MULTIPACTOR SIMULATIONS IN AXISYMMETRIC AND NON-AXISYMMETRIC RADIO FREQUENCY STRUCTURES

M.A.Gusarova, I.V.Isaev, V.I.Kaminsky, S.V.Kutsaev, M.V.Lalayan, N.P.Sobenin, MEPhI, Moscow, Russia
L.V.Kravchuk, INR, Moscow, Russia

Abstract

A new computer code for simulation of multipacting phenomenon in axisymmetric and non-axisymmetric radio frequency (RF) structures is presented. Simulation results in various RF devices are compared with theoretical calculations and experimental measurements.

INTRODUCTION

Multipactor is an effect that occurs in radio frequency (RF) devises, when electrons accelerated by radio-frequency fields are self-sustained in a vacuum via an electron avalanche caused by secondary electron emission. Multipactor may lead to problems of the RF system such as damage of RF components. Therefore, design of accelerating cavities, input power couplers and other RF devices for the charged particle accelerators should provide the conditions of multipactor discharge elimination.

For the geometries having no axial symmetry the full 3D multipactor modelling is essential with electromagnetic fields non-symmetric pattern taken into account. The code MultP–M is a tool that allows the analysis of multipacting in fully 3 dimensional RF structures and the modification for multipactor suppression.

MULTP-M

MultP–M is the succeeding code for MultP [1, 2]. The latter was upgraded to get more functionality. The main window MultP-M is presented on Fig. 1.

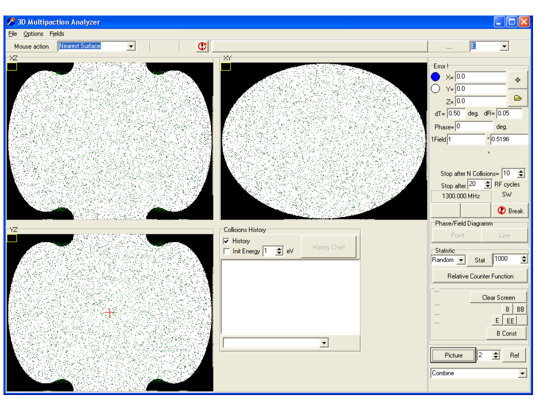

Figure 1: The main window.
Example: Ω- shape cavity.

The code MultP–M solves the non-relativistic equation of motion of electrons in time harmonic rf-fields. MultP-M provides different options of numerical study of electron multipacting:

- to track separate electrons;
- to track a group of electrons;
- to scan electric field levels and initial phases of electrons and to determine a possibility of resonance electron multipacting;
- to simulate multiplication of a number of randomly distributed electrons.

The resulting trajectories can be analyses by means of electron counter function and various statistics (statistics - particle counter, statistics - impact energy distribution, statistics - distribution of impact phases, statistics - the collision counter, statistics - finding trajectories with more than n impacts). The final decision whether multipacting is possible or not is up to the user.

EXAMPLES SIMULATION

In order to illustrate MultP-M usage let us consider several examples.

Axisymmetric Radio Frequency Structures

The accelerating elliptical shape cavity is good choice to illustrate multipactor simulation in axisymmetric radio frequency structures. Let us consider the simulation of multipactor in superconducting accelerating elliptical shape cavity with β=0.81 for Spallation Neutron Source [3]. Its model made in MultP-M is shown on Fig. 2.

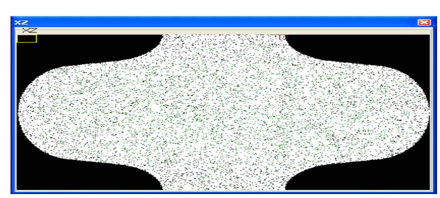

Figure 2: Geometry β=0.81 cavity in MultP-M.

Electromagnetic field distribution used for simulation had values defined for N_x=69 N_y=69 N_z=27 nodes. Electron energy providing SEY>1 was 50 to 1500 eV. Simulation made for 3000 initial particles. The results of simulation done by MultP–M are presented on Fig. 3 – 4.

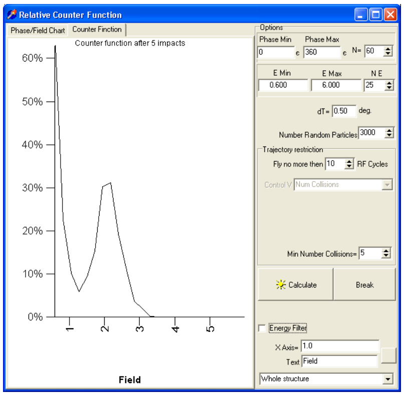

Figure 3: MultP-M, electron counter function; (normalized, 1 unit = 8.8 MV/m).

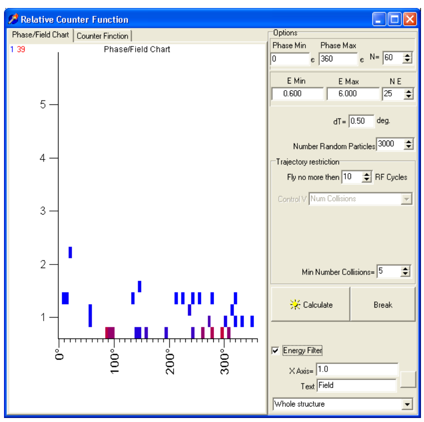

Figure 4: MultP-M, Phase/Field diagram; (1= 8.8 MV/m).

Counter-function graph (Fig. 7a) proves that for the electric field strength 1.2 to 2.8 relative units (correspond to 10 to 25 MV/m) a 5 to 35% of primary electrons preserve in structure. This means that these electrons have stable trajectories not decaying after 10 rf field periods. From “Phase/Field” diagram presented on Fig. 7b it is clear that resonant trajectories for field strength from the range mentioned above could exist for any field phase.

Separate stable electron trajectories for field strength 1.2 – 3.3 (10 – 30 MV/m) were found in cell equator area. These trajectories correspond to two-point multipactor. In case of field strength exceeding 2.175 (20 MV/m) electron impact energy is 2 – 13 keV, that is more than 1500 eV. Therefore cavity operation with field strength 10 – 20 MV/m is most dangerous with respect to multipactor. for fields stronger than 1.2 (about 10 MV/m) up to 1.6 (13 MV/m) resonant trajectories are found near equator. Electrons hit energy falls in dangerous range (50 to 1500 eV). The resulting discharge is two-point first order multipactor.

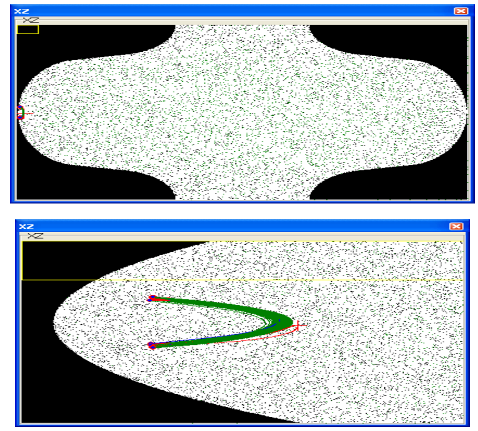

Figure 5: Resonant trajectories near cell equator

Resonant conditions for discharge are different in case of SEY more than one is provided for another electron energy range (150 to 750 eV) by cavity surface cleaning and cavity processing. Phase/Field diagram showed significantly less trajectories. Moreover these trajectories are found to be unstable and decaying after several field oscillations.

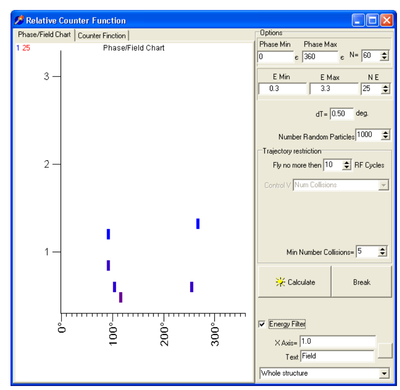

Figure 6: MultP-M, Phase/Field Diagram; (1= 8.8 MV/m).

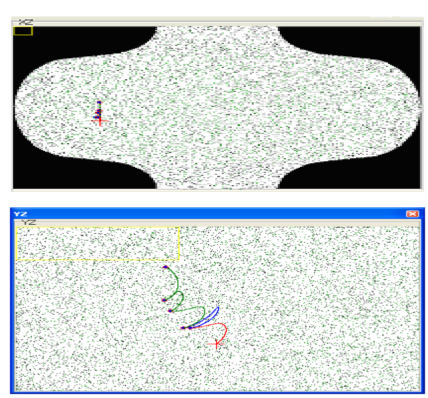

Figure 7: Multipactor electrons trajectories

So for the cavity made of niobium having SEY more tan one for energy span 50 to 1500 eV the two-point multipactor could occur in equator area at on-axis accelerating field strength Ez equal to 5 – 15 MV/m. Niobium cavity with well processed surface will have another electron energy span (namely SEY>1 for 150–750 eV). This cavity will be multipactor-free. This conclusion agrees with known data.

Non-Axisymmetric Radio Frequency Structures

Researches of multipactor in rectangular waveguides and its suppression ways.

For the geometries having no axial symmetry such as rectangular waveguide the full 3D multipactor modelling is essential with electromagnetic fields non-symmetric pattern taken into account.

Simulations were made for rectangular waveguide type WR650 with cross section 165 x 82.5 mm. Fig. 9 illustrates the simulation results obtained using MultP-M for peak electric field strength equal to E = 1.759x105 V/m, this corresponds to transmitted power P=200 кВт.

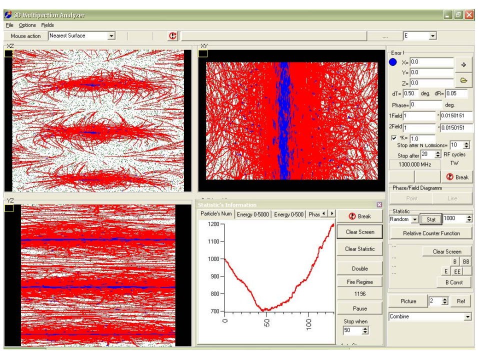

Figure 8: Multipactor in rectangular waveguide.

From Fig. 9 it is seen that electron avalanche occurs in the middle of waveguide wide wall. Particle counter statistics shows that electrons number starts to increase exponentially after 50 field oscillations. This indicates that in such conditions multipactor discharge could occur.

As the multipactor remedy in [4] the rectangular waveguide with groove at wide wall was proposed. This solution for 165 x 82.5 mm waveguide operated at 250 kW was studied using MultP-M.

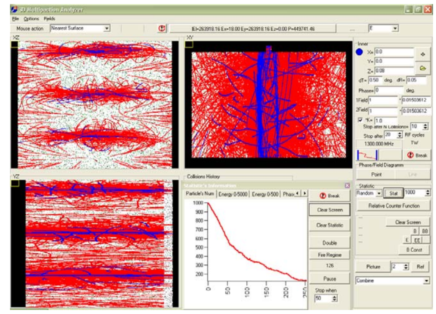

Figure 9: Waveguide with groove. Multipactor is suppressed.

Comparing the results for two designs analyzed (for example the electrons distribution patterns presented on Figs. 8 and 9), one could conclude that groove appreciably affects on electrons trajectories. Particle counter statistics shows lowering the electrons number thus indicating multipactor suppression.

SUMMARY

MultP–M is a convenient and reliable code designed for multipactor discharge simulations in RF devices having complicated 3D shape. The results obtained using MultP-M code agree with theoretical and experimental data. MultP–M makes the modification, optimization and design available for RF components used in the charged particle accelerators.

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