Dynamics Analysis of Particles in Coaxial Lines Loaded Ceramic window

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Abstract: Multipacting is electron discharge that occurs in components where operate with RF high-power electromagnetic fields. In this paper, we will study the motion characteristics of particles in the coaxial structure with a ceramic window. A Monte Carlo algorithm is used to track the secondary electron trajectories and study the multipactor scenario on the surface of a ceramic window by using 2-D particles trajectory code. By studying the motion of particles, we can provide guidance for suppressing secondary electron multiplication in coaxial waveguide loaded ceramic.

Keywords: Ceramic, Monte Carlo algorithm, Coaxial line

INTRODUCTION

The multipactor effect is a resonant vacuum electron discharge that appears in vacuum devices operating with RF high- power electromagnetic field [1]. This phenomenon is present in many different situations, such as RF satellite payload [2][3][4], particle accelerators, klystrons, or cyclotrons [5]. When free electrons in the device get synchronized with the RF electric field and impact against the metallic walls of the component with enough energy to release secondary electrons from the surface. The growth in the electron population in the device can lead to one or several discharges. These discharges have several negative effects that degrade component performance. Thus, all of these leads to remarkable power losses and heating of the wall, so that it becomes impossible to increase the fields by raising the incident power [6]. A schematic of a simple hollow cylindrical ceramic window is shown in Fig.1. the ceramic window and coaxial waveguide are always concentric.

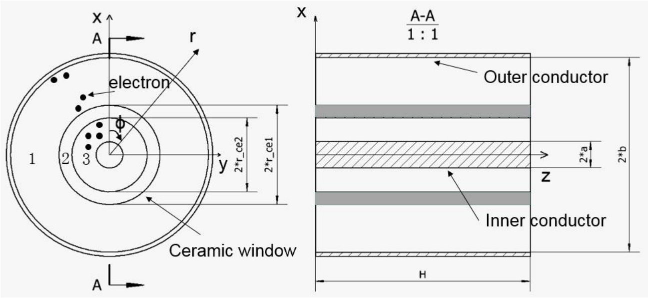

Fig. 1. Hollow cylindrical ceramic window in the coaxial line

The structure considered is a coaxial line with an outer conductor radius $b = 46mm$ and an inner conductor radius $a = 6.25mm$. The length of the coaxial line is $H = 100mm$. The hollow cylindrical ceramic window with an outer radius $r_{ce1} = 23.5mm$. And an inner radius $r_{ce2} = 17.5mm$. The structure is divided into three regions. The region 1 is between the outer conductor and the ceramic, which filled with a vacuum at $r_{cel} < r < b$; the region 2 is the dielectric region at $r_{ce2} < r < r_{ce1}$; the region 3 is between the ceramic and inner conductor, which also filled with a vacuum at $a < r < r_{ce2}$.

THEORY OF THE MULTIPACTOR

This article only considers the main mode of the coaxial line TEM mode. Thus, the amplitude of the electric field will be inversely proportional to the distance from the center of the line. Considering the symmetry of the structure, there will be no dependence on the angle around the coaxial axis, which means that the circumstance can be studied as a two-dimensional problem. Denoting by f the frequency. The electric field can be written as:

$$\mathbf{E}_1 = \frac{U_0}{x\left[\ln\left(\frac{b}{a}\frac{r_{ce2}}{r_{ce1}}\right) + \frac{1}{\varepsilon_r}\ln\left(\frac{r_{ce1}}{r_{ce2}}\right)\right]} e^{-j\beta z}\mathbf{e}_x, \quad r_{ce1} < x < b \qquad (1)$$

$$\mathbf{E}_2 = \frac{U_0}{x\varepsilon_r\left[\ln\left(\frac{b}{a}\frac{r_{ce2}}{r_{ce1}}\right) + \frac{1}{\varepsilon_r}\ln\left(\frac{r_{ce1}}{r_{ce2}}\right)\right]} e^{-j\beta z}\mathbf{e}_x, \quad r_{ce2} < x < r_{ce1} \qquad (2)$$

$$\mathbf{E}_3 = \frac{U_0}{x\left[\ln\left(\frac{b}{a}\frac{r_{ce2}}{r_{ce1}}\right) + \frac{1}{\varepsilon_r}\ln\left(\frac{r_{ce1}}{r_{ce2}}\right)\right]} e^{-j\beta z}\mathbf{e}_x, \quad a < x < r_{ce2} \qquad (3)$$

And the assumption that the position charge on the hollow cylindrical ceramic is uniformly distributed on the surface. This assumption leads to the simple form of equation (6) by Gauss's low. Then it is assumed that the electron dynamics is governed by the Newton-Lorenz equation (5) using the Runge-Kutta method to compute electron trajectory.

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$$\frac{\partial^2 \mathbf{l}}{\partial t^2} = \frac{-e}{m}\left(\mathbf{E}_i + \boldsymbol{E}_{dc} + \frac{\partial \mathbf{l}}{\partial t} \times \mathbf{B}_i\right) \tag{4}$$

$$\mathbf{E}_{dc} = \frac{eN}{2\pi\varepsilon_0 xH}\mathbf{e}_x \tag{5}$$

The equation of motion is solved numerically to compute the trajectory of the emitted electrons. The simulation process is shown in Fig.2

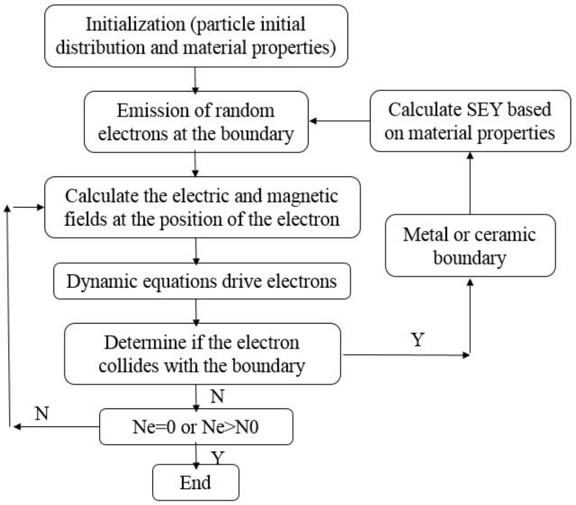

Fig.2 Flowchart of the full design

SIMULATION RESULTS

The simulation runs presented that had 10 seeded particles, with half of them launched from the surface of the outer conductor, and half of them launched from the inner conductor's surface. All the particles have random velocity (the average energy of electrons $W_0 = 3.2eV$) and the random initial emission phase θ_0 . Moreover, the initial electrons are evenly distributed on the surface

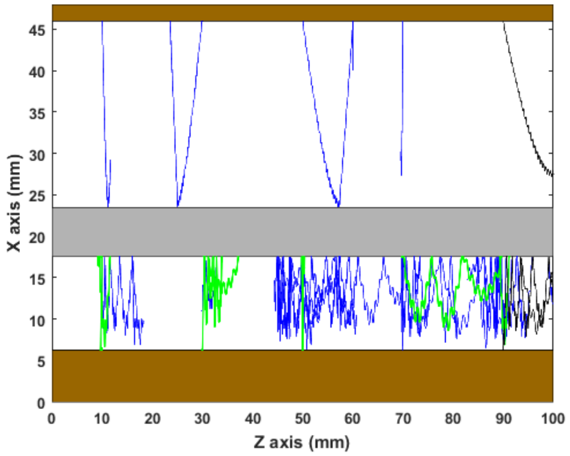

Fig.3 Particle trajectory map at times T=30 cycles. The initial particle Ne=10, transmission power P=200kW, and frequency=1.3GHz.

Fig.3 and Fig.4 show that the electron's trajectories with times T=30 cycles and we recorded the trajectories of the particles. And the electron trajectories are shown in a 2-D map for each run, showing paths in different colors, which depending on the position where the electron disappears due to the collision. The blue line represents the electrons that are still moving in the coaxial line. Redline represents the disappearance of electrons when the electron collides with the outer or inner conductor. The light cyan line stands for the disappearance of electrons when the electron collides with the surface of the ceramic window.

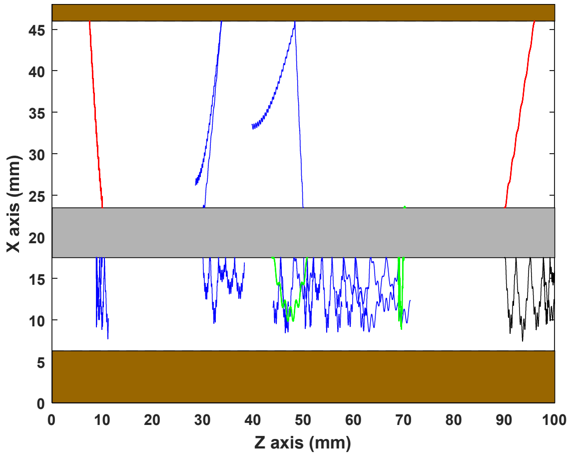

Fig.4 Particle trajectory map at times T=30 cycles. The initial particle Ne=10, transmission power P=200kW, and frequency=1.3GHz.

CONCLUSION

Using 2-D particles trajectory code, we can simulate the motion of particles in the coaxial line loaded ceramic window at any time, which can directly analyze secondary electron multiplication in coaxial waveguides. To provide guidance for effectively suppressing secondary electron multiplication.

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REFERENCES

[1]. Vaughan. J, Multipactor, IEEE Trans. Electron Devices, Vol.35, No.7, pp.1172-1180, July 1988.

[2]. Semenov, V. E., Rakova, E. I., Anderson, D., Lisak, M. and Puech, J., Phys.Plasmas 14, 033501 (2007).

[3]. Sazontov, A. G. and Nevchaev, V. E., Phys. Plasmas 17, 033509 (2010).

[4]. Frotanpour, A., Dadashzadeh, G., Shahabadi, M. and Gimeno, B., IEEE Trans. Electron Devices 58, 876 (2011).

[5]. Saito, Y., IEEE Trans. Dielectr. Electr. Insul. 2, 243 (1995).

[6]. Padamsee, H., Knobloch, J., Hays, T., RF Superconductivity for Accelerators, Wiley, inc., New York, 1998.