

# MULTIPACTING ANALYSIS OF SUPERCONDUCTING RF CAVITIES USING A FINITE ELEMENT BASED CODE EMPLOYING LEAP FROG METHOD\*

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## Abstract

BARC is involved in the development of superconducting cavities for Accelerator Driven Sub-critical System (ADSS). The performance of superconducting RF structure can be greatly affected due to multipacting. Hence 2D and 3D multipaction simulation studies have been carried out for a medium velocity ( $\beta=0.49$ ) elliptical Niobium cavity operating at 1050 MHz. An in-house code has been developed which uses finite element method based software to calculate electromagnetic field of the structure. Leap frog method algorithm has been used to solve Lorenz force equation for trajectory tracking of electrons which are launched inside from different initial positions. Electron trajectories are tracked until they hit the surface. An interpolation function is used to calculate SEY at different impact energies. By repeating the process at different field level for different primary electrons multipacting field levels are identified. The study revealed that the cavity structure is not multipacting prone up to 17 MV/m average accelerating field. Two point first order multipacting is observed at the equatorial region of the cavity when the accelerating field is between 18 MV/m and 28 MV/m.

## INTRODUCTION

Multipacting discharge is a parasitic phenomenon for RF system device like cavity, coupler etc especially when they are superconducting. Multipacting is a phenomenon of electron multiplication cumulating in an electron avalanche. The avalanche absorbs RF energy, leading to high power losses and heating of the walls, making it impossible to raise the field by increasing the power input. Multipacting can cause electrical breakdown in high RF components.

BARC is involved in the development of technology for the accelerator driven sub-critical system (ADSS) which opens up opportunities for designing a new hybrid reactor which can be powered by Thorium as the main fuel and can be utilized for the transmutation of nuclear waste. The application demands fabrication of a 30 mA of proton beam linear accelerator (LINAC) having energy 1 GeV. In the high energy part of the LINAC, RF superconducting elliptical cavities will be used to accelerate protons up to 1 GeV. As a preliminary design, a single cell prototype cavity of RF frequency 1050 MHz will be fabricated and tested at BARC, India.

To investigate the likelihood of multipaction occurring in a 1050 MHz cavity, a kinetic model of multipaction

inside the cavity structure is developed. This model, after validation, is applied to the cavity structure in question. And it identifies the possible multipacting field levels, the possible multipacting sites as well as the order and type of multipacting expected to occur in the cavity structure.

## NUMERICAL MODEL

The cavity designed is an elliptical cavity with  $\beta$  value 0.49 and frequency 1050 MHz. It is made up of Niobium which becomes superconducting around 9 K. Since the structure is axi-symmetric, the simulation can be performed in two dimensions. The cavity is designed using 'SUPERFISH', a 2 dimensional finite difference based simulation code. The electro-magnetic field inside the cavity is again computed using Finite Element Method based code 'femlab'. The cavity structure sustains a  $TM_{010}$  mode and hence a third-order triangular base element and a refined mesh is used to obtain an accurate field map. For three dimensional field calculation 'CST microwave studio' has been used. Field values obtained from all the three codes are plotted and compared as indicated in Fig.1. Since CST gives result in 3D it is difficult to map it in 2D, so the results obtained from CST can be a little inaccurate.

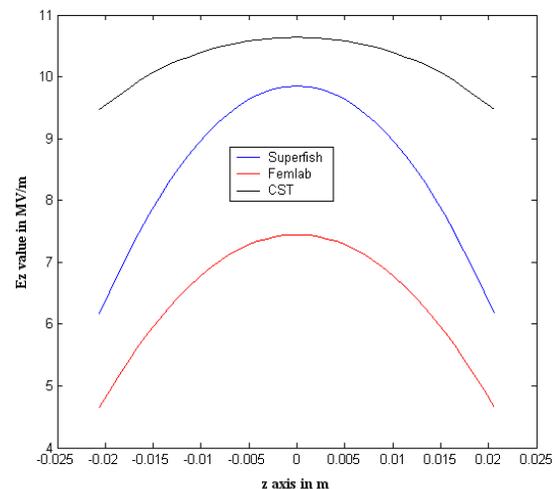


Figure 1:  $E_z$  values obtained from different codes.

Interaction of the field with primary electrons launched from the cavity wall is studied. Trajectories of primary electrons are tracked until they hit the cavity wall, where they might emit secondary electrons. The Leap Frog method is used for numerical solution of the equation of

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motion of electrons. In this method, an appropriate time step,  $\delta$  is chosen to ensure convergence of solution. In every time step, the electron first undergoes half acceleration due to electric field, a subsequent rotation due to presence of magnetic field and a final half acceleration due to electric field. After each time step position and velocity of primary electrons are noted and stored.

Large number of primary electrons are launched which are uniformly distributed along the cavity walls, in order to scan for the potential site of multipaction occurrence. Secondary emission yield (SEY) is the number of secondary electrons generated after each impact of primary electron with the wall. SEY is computed from the SEY graph for niobium baked at 300 K as shown in Fig. 2.

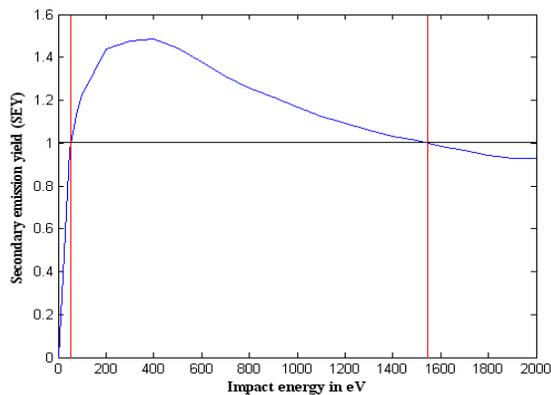


Figure 2: SEY vs. impact energy for Nb baked at 300K.

The following counter functions are calculated for multipacting analysis. The enhanced counter function,  $e_N$ , is the total number of secondary electrons (estimated according to the SEY at each impact) after N impacts, where N is 20.  $E_N$  is the impact energy of the electron after N impacts. The simulation is repeated for different field levels and multipaction field levels are identified.

## SIMULATION RESULTS

### Electro-magnetic Field Values

The eigen frequency of the cavity as calculated from “SUPERFISH” and “FEMLAB” are 1047.12388 MHz and 1046.66 MHz respectively and they are found to be almost same. The surface plot of magnetic field in the cavity (one-half of the cavity is plotted for reasons of symmetry) is shown in Fig. 3; the magnetic field is 0 at the beam axis and increases along cavity equator. It is highest near cavity equator which is to be expected. Normal electric field is found to be 0 at the cavity equator and it increases from equator to axis. It is highest near the elliptical portion near the iris.

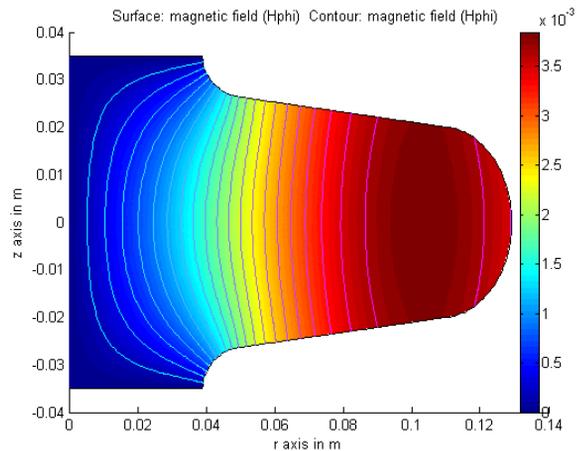


Figure 3: Magnetic field (A/m) of the cavity.

### Multipaction Occurrence

The simulation shows that multipacting is more prone to occur at equatorial region of the cavity. Evidence of two-point multipacting is found at the equatorial region as indicated by red line shown in Fig. 4.

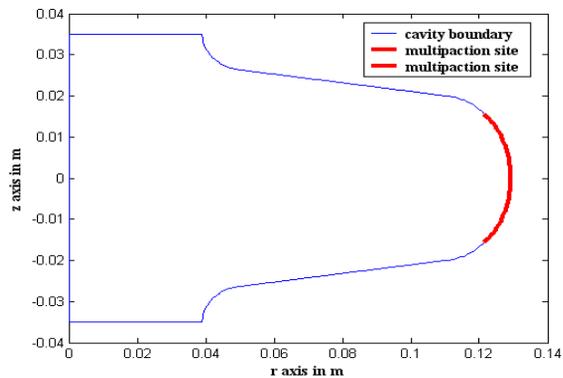


Figure 4: Probable multipaction site on the cavity wall.

### Type and Order of Multipacting

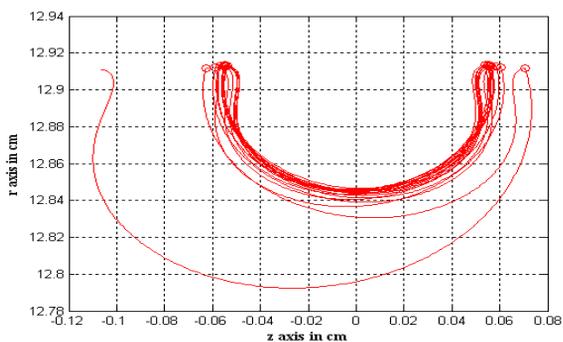


Figure 5: Multiple trajectory plot at 20MV/m.

Figure 5 shows the trajectory plot of an electron emitted from a point on the equatorial region of the cavity wall

with an initial kinetic energy of 2eV, and a launching phase of  $180^\circ$ . The electric field level is 20 MV/m. The trajectory shown here is for 20 successive impacts. It is evident from the figure that primary electron exhibit 2-point multipacting since it is repeating its trajectory in alternate impact. Further, since the time taken by the electron to reach the opposite wall is one half of the time period, the order of multipacting is one. This is evident from Fig.6 where the graph shows plot of r axis vs. time period for the sample electron.

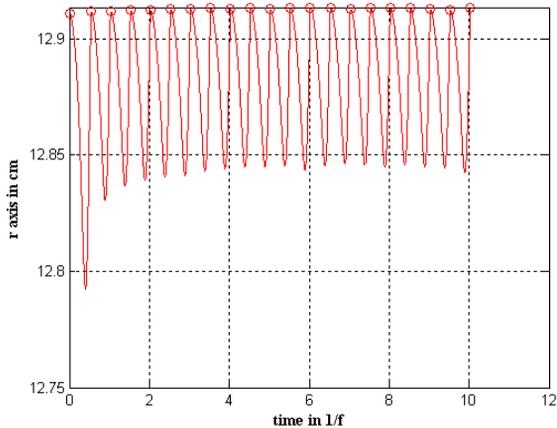


Figure 6: r axis vs. time period plot at 20 MV/m.

### Multipacting field level

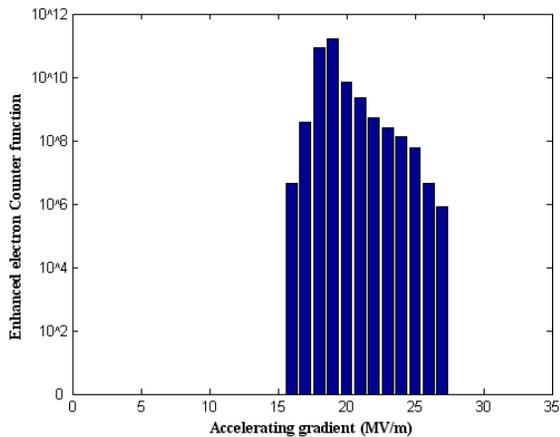


Figure 7: Multipacting field levels of cavity

Cavities may not be prone to multipacting at all field levels. In order to find the multipaction prone levels, the analysis must be repeated at several field levels. Field levels are chosen from 1 MV to 35 MV, in steps of 1 MV/m. For each level multipacting analysis has been done and enhanced counter functions for 20 impacts are calculated and plotted as a function of field level as shown in Fig. 7.

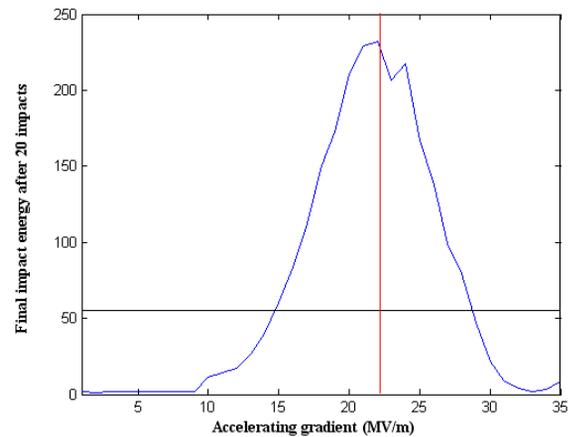


Figure 8:  $E_N$  vs. accelerating gradient.

Figure 8 shows the final impact energy ( $E_{20}$ ) after 20 impacts at several field levels. It is evident that multipacting is likely to occur at field levels ranging from 17 MV/m to 27 MV/m. Maximum multipaction occurs at  $E=20$  MV/m. The cavity may therefore be diagnosed to be prone to mutipacting at several field levels.

## CONCLUSIONS

A code has been developed to study mutipacting in RF structures. The code is used to study multipaction of cavity designed at 1050 MHz for ADSS application. With the developed code, we are able to conclude that the designed cavity is multipacting prone in several field levels. However, it is safe to operate the cavity till 17 MV/m accelerating gradient. It is also possible to identify the multipacting sites, type and order of multipacting expected to take place in the cavity structure.

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