yield. No strong MP at the operating voltage of 5MV. The MP bands in similar coaxial couplers have been observed in RF processing and have shown that such MP can normally be processed through. We would not expect the MP in the coaxial coupler be a significant barrier. However one could use a different impedance coaxial line to improve MP resonance conditions.

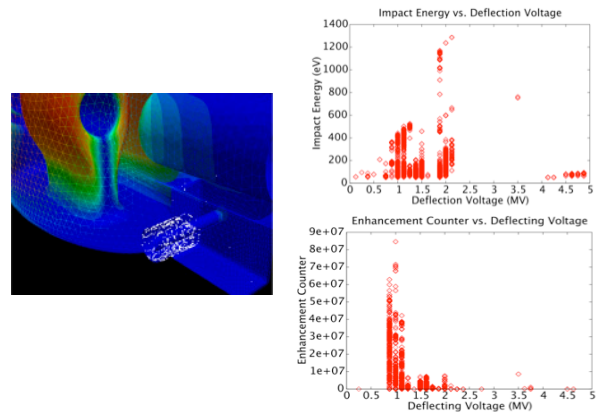


Figure 9: Left: Stable MP trajectories in the input coupler region; Right: MP band distribution and enhancement counter for 50 RF cycle.

SUMMARY

Track3P was used to analyze potential MP in the cavity and the LOM, HOM and FPC couplers. No resonances were found in the LOM couplers and the coaxial beam pipe. Resonant trajectories were identified on various locations in cavity, HOM and FPC couplers. Most of the resonances are not at the peak SEY of Nb. Run-away resonances were identified in broader areas on the cavity end plate and in the HOM coupler. The enhancement counter for run-away resonances does not show significant MP. HOM coupler geometry will be optimized to minimize the high SEY resonance.

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