A 2D MULTIPACTOR SIMULATION CODE FOR RF COMPONENTS AND ACCELERATING CAVITIES

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Abstract

A code was developed in order to investigate multipactor occurrence in accelerating cavities and power coupler components, such as coaxial lines and RF windows. Resonant electron trajectories can be harmful or lead to lengthy conditioning, therefore an effort should be made to predict and reduce them at design stage. The present code directly uses electromagnetic fields computed by Superfish. In this paper, simulation results are given for several existing components and are compared with experimental results.

1 INTRODUCTION

Multipactor (MP) is a parasitic phenomenon that may occur while operating RF accelerator components. Phase and field level conditions exsist, for which electronic trajectories starting on a surface may become resonant. In such cases, an electron may return periodically to its starting position (1 point resonance) or may oscillate between n impact points on the surface of the device (n point resonance). Considering now the secondary emission coefficient δ of materials constituting the surface, and its dependence from the electron impact energy, particular trajectories may exhibit an electron multiplication rate greater than unity. This multipacting behavior prevents correct operation of the device since RF power is consumed by electrons, energy deposition on surfaces leads to heating and outgassing. In the case of superconducting RF cavities, transition to normal conducting state can be driven by multipactor. Analytical treatment of this phenomenon can be carried out for very simple geometries, but numerical simulation is required to investigate multipactor for any realistic design. A new code presented in this paper has been developed to study multipacting for any axi-symetrical RF structures. Simulation results have been first compared to experiments on various power couplers components and a set of superconducting cavities. A good agreement was found, be the structures multipacting or not.

2 CODE CAPABILITIES

2.1 Modeling

The present version of the code is restricted to axi-symmetrical geometries, and relies on Superfish codes package [1] for electromagnetic field solutions. This implies that any standing wave ratio condition can easily be simulated. The problem geometry is defined using basic elements such as line segments and ellipse arcs, so that the exact surface equation is used instead of discretized elements, to keep accuracy as high as possible. Secondary electron emission (SEE) properties can be defined for each surface element. SEE coefficient can be described by an analytical model or experimental data. No limiting phenomenon such as space charge effects or electron interaction with residual gas was taken into account.

2.2 Electron tracking

Since the main task of the code is to integrate equations of motions of an electron in an electromagnetic field, the numerical integration method must be chosen with care. A 4-5th order adaptative Runge-Kutta Method [2] is used for two reasons : several orders of magnitude variations of EM fields can exist between different regions of an RF structure, requiring a demonstrated robustness of the method ; trajectories can exhibit parts with a high curvature, dominated by magnetic field, asking for fine integration steps, and straight regions, E-field dominated, where accuracy goal can be reached with a rougher integration step. Computing time constraints calls for the adaptative capability of the integration method.

For each phase, field level and starting location, an electron is emitted and followed from an impact to the next. At each impact, labeled i, the SEE coefficient δ_i is computed according to the e^- energy and impact angle. An effective electron number N_i at impact is computed as $N_i = N_{i-1} \times \delta_i$ with the initial condition $N_0 = 1$. The calculation is dropped when one of these conditions are met : N_i is lower than N_{min}, of the order of 10^{-12}, or i exceeds the maximum number of impacts specified by the user. No special action is taken when the electric field at the electron starting point and phase is decelerating, since preventing its emission is not always justified (see §4.1) .

2.3 Performance issue

Since an extensive case study with a one percent or finer stepping for each three simulation parameters implies typically $10^6 - 10^8$ configurations, computing time can rapidly be a concern when trying to optimize a design by testing several geometries. To cope with this issue, a parallel version of the code was developed, that can be spread on a network of workstations. The present computing problem is favorable to parallelization on multiple computers using a master/slave scheme since every computation is independent from the other, thus no common memory is needed. A master program manages slave processes on remote computers sending them parameters and collecting the results. Network is kept low since this represents a small amount of data. As soon as a slave has returned its results, it can be fed with new parameters. This task management method provides load balancing in a straightforward manner. The portable PVM (Parallel Virtual Machine) [3] standard library has been used to work the parallelization out.

3 POWER COUPLER COMPONENTS

3.1 Coaxial lines

Coaxial lines are widely used as the main part of power couplers on SC cavities. In matched condition operation, a traveling wave (TW) propagates in the line. Multipacting conditions can be easily classified with their order which accounts for the number of RF periods between two impacts. As the RF power is increased, multipactor barriers are crossed corresponding to decreasing orders. Figure 1 shows simulated electron multiplication factor for a 61.6 mm diameter 50 Ω coaxial line at 1.3 GHz in the TW regime. Main barriers are those corresponding to trajectories impacting on external conductor only (one point MP). Scaling laws [4] show a dependence with the fourth power of coax external diameter for these barrier levels, indicating that choosing a larger diameter coax line helps reducing multipactor risks [5]. It should be noted here that multipacting electrons follow the RF wave.

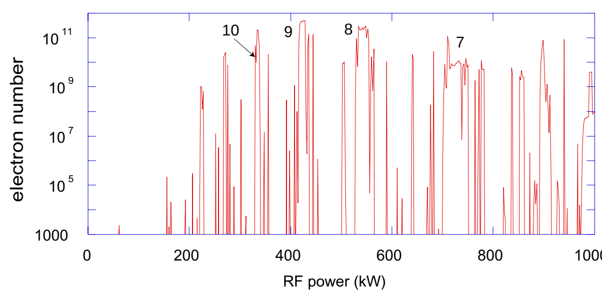

Figure 1: Multipactor simulation for a 61.6 mm diameter 50 Ω coaxial line at 1.3GHz, TW, limited to 50 impacts. Orders are indicated for main barriers

3.2 RF coaxial windows

Since RF windows are usually made of alumina, whose SEE coefficient can typically reach maximum values of 2 to 9, special care must be taken as to avoid electron multiplication in their vicinity. To reduce both surface charge buildup and the SEE coefficient of a window, a thin TiN coating is generally deposited on its vacuum side, inducing higher RF losses and complicating fabrication process. We illustrate here the case of the most simple coaxial window design, a 1.3 GHz self-matched $\lambda/2$ window, that was designed for a TTF coupler prototype [6]. It simply consists in a half wavelength thick alumina disk inserted in a coaxial line. Since MP electrons propagate along the wave in the coax, they hit the upstream side of the ceramic, and are multiplied according to the high SEE function of alumina. In contrast, e^- starting from the downstream side of the window will not experience this multiplication, thus electronic activity should reflect the MP characteristic of the bare coax. Figure 2 shows a comparison between experimental electron probe data and a simulation of the upstream side of this $\lambda/2$ window on a 61.6 mm 50 Ω coax. A good agreement is found for the most intense MP simulated barriers power levels which should be compared to those on figure 1. Thinnest barriers may not be observed experimentally since their width is smaller than fluctuations of the RF power source.

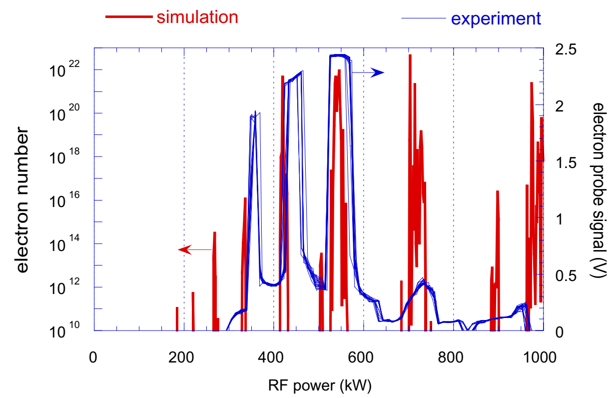

Figure 2: Multipactor simulation of a $\lambda/2$ at 1.3GHz, TW, limited to 50 impacts.

4 SUPERCONDUCTING CAVITIES

4.1 High intensity proton linac cavities

Medium β SC cavities are used as the main option for the high energy part of high intensity proton linacs needed by multiple applications. RF frequencies lie typically in the range 700-800 MHz, and expected accelerating fields should stand around 10 MV/m. First tests on three different 700 MHz $\beta = 0.65$ single-cell cavities have been carried out. They all have gone through the same fabrication and cleaning processes. On figure 3 are shown the tests results for the INFN/Milano elliptical cavity.

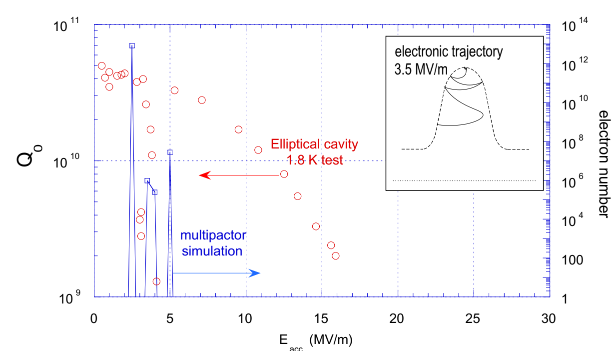

Figure 3: Comparison of elliptical cavity tests and simulation. A example of electronic trajectory is shown in the top right corner.

Reproducible electron activity was observed at well defined field levels, indicating a multipacting behavior. This MP activity in the region 2.5 - 5 MV/m is well reproduced by numerical simulations. Inspection of electron simulated trajectories shows that two points MP resonance takes place in the equator region of the cavity, where electron motion is dominated by magnetic field. Figure 3 illustrates this point for a trajectory starting at the iris, where the electric field and therefore electron emission probability is maximum. It is to be noted that in the equator region, electric field is so weak that it cannot prevent any about 2 eV electron from being emitted from the surface, even at decelerating starting phases.

CEA/Saclay [7] cavity presents a circular shape at the equator. Both simulation and RF measurements indicate that this design is multipactor-free as can be seen on figure 4. The third test was done on a assymetrical assembly of

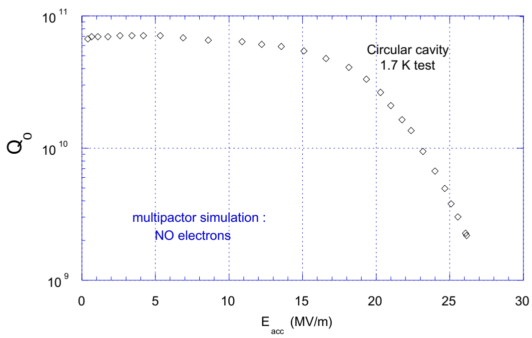

Figure 4: Saclay cavity tests results.

the two half end cells of the 5 cell APT cavity [8]. The equator has a circular shape, but the radii are 65 % and 85 % of the Saclay design equator radius. Electronic activity occured continuously on a wide range of accelerating field values as shown on figure 5, which could not be processed away even after He processing. Simulation indicates a MP resonance at 6.0 MV/m only. Although this computed barrier lies in the right range, simulation could not reproduce experimental behavior.

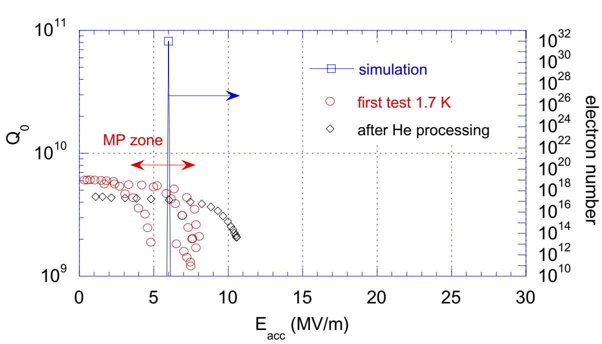

Figure 5: APT assymetric assembly tests and simulation.

4.2 *SEE function influence*

For each cavity, simulation was run with 3 different SEE functions caracterized by their maximum δ_{max} occuring for an impact energy of E_{max}. Going from cleanest to less clean Nb, the first two correspond to He processed Nb and baked Nb respectively [9]. No MP activity could be detected during the simulation with these functions. The third SEE function is an intermediate between water cleaned and baked Nb. Results for these δ are summarized in table 1.

Table 1: Simulated multipactor range for different SEE functions

E_{max}	δ_{max}	circular	elliptical	assymetric
350	1.25	no	no	no
350	1.48	no	no	no
350	1.8	no	2.5-5MV/m	6 MV/m

5 CONCLUSION

We have developed a new multipactor simulation code that has proven its ability to reproduce resonant behaviors for various RF accelerator components in standing or traveling wave regime. This code can be used to analyse test bench experiments and can be useful to investigate new RF window concepts and multipactor inhibition schemes.

ACKNOWLEDGMENTS

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