SIMULATION OF MULTIPACTING IN RF CAVITIES AND PERIODICAL STRUCTURES

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Abstract

The code for multipacting simulations in axisymmetrical RF cavities, periodical structures and coaxial lines is presented. Physical model includes secondary emission simulations and particle trajectory integration in realistic RF fields. The code calculates multipacktor voltage levels and discharge distribution. The paper contains simulation results for 180 MHz cavity of INP microtron-recuperator as well as measured data for this cavity demonstrating good agreement with the calculations.

1 PHYSICAL MODEL AND ALGORITHM

Physical model and algorithm consist of two parts. The first part is the calculation of electrons trajectories in electromagnetic fields. The second part is the surface phenomenons simulation such as secondary emission and back-scattering of electrons.

1.1 Electrons trajectories

Since the density of electrons is supposed to be small, trajectories of electrons are calculated by means of integration of motion equations in axisymmetrical external electromagnetic field without taking into account space charge distribution. The code SLANS [1] is used for geometry input, finite element mesh generation and calculation of RF field in the nodes of the mesh. If there is an external electro- and magnetostatic field, the codes SAM [2] is used for its calculation in the same nodes. Using node values, field is interpolated by using finite element method and electron trajectory is calculated by Runge-Kutte's method of integration. The calculation of electron trajectory continues until the collision with the surface.

1.2 Surface phenomena

When the electron collides with the surface, two phenomena take place secondary emission and back-scattering [3]. Both of them are taken into account. The distributions of back-scattering coefficient and secondary emission coefficient versus the energy of arrival electron and the angle of its velocity vector with respect to the surface were taken from [3] and modeled by analytical functions for each type of material.

After each collision the decision about back-scattering of electron is made and the number of secondary electrons is calculated. The decision is made after comparison of the value of back-scattering coefficient for this collision with random number from the range [0;1]. If the random number is less then the value of back-scattering coefficient, the electron is scattered back. Back-scattered electrons have the same energy as arrival one and the opposite direction.

The number of secondary electrons is calculated using following procedure. If acts of emission of secondary electrons are supposed to be independent on each other, the process of emission can be described in term of Bernulli model of random processes [4] and then the probability of emission of n electrons is

$$P_n = \frac{(F\delta)^n}{n!}\exp^{-F\delta} \qquad (1)$$

where δ - value of secondary emission coefficient for each collision, i.e. for the energy and the angle of the arrival electron, F - enhancement factor, which depends on the material and the condition of the surface. To determine the number of secondary electrons, a random number x from the range [0;1] is compared with value

$$x_k = \sum_{n=0}^{k} P_n \qquad (2)$$

for k =0,1,2,... If x more then x_{k-1} and less then x_k, k is supposed to be the number of secondary electrons for this collision.

The energy and angular distributions of secondary electrons were taken from [3] for each type of material. Using those distributions, two equations are solved, to get the energy and the angle of each secondary electron:

$$\int_0^{E_2} F_E(E)dE = x_E \qquad (3)$$

$$\int_0^{\Theta_2} F_\Theta(\Theta)d\Theta = x_\Theta \qquad (4)$$

where E_2 - the energy of the secondary electron, Θ_2 - the angle between the secondary electron velocity vector and the normal vector to the surface in the point of collision, $F_E(E)$ and $F_\Theta(\Theta)$ - the energy and angular distribution of secondary electrons, x_E and x_Θ - random numbers from the range [0;1].

In our model the process of back-scattering and secondary emission is assumed to have no time delay between impact and scattering or emission because of in reality its values are negligible.

2 THE COMPUTER CODE MPS

Based on described above methods and algorithms, codes MPS (MultiPacting Simulation) was developed and tested.

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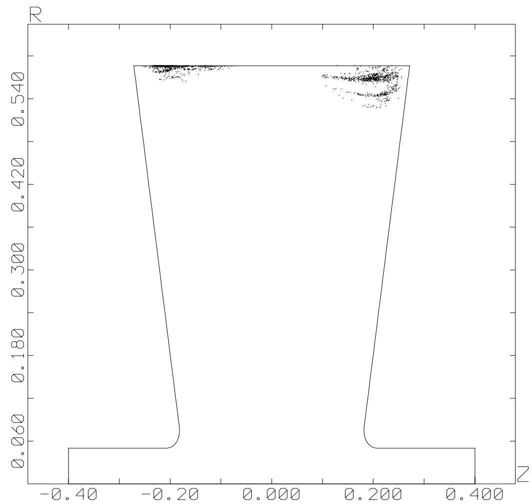

Figure 1: The geometry of 180 MHz cavity for microtron-recuperator and electrons inside.

To simulate multipacting in axisymmetric device, this code is run after saving data from SLANS and SAM to files. The following initial parameters have to be defined, before the start of the calculation:

- radio-frequency
- normalization of field in term of peak voltage for cavity or power for travelling wave structure
- materials of surface
- enhancement factor for each material
- elements of surface, where initial electrons will start
- number of initial electrons
- initial phase shifts of electrons
- number of RF-cycles to calculate
- step of integration

During the process of calculation, it is possible to monitor electrons dynamics inside the device and behavior of regions of multipacting in first output window (see Figures 1 and 4) and the time dependence of the number of electrons in the second output window(see Figure 2). If the number of electrons are increasing dramatically, the multipacting is supposed to take place in such a device under defined conditions.

3 TEST RESULTS

A few final tests were performed to check the code:

- Two parallel plates with homogeneous electric field
- 430 MHz E_{010}-mode toroidal cavity
- 180 MHz E_{010}-mode cavity for microtron-recuperator

3.1 Two parallel plates

Series of calculation were performed for two parallel plates with homogeneous electric field between plates:

$$E_z(t) = \frac{U}{d}\cos(2\pi f t) \tag{5}$$

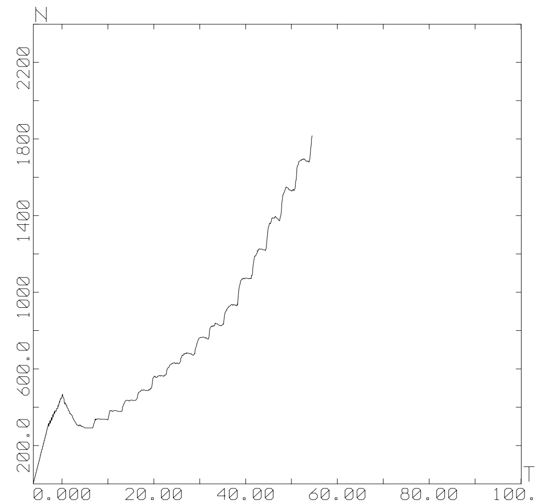

Figure 2: The time dependence of the number of electrons in the cavity.

to determine multipacting zones on the parametric plane $(U; fd)$, where U - peak voltage between the plates, f - frequency of voltage, d - gap between the plates. Two zones was determined for two values of enhancement factor 1.5 and 2.0. This two zones and the experimental data [5] are shown on the Figure 3. The experimental data are presented by three curves: 1 - initial, 2 - intermediate, 3 - final. Each curve is for different time of discharge process, dur-

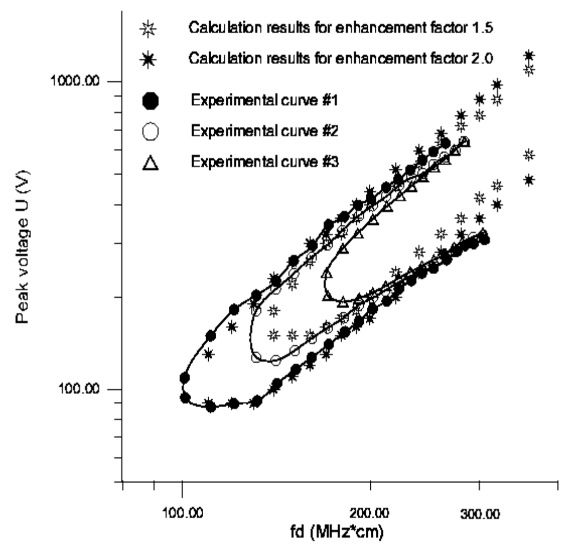

Figure 3: The results of the experiment and the simulation for parallel plates.

ing which the enhancement factor is getting smaller until the constant value is set up (curve 3). The Figure 3 demonstrates a good agreement between the experiment and the simulation for parallel plates.

3.2 Toroidal cavity

Simulation of multipacting in the 430 MHz E_{010}-mode toroidal cavity (see Figure 4) was made under various values of voltage along the axis, which is

$$U = \int_{-\infty}^{\infty} E_z(z)dz \quad (6)$$

The multipacting zone was determined for two side high

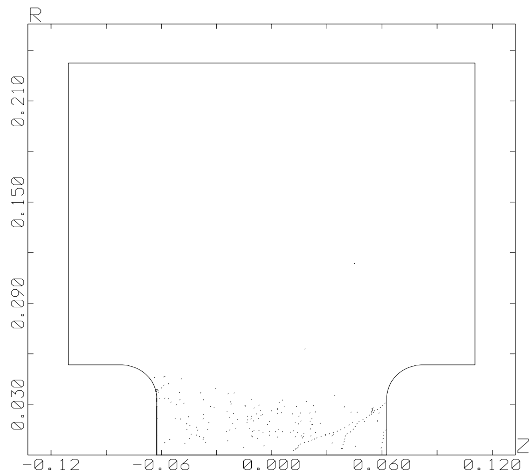

Figure 4: The geometry of 430 MHz toroidal cavity and electrons inside.

order multipacktor in the central gap. Obtained results were compared with measurements of electron current in the central gap under various axial voltage [6], which were carried out by using Faraday pick-up. The result of comparison is presented on the Figure 5.

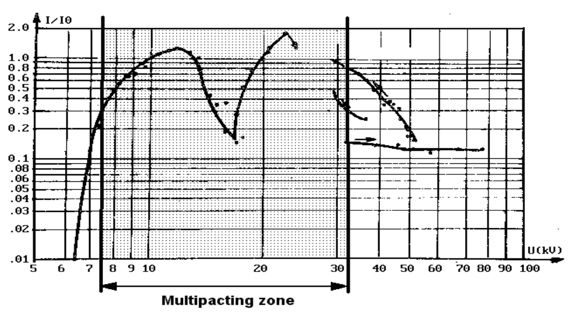

Figure 5: The results of measurement and calculation in the toroidal cavity.

The dotted area represents the calculated multipacting zone and the curve represents measured Faraday pick-up's current versus axial peak voltage. A good correlation between the calculation and the measurement can be seen.

3.3 Cavity for microtron-recuperator

The simulation of the multipacting in the 180 MHz E_{010}-mode cavity for microtron-recuperator [7] (the geometry of the cavity is shown on the Figure 1) was made under various values of axial voltage. On the Figure 1 the region of multipacting and the discharge distribution can also be seen as electrons cloud near the outer wall.

Multipacting was found for a few levels of axial voltage. Each levels corresponds to a different order of multipacting (see the Table).

n	F_m	U(kV)
1	0.99	930
2	1.33	550
3	2.26	370
4	3.7	280

Where n - order of multipacting, F_m - minimal enhancement factor for which multipacktor still take place under the axial voltage - U. The order of multipacting can be determined visually during the observation of electron dynamics or after analysis of time dependence of the number of electrons.

For this cavity the measurement of axial voltage levels was carried out [8] and following results were obtained. At first the multipacting levels were 380...580 kV and 800...1000 kV. The first zone disappeared after few minutes of RF processing. It appeared again after opening of the cavity but was processed easily as well. The second zone remained all the time, only it got very weak and narrower: 900...950 kV. As one can see, the comparison of the measurement with the calculation demonstrates a good agreement between them for the first and the second order multipacktors. The measurements of the higher order multipacktors were not carried out because of in reality the enhancement factor is not enough high to get the multipacting.

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5 REFERENCES

[1] Myakishev D.G. and Yakovlev V.P., "An Interactive Code SuperLANS for Evaluation of RF-cavities and Acceleration Structures," Proceedings of IEEE Particle Accelerator Conference, May 6-9, 1991, V.5, pp.3002-3004.

[2] M.A.Tiunov, B.M.Fomel and V.P.Yakovlev, "Computer-Aided Electron Gun Design," Proceeding of the XIII International Conference on High Energy Accelerators, August 7-11, 1986, V.1, pp. 353-355.

[3] I.M.Bronshtein and B.S.Fraiman, "Secondary electron emission," Nauka Edition, Moscow, 1969.

[4] S.M.Rytov "Introduction to Statistical Radiophysics", Nauka Edition, Moscow, 1978.

[5] H.Tamagawa, "On the Mechanism of the High Frequency Vacuum Discharge," ETJ of Japan, June 1957, pp. 42-46.

[6] I.K.Sedlyarov and V.D.Shemelin, "Resonant Radio-Frequency Discharge in Toroidal Cavity," Preprint INP9-73, Novosibirsk, 1973.

[7] V.S.Arbuzov et al., "RF System of the CW Race-Track Microtron-Recuperator for FELs," Proc. of the 1993 Particle Accelerator Conference, V.2, pp 1226-1228.

[8] V.G.Vesherevich and I.K.Sedlyarov, BINP, Private Communication, 1996.