MULTIPACTOR IN MINIMUM ELECTRIC FIELD REGIONS OF TRANSMISSION LINES AND SUPERCONDUCTING RF CAVITIES*

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Abstract

Multipactor in beam-pipe transitions of superconducting RF cavities can be explained using RF potential well theory [1]. In this paper we present simulation results supporting this explanation for both RF cavities and transmission lines.

INTRODUCTION

Curved-shaped transition regions between a cavity and a beam pipe were thought to be multipactor-free. Thus recent experimental observations of multipactor (MP) in two such transitions in Cornell ERL injector cavity [2] and KEK Ichiro cavity [3] surprised experimenters. The possibility of multipacting in those geometries was later confirmed in computer simulations. Analyzing these cases we have noticed that the electric field along the cavity profile has a minimum at the locations of MP. We proposed an explanation based on the Gaponov-Miller theory [4]. According to the theory an electric field minimum is associated with the local potential well, thus attracting electrons. This creates conditions favorable for multipacting. More details can be found elsewhere [1]. To check this explanation, we performed MP simulations for cavity geometries with different transition shapes, which confirmed that multipactor is suppressed for transitions with no electric field minimum.

The potential well theory can be applied to transmission lines too. For example, Miller force was used in [5] to derive an analytic solution of electron motion in a coaxial line and also was invoked in discussion of MP in a waveguide iris [6]. This force can also explain drift of multipacting electrons from the waveguide midline to sidewalls, that was observed in computer simulations [7] and, in case of partial or full standing wave in a transmission line, migration of electrons toward the standing wave minimum. We explore electron migration in the latter case for coaxial line and rectangular waveguide later in this paper.

Simulation results presented here were obtained with computer codes MultiPac [8] (for cavity-to-beam-pipe transitions and a coaxial line) and XingRK4 [9, 10] (for a rectangular waveguide.)

MP IN CAVITY-TO-BEAM-PIPE TRANSITIONS

Figure 1 shows MP trajectories at the electric field minimum in the transition form the Cornell ERL injector cavity end cell to a beam pipe. The contour line of the geometry, shown in Figure 2, consists of elliptic arcs connected with tangential straight segments. *Ae, Be, Ai, Bi* 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; *Req* is the equatorial radius, *Rbp* is the radius of the beam-pipe.

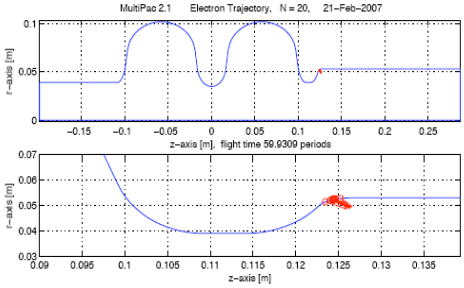

Figure 1: MP in the ERL injector cavity [2].

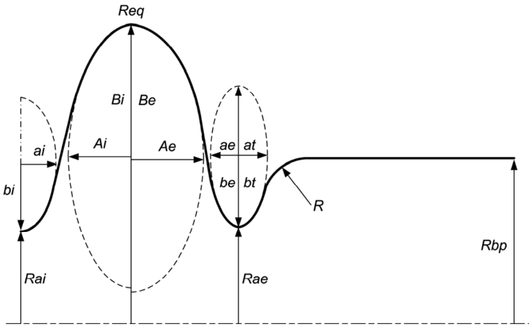

Figure 2: Geometry of the cavity-to-beam-pipe transition.

We have examined a transition from the end iris aperture *Rae* = 37 mm to the beam-pipe radius *Rbp* = 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 $E_{pk}/E_{acc} = 2.0$.

Figures 3 and 4 show dependence of the maxima of the enhanced counter function *A* on the radius *R* and corresponding values of the peak electric field *E*. Three sets of points correspond to three different MP bands. Analyzed values of field levels were in the range from 25 to 35 MV/m as it has the most distinct maximum of the function *A*. Two points from Figures 3 and 4 corresponding to *R* = 12 mm are further looked at in Figure 5. Two maxima of the normalized enhanced function e_{20}/c_0 and corresponding impact energies and trajectories are presented. These trajectories can be related to two kinds of MP: three-periodic for 25 MV/m, and two-periodic MP for 33.5 MV/m (with some deviations from exact periodicity). Both are located in the flat minimum of the electric field.

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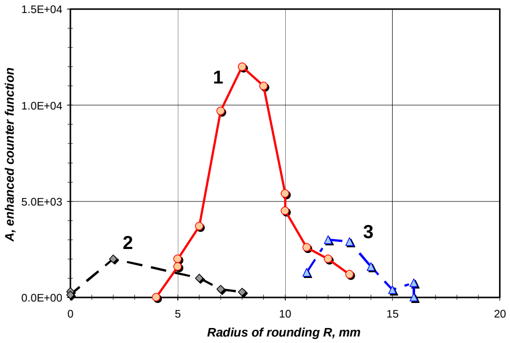

Figure 3: Dependences of maximum *A* on *R*.

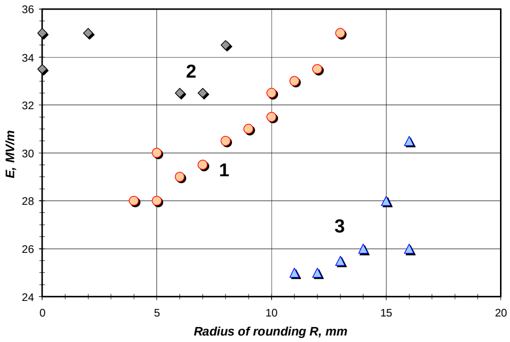

Figure 4: Dependences of *E* corresponding to max *A* on *R*.

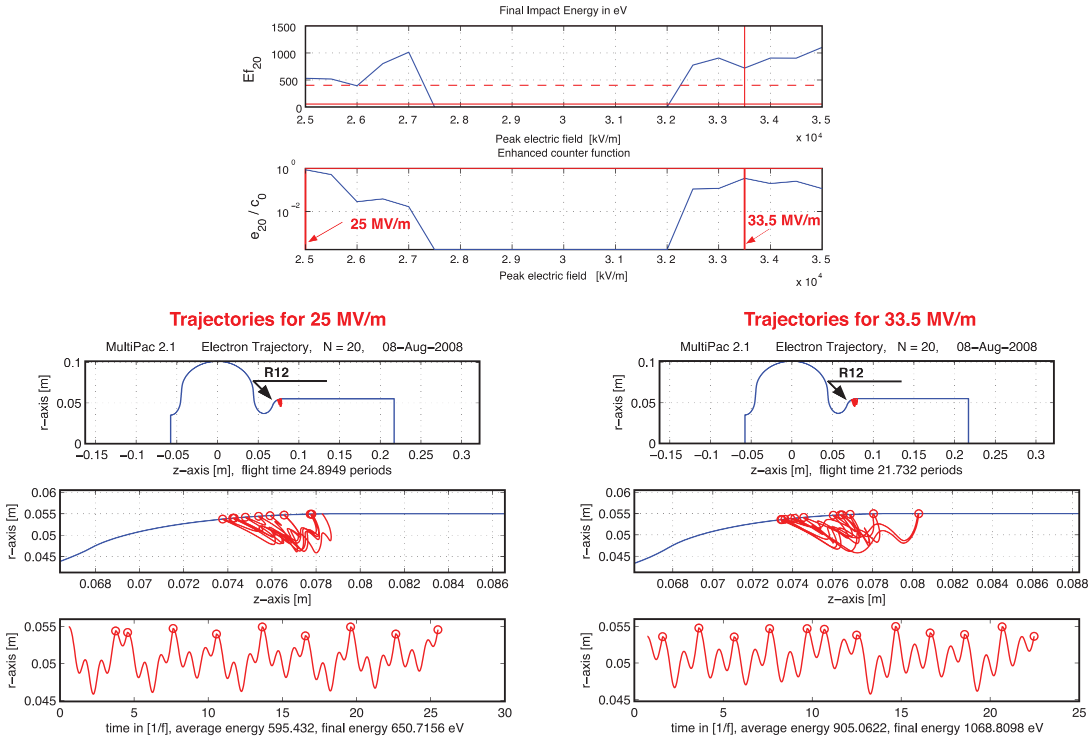

Figure 5: Three- and two-periodic MP at two different amplitudes of the peak electric field for *R* = 12 mm.

MP IN TRANSMISSION LINES

Two cases were studied: coaxial line and rectangular waveguide. With full standing wave conditions we have simulated trajectories of MP electrons along the transmission lines. In both cases particles were drifting toward the electric field minimum.

Multipactor in a half-wavelength long coaxial line with short boundary conditions at both ends was simulated at 1300 MHz in power ranges from 100 kW to 400 kW. One of these ranges is presented in Figure 6. A number of MP zones were found and for all simulated trajectories electrons were drifting from the maximum electric field in the middle of the line toward the minimum electric field at one of the ends. Figure 7 shows one of such trajectories.

A 1″ high by 5″ wide rectangular waveguide was simulated at 1500 MHz in the power range from 5 kW to 50 kW. Full standing wave was assumed with the electric field maximum at $z = 0$. Several MP zone were found and, as in the previous case, all electrons launched off the electric field maximum were drifting toward the minimum electric field. Figure 8 shows one of simulated trajectories.

CONCLUSIONS

Attraction of MP electrons to the minimum of electric field can be explained in terms of the potential well created in the RF field [4]. We would like to point out that MP near the cavity equator also exists near the minimum (zero) of the electric field. This is usually one-periodic MP. In the cases analyzed in this paper, we see more complex trajectories of MP electrons in the region of minimal E.

The fact that the MP electrons are attracted to a minimum of electric field gives us an insight into how to avoid this phenomenon. Namely, the multipactor-free transitions between cavities and beam-pipes should have shapes designed to avoid local minima of the surface electric field. In such transitions electrons, instead of being attracted to "calm corners," will drift in the direction of decaying field.

Similarly, in transmission lines with full or partial standing wave MP electrons experience a force directed toward the electric field minimum. In transmission lines with a non-uniform cross-section MP particles will tend to move to locations where the electric field magnitude is smaller. One could say that there is an "electron wind" blowing in the direction of lower electric field along a transmission line. This electron wind can be gentle (the drift is slow) if the field has a small gradient, for example near the field maximum. In this case it does not inhibit MP in high-field areas but only increases susceptibility thresholds there while simultaneously enhancing MP in lower-field regions.

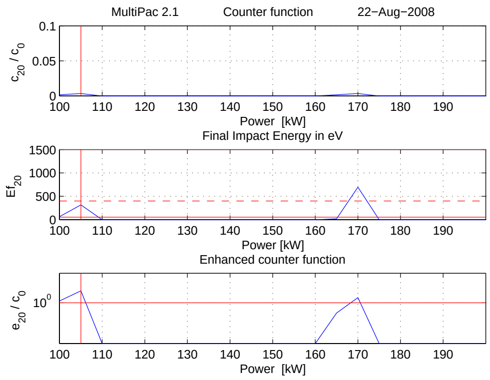

Figure 6: MP zones in power range from 100 to 200 kW.

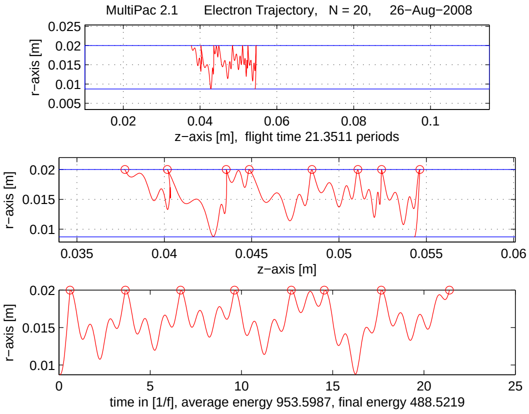

Figure 7: Trajectory of MP electrons in a coaxial line with full standing wave at 170 kW.

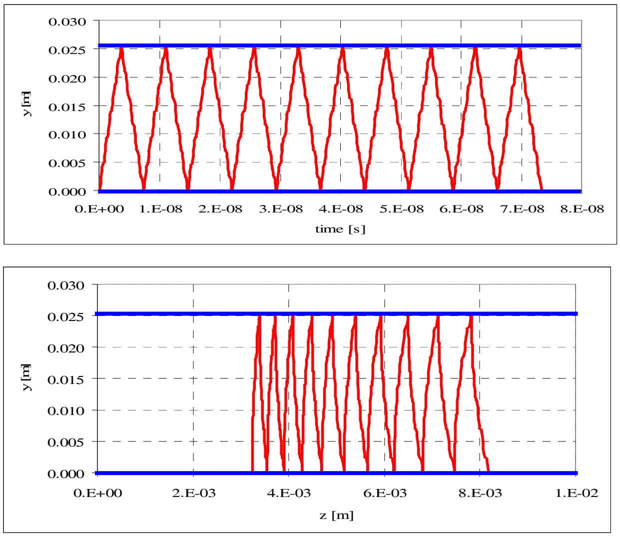

Figure 8: Trajectory of MP electrons in a rectangular waveguide with full standing wave at 36 kW.

ACKNOWLEDGEMENT

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