DESIGN AND MULTIPACTING STUDY OF A BETA=1, FREQUENCY 1050 MHZ RF SUPERCONDUCTING ELLIPTICAL CAVITY FOR PROTON BEAM LINAC

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Abstract

A prototype single cell elliptical cavity of β=1 at 1050 MHz frequency has been designed for proton beam linac. Cavity shape has been optimized using two dimensional cavity tuning program "Ellfish" of the "Poisson Superfish" code. For various dimensions of the cavity, peak electric (E_{pk}) and magnetic fields (Bpk), power dissipation (P_s), Quality factor (Q), effective shunt impedance (ZT^2) etc were calculated and compared. Once the design parameters of the cavity has been optimised and fixed the electromagnetic field of the cavity was calculated using a finite element based code "FEMLAB" and 3D high frequency simulation code CST Microwave studio. The results obtained from different codes are compared. The multipacting analysis of the newly designed cavity has been done using an in-house finite element based code employing leap frog method. The multipacting analysis has been done for several field levels up to 40 MV/m. The new structure is found out to be not multipacting prone for all these levels.

INTRODUCTION

A high current proton LINAC (1 GeV, 30 mA) is an integral part of ADSS (accelerator driven sub-critical system) technology. In the high energy part of LINAC, RF superconducting elliptical cavities will be used to accelerate protons up to 1 GeV [1]. A single cell prototype cavity of β=1 at 1050 MHz has been designed. Cavity shape optimization has been done by means of 2D simulation code SUPERFISH.

Multipacting discharge is a parasitic phenomenon for RF system device like cavity, coupler etc especially when they are superconducting. It can cause electrical breakdown in high RF components and thermal breakdown in superconducting components [2]. Hence any new cavity should be investigated for multipacting occurrence. An in house numerical code has been developed for multipacting analysis. The new cavity designed has been analysed for multipacting using the code.

OPTIMISATION OF CAVITY SHAPE

The cavity shape has been optimized using 'SUPERFISH' code. Figure 1 shows a cross section of the right half of an elliptical cavity set up by SUPERFISH code. The lower left corner is the center of the cell. The left edge is the cavity mid-plane and the bottom edge is the beam axis. The boundary conditions are Neumann at the left edge and Dirichlet at the right edge. As we see from the figure 1 the bore radius is R_b, the cavity diameter is D. The full cavity length is $L = \lambda / 2$ .The cavity includes a circular dome with radius R_c, a sloping straight segment at angle α_ω from the vertical, an ellipse near the iris with semi axes b and a. The SUPERFISH program uses control-file entries for the dome vertical semi-axis b_D, the dome-ellipse aspect ratio, the iris-ellipse aspect ratio a / b, and the wall angle α_ω .

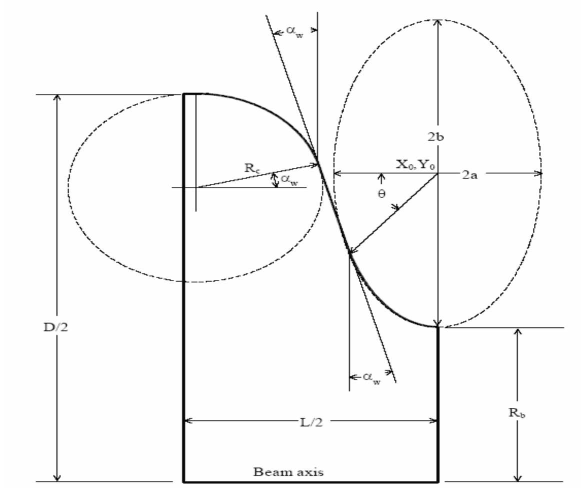

Figure 1: Symmetric half cavity shape and parameters.

For a superconducting cavity design, the peak surface magnetic field H_{pk} is important because a superconductor will quench above the critical magnetic field. E_{pk} is important because of the danger of field emission in high electric field regions. So to maximize the accelerating field (E_{acc}) it is important during a cavity design to minimize E_{pk}/E_{acc} and H_{pk}/E_{acc}. There are some more Figures of merit to compare different designs such as power dissipation P_c, quality factor Q and effective shunt impedance ZT^2. But these parameters are not so crucial to the SC cavity design.

The particle velocity fixes the cavity length (L). Again cavity diameter D is used for frequency tuning since it is most sensitive to frequency tuning. The bore radius has been fixed in conjunction with beam dynamics at a value of 39 mm. circular dome has been chosen from mechanical point of view. We tuned a series of cavities with different choices of the dome radius, wall angle, iris ellipse ratio and E_{pk}/E_{acc} and B_{pk}/E_{acc} were calculated. The optimization of these values gave the values for cavity design parameters which are listed in table 1.

Table 1: Design parameters of β=1 cavity

Accelerating Gradient	10 MV/m
Bore radius	39mm
Cavity diameter	256.379 mm
Wall angle	14 degree
Iris a_I / b_I	0.4
Dome ellipse a_D / b_D	1
Dome radius	45 mm
E_{peak} / E_{acc}	1.6616
H_{peak} / E_{acc}	3.368mT/(MV/m)
Quality factor Q	1.2101e10
r/Q	59.783 ohm

MULTIPACTING ANALYSIS

Electro-magnetic field Values

The electro-magnetic field inside the cavity is computed using Finite Element method (FEM) based code "FEMLAB". A third-order triangular elements and a refined mesh was used for the accurate calculation. The eigen frequency of the cavity calculated from "FEMLAB" is 1049.72 MHz. The surface plot of magnetic field in the cavity is shown in Figure 2; 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.

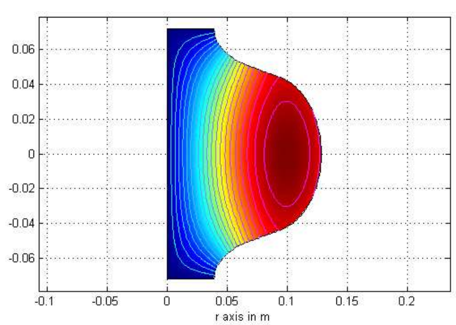

Figure 2: Magnetic field (A/m) of the cavity.

Trajectory calculation & Multipacting analysis

For multipaction stud, electrons from different positions of the structure wall are launched inside the cavity and their trajectories 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 motion of electrons. 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 vs. kinetic energy graph of niobium baked at 300 k [4]. For niobium SEY>1 if the kinetic energy of impacting electron lies between 53 eV and 1545 eV. 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. These counter functions are calculated to ascertain multipacting occurrence. The simulation is repeated for different field levels to identify multipacting field levels.

Figure 3: Trajectory of an electron at 18MV/m field.

Figure 3 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. The electric field level is 18 MV/m. The trajectory shown here is for 5 successive impacts. It is evident from the figure that since the trajectory size is gradually diminishing for successive impacts this electron does not have repeated trajectory and cannot cause multipaction. The simulations were carried out for several field levels but resonant electron trajectories were not found. The kinetic energy of the primary electron in equatorial region is always found to below 35 eV for which SEY<1. Hence it can be said the cavity is not multipacting prone up to 40 MV/m.

CONCLUSIONS

Cavity shape optimization of a prototype single cell superconducting elliptical cavity of 1050 MHz frequency and β=1 has been done using SUPERFISH code. Multipacting analysis of the new cavity has been done using an in-house developed code. Up to 40 MV/m field level, no multipacting prone site in the cavity has been found.

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