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Multipacting-free transitions between cavities and beam-pipes

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ABSTRACT

Recently multipacting (MP) has been experimentally found in two superconducting cavities to the surprise of experimenters. Computer simulation showed that the MP has occurred in transition regions between a cavity and a beam-pipe, [R.L. Geng, et al., Fabrication and performance of superconducting RF cavities for the Cornell ERL injector, in: Proceedings of the PAC 2007, Albuquerque, NM, 2007; Y. Morozumi. RF structure design and analysis XXXIII, 〈http://lcdev.kek.jp/ILC-AsiaWG/WG5notes/〉, 18 May 2007]. Our analysis offers an insight into which electromagnetic field configuration is necessary to support MP in such geometries. Namely, a minimum of the electric field along the cavity profile line, associated with the RF potential well, attracts electrons and thus creates conditions favorable for multipactor. Choosing geometries without a minimum of the electric field allows MP-free beam-pipe transitions. Simulation results confirming this conclusion are presented.

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1. Introduction

Multipacting (MP) in an elliptic superconducting cavity can occur near the equator but usually it is not very strong and it was shown in Ref. [3] that one can shift the MP zone to higher fields by changing the cell shape in the equatorial region. It was thought that such cavities are essentially multipactor-free. However, recent tests of the Cornell ERL injector cavity [1] and KEK Ichiro cavity [2] showed relatively strong MP, which was later attributed, by performing computer simulations, to the transition regions between the cavity end cells and beam-pipes. For the ERL cavity the presence of MP in this region was experimentally confirmed by a biased probe and correlated temperature changes at the outer wall [1]. Our analysis shows that the amplitude of the electric field along the cavity profile line has a minimum at the location of MP. Similarly, a possibility of MP existence in the transition region was found during our current work on designing a multicell superconducting cavity for the future Cornell ERL-based X-ray light source.

We proposed an explanation that an electric field minimum is associated with the local RF potential well, thus attracting electrons to its location and creating conditions favorable for MP. Simulations, performed using computer code MultiPac [4], confirm that smoothening out the transition to eliminate the minimum results in suppression of MP.

2. Cavity with transition from an iris to a larger diameter beam-pipe

The transition from the cavity end cell to a beam-pipe is shown in Fig. 1. The contour line of this part of the multicell cavity consists of elliptic arcs connected with tangential straight segments. A_e, B_e, A_i, B_i and so on are half-axes of the ellipses, i refers to the inner half of the cell, e refers to the outer half, R is the radius of the circle smoothening the transition; R_{eq} is the equatorial radius, R_{bp} is the radius of the beam-pipe.

We examined a transition from the end iris aperture $R_{ae} = 37$ mm to the beam-pipe radius $R_{bp} = 55$ mm with different radii R. Half-axes of the end iris ellipses were ae = at = 12.53 and bt = be = 20.95 mm. Other dimensions of the cavity are chosen to tune its frequency to 1300 MHz and the ratio of the peak electric field to the accelerating field to $E_{pk}/E_{acc} = 2.0$.

Results of MP calculations for $R = 9$ mm are presented in Fig. 2. We can see nearly stable trajectories with the final impact energy mainly sufficient for multiplication. However, there are some irregularities in the phase motion which repeatedly cause a low impact energy and the cumulative secondary electron yield (SEY) becomes <1. The enhanced counter function [4] e_{20}/c_0, as designated on the graph, is about 1, i.e. at the boundary value; for a sustained discharge it should be >1. (Actually, e_{20}/c_0 is a

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normalized enhanced counter function, as distinguished from the enhanced counter function A, which is the number of secondary electrons after a given number, $N = 20$ in our case, of impacts. Normalization means that $A = e_{20}$ is divided by c_0, number of initial "seed" electrons distributed along the contour line with a given space and phase distribution relative to the field.) The data for the SEY were taken from the code [4] with a maximum equal to 1.5 at 400 eV and crossover points 50 and 1500 eV when SEY = 1, corresponding to a clean niobium surface. This is a typical situation when in an experiment the MP can initially occur, but is easily processed after some operation with RF power when the surface becomes free of absorbates.

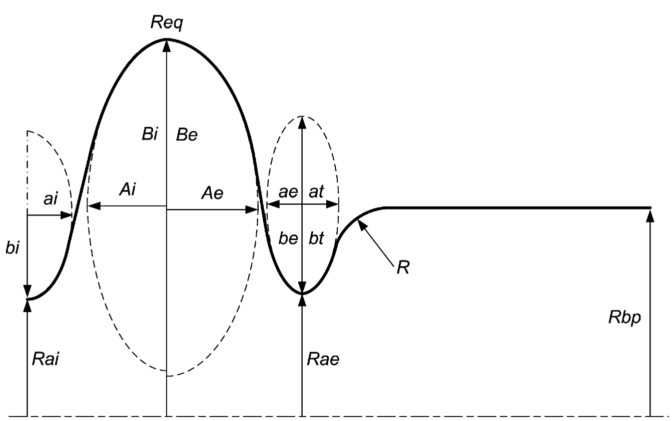

Fig. 1. Geometry of the iris-beam-pipe transition.

Let us emphasize that the location of the MP between $z = 70$ and 76 mm coincides with the minimum of the electric field E shown in the lower left plot in Fig. 2. The whole distribution of the fields along the profile line starting from the equator ($z = 0$) is shown in the lower right plot.

Increase of the radius R to 18 mm eliminates MP though the very shallow minimum E still exists, Fig. 3. This minimum disappears when the radius reaches $R = 36$ mm (right-hand part of Fig. 3), which is 2 times the difference between R_{bp} and R_{ae} (Fig. 1). This is possibly a sufficient condition to exclude MP in such transitions.

The change of the radius R in the explored range changes the cavity resonant frequency by <1 kHz, the change of the Q-factor is negligible as well.

A more detailed study indicates that there are several MP bands appearing at different field levels. Figs. 4 and 5 show dependence of the maxima of the enhanced counter function A on the radius R and corresponding values of the peak electric field E as a function of R. Three sets of points in Figs. 4 and 5 correspond to three different bands of MP. Analyzed values of field levels were in the range from 25 to 35 MV/m. This range of peak electric field was chosen for illustration because it has the most distinct maximum of the function A. Two points from Figs. 4 and 5 corresponding to $R = 12$ mm are further analyzed in Fig. 6. Two

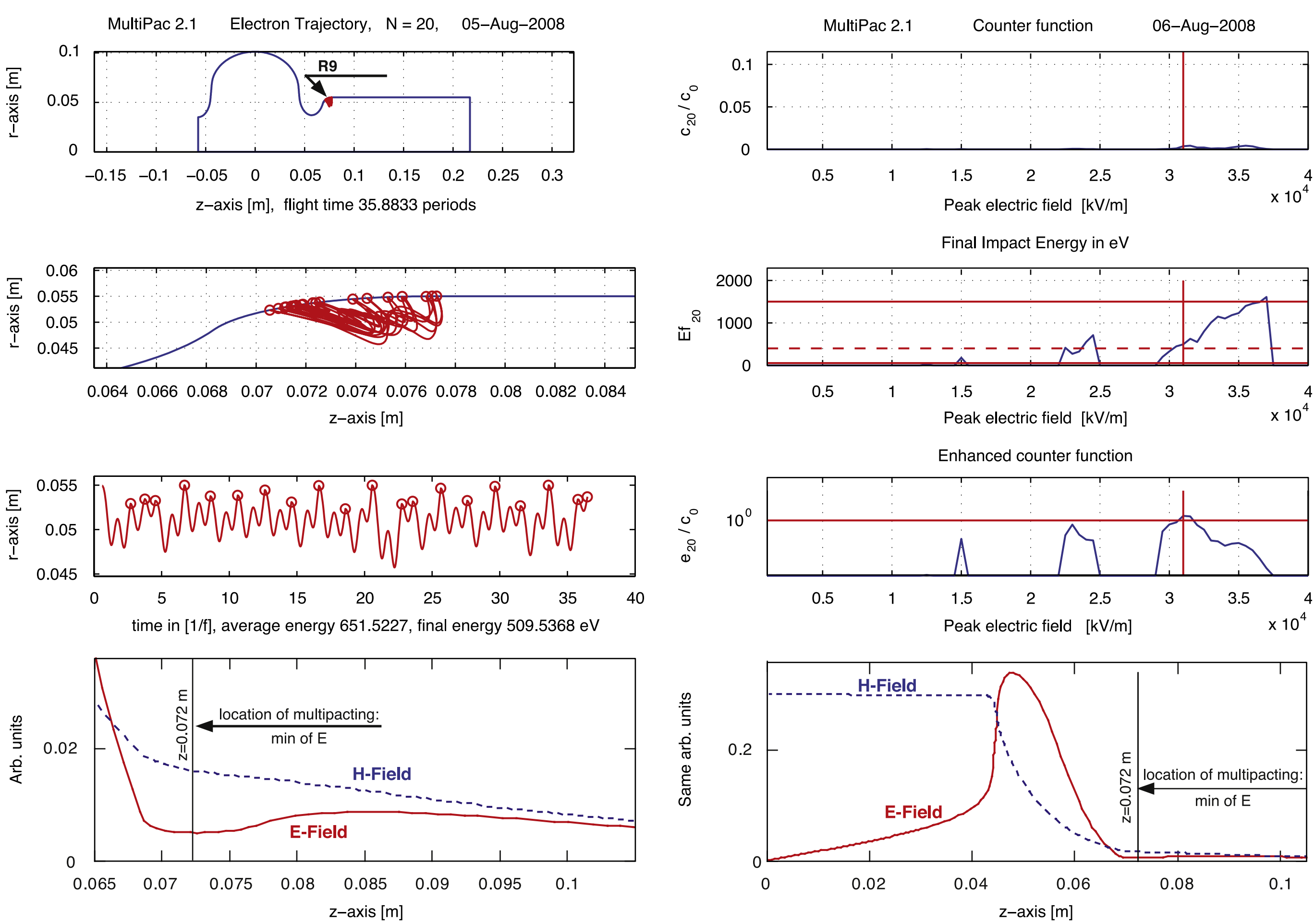

Fig. 2. MP simulation for a cavity having an inner corner rounded with $R = 9$ mm.

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