

MULTIPACTING SIMULATION IN RF STRUCTURES

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

Abstract

A new computer code for 3D simulation of multipacting phenomenon in radio frequency (RF) structures is developed. Simulation results in various RF devices are compared with theoretical calculations and experimental measurements.

INTRODUCTION

Design of accelerating cavities, input power couplers and other RF devices for the charged particle accelerators should provide the conditions of multipactor discharge elimination or suppression. The multipactor effect is a phenomenon in radio frequency (RF) devices (cavities, waveguides and others), where, under certain conditions, secondary electron emission in resonance with an alternating electric field leads to exponential electron multiplication, possibly damaging and even destroying the RF device.

Currently, there are three general approaches for suppressing multipactor discharge: conditioning of the components by the discharge, coatings and other surface treatments, and geometrical modifications. Proper design and geometry choice are the most powerful methods for multipactor suppression. Geometry modification results in electromagnetic field pattern changes. Latter leads to electrons trajectories distortion that breaks resonant conditions for multipactor discharge.

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

The main window MultP-M is presented on Fig. 1. The code was programmed using Object Pascal in Delphi environment.

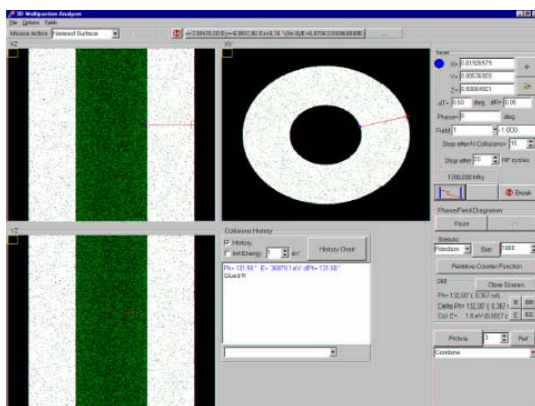


Figure 1: The main window. Example: single trajectory in a coax cavity.

MultP-M is the succeeding code for MultP [1, 2]. The latter was upgraded to get more functionality.

The code MultP-M is a tool that allows the analysis of multipacting in fully 3-dimensional RF structures. It solves the non-relativistic equation of motion of electrons in time harmonic rf fields. MultP-M does not contain a field solver, but it provides an interface to import the field-map from a text-file. The external field solver must be able to export field-maps to text-files, and it is strongly recommended that it uses a conformal mesh (mesh-points coincide with the boundary). MultP-M takes into account the RF device operation mode and allows simulation both for standing and traveling waves.

The resulting trajectories can be analysed 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). All parameters used in the calculation (field level ranges, SEY, initial energy of electron, electron emission phases, initial number of particles, minimal collision, frequency, and limitation of number of field periods for calculation) are assigned by user.

The final decision whether multipacting is possible or not is up to the user.

Testing of MultP-M

As the test several narrow rectangular waveguides were simulated. For the narrow rectangular waveguides it is possible to do the theoretical estimation of the electric field strength threshold providing the conditions to multipactor discharge (equation 1). Resonance sizes of discharge gaps $h(k)$ can be calculated using expression (2).

$$E_0 = \frac{\omega}{e} \sqrt{\frac{W_1 m}{2}} \quad (1) \quad h(k) = \frac{e E_0 k \pi}{m \omega^2} \quad (2)$$

Here h - distance between the wide walls of waveguide, k - multipactor order, W_1 - energy of primary electron providing $SEY > 1$. These equations are rather simple and leave out the electron's initial phase and velocity spread.

Two rectangular waveguides were studied namely copper waveguides of 70x3.5 mm and 70x2.1 mm operated on 1.3 GHz.

Fig. 2 illustrates direct modeling results for 70x3.5 mm waveguide presented in two cross sections in xy and yz planes. The region subject to multipactor electrons burst is marked with dark blue.



Figure 2: Multipactor discharge region in narrow rectangular waveguide.

The results of theoretical calculation of electrical field strength threshold and simulation done by MultP-M code are summarized in table 1.

Table 1: The Results of Theoretical Calculation of Electrical Field Strength Threshold and Simulation Done by MultP-M.

Narrow waveguide (normal conducting, Cu) 70×3.5 mm		
	Theoretical calculations	MultP-M
Field strength, kV/m	450	448
Order of the multipacting	5	5
Narrow waveguide (normal conducting, Cu) 70×2.1 mm		
	Theoretical calculations	MultP-M
Field strength, kV/m	450	447
Order of the multipacting	3	3

It is seen that the results are in good agreement within ±3 kV/m. This divergence can be caused by constant secondary electron emission yield value for impact energy 200 eV, used for analytical calculation, whereas the entire yield on energy dependence was used in numeric simulation.

EXAMPLES SIMULATION

In order to illustrate MultP-M usage let us consider accelerating cavity (standing wave mode) and ceramic window (traveling wave mode) analysis

RF Cavity

The superconducting accelerating cavity for Energy Recovery Linac [3] is good choice to illustrate multipactor simulation in standing wave device. Its model made in MultP-M is shown on Fig. 3.

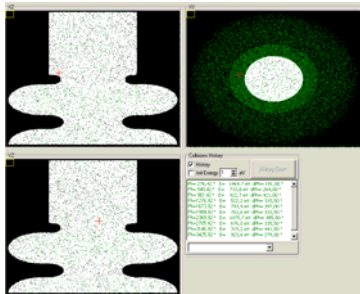


Figure 3: Cavity model in MultP-M.

Electromagnetic field distribution used for simulation had values defined for $N_x=100$ $N_y=100$ $N_z=300$ nodes. Electron energy providing $SEY>1$ was 50 to 1500 eV. Simulation made for 1000 initial particles. The results of simulation done by MultP-M are presented on Fig. 4 – 6.

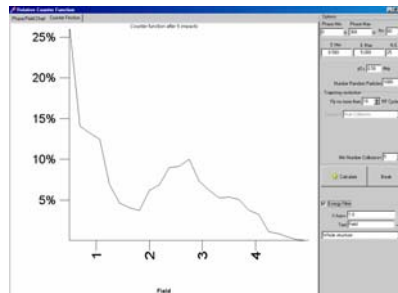


Figure 4: MultP-M, Electron Counter Function; (1= 11.635 MV/m).

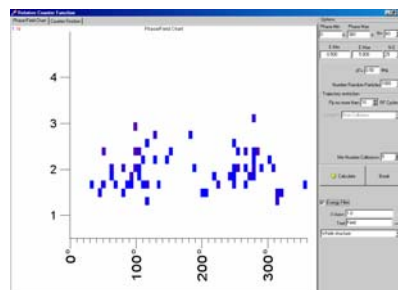


Figure 5: MultP-M, Phase/Field Diagram; (1= 11.635 MV/m).

From simulation results namely Electron Counter Function and Phase/Field diagram presented on Fig. 4. It is seen that about 10% of the primary particles remain in the structure for the field strength ~ of 21 - 36 MV/m (normalized value 1.8 – 3.1). Impact energy distribution study for this field strength range showed that electrons impact energy corresponds to SEY value exceeding one.

Electron trajectories thorough analysis showed the resonant conditions exist in rounded interconnection area between cell and drift tube. These trajectories are shown on Fig. 6 exist for electric field strength on axis ranging from 22 to 36 MV/m.

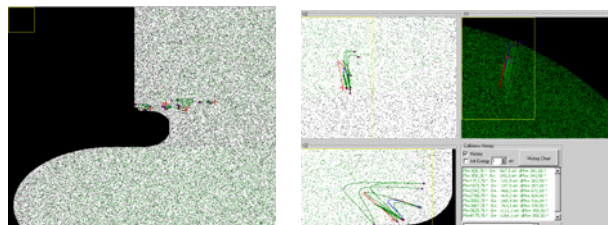


Figure 6: Resonance electron trajectories.

Summarizing the results described above one could conclude that this structure is subject to multipactor discharge on drift tube to cell interconnection region. Multipactor is most possible to occur for on-axis electric field strength range 22–36 MV/m. This result obtained using MultP-M code agrees with published data [3].

Ceramic RF-windows

Ceramic vacuum windows are traveling wave operating devices. It is to be noted that usually there are at least two different materials featuring diverse SEY values used in design. In order to simulate multipactor in this case MultP-M allows assigning different properties for all materials used in single model.

Some results of Energy Recovery Linac [4] RF-coupler cold window simulation using MultP-M code are presented below. The cold window model used for simulations included the ceramics, upstream coaxial line from warm window ($D=62$ mm, $d=28.8$ mm) and the downstream one to cavity ($D=62$ mm, $d=22.8$ mm).

Fig.7 - 8 illustrates the direct modeling results for multipactor discharge at 100 and 700 kW transmitted power.

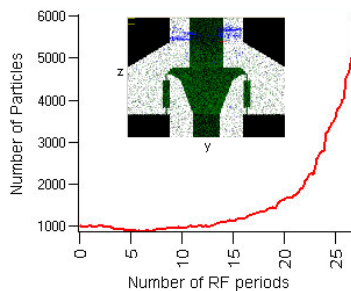


Figure 7: Statistical simulation results for ceramic window operated at 100kW.

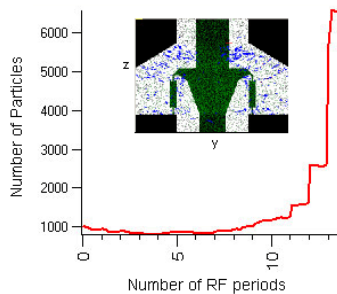


Figure 8: Statistical simulation results for ceramic window operated at 700 kW.

The statistical simulations were made using 1000 initial particles of 1eV energy. Secondary electron emission yield for metal was equal to 3 and for the ceramics was 6. Electromagnetic fields were obtained using Microwave studio run for model with 30.000 nodes. The area where multipactor occurs is marked with dark (blue) fill.

The simulation results showed that the multipactor could occur when power > 50 kW. It is seen, that for low power less than 200 kW the dangerous areas located close to coaxial waveguides Fig. 7 whereas the discharge in the ceramics vicinity could occur for higher power Fig. 8.

CONCLUSIONS

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

REFERENCES

- [1] L.V.Kravchuk, G.V.Romanov, S.G.Tarasov, "Multipacting Code for 3D Accelerating Structures", XX International Linac Conference, Monterey, California. 2000
- [2] M.A.Gusarova, V.I.Kaminskii, L.V.Kravchuk, S.V.Kucaev, M.V.Lalayan, S.G.Tarasov, N.P.Sobenin "Evolution of 3D simulation multipactoring code MultP", XX International Workshop on Charged Particle Accelerators, Ukraine, Alushta, 2007
- [3] S. Belomestnykh, V. Shemelin, "Multipacting-free transitions between cavities and beam-pipes", SRF 080415-01
- [4] 11. M.A.Gusarova, A.A.Zavadtsev, D.A.Zavadtsev, A.A.Krasnov, M.W.Lalayan, N.P.Sobenin," Input coupler development for superconducting cavity 500kW CW power feed", Problems of atomic science and technology, 2006, #3,P.101-103.