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DIFFERENT COUNTERMEASURES OF ELECTRON AMPLIFICATION IN THE PHOTOCATHODE UNIT*

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Abstract

Superconducting radio frequency (SRF) structures may be subjected to electron multipacting (MP). The electrons emitted from one of the structure's wall, under certain conditions, are accelerated by the RF field, thereby they may impact the wall again based on the field pattern in the structure. Accordingly the number of electrons increases exponentially caused by secondary electron emission [1]. The latter depends on the secondary emission coefficient of the surface material and the electron trajectory in the device under study [2]. This phenomenon limits the accelerating gradient in the cavity, moreover, it might cause impair of RF components and distortion of the RF signal. Therefore, there should be an efficient countermeasure to suppress MP in order to boost the performance of the SRF gun. In this paper, three techniques of suppression of the electron cloud from the vicinity of the cathode, such as DC-bias, simple geometric modification of the cathode and microstructuring of the cathode's surface, in the Rossendorf SRF gun are presented. The simulation has been done using CST Microwave Studio® (CST MWS) and CST Particle Studio® (CST PS) [3, 4]. Eventually, the efficient suppression method would be chosen for this particular case.

INTRODUCTION

The superconducting radio frequency gun (SRF gun) is in operation since 2007 at Helmholtz-Zentrum Dresden-Rossendorf (HZDR). Yet, the SRF gun is subjected to electron multipacting (MP). This phenomenon is a serious problem that limits the accelerating gradient in the cavity. A new design of the SRF gun is under investigation that shall allow the SRF gun to operate up to the desired electric peak field 50 MV/m. The complete CST MWS model for the Rossendorf SRF gun is visualized in [5]. In order to increase mesh resolution, the structure is further simplified. The simplified model consists of a niobium half-cell cavity, a copper cathode and a choke filter as illustrated in Fig. 1. The normal conducting photocathode is inserted at the circular end of the niobium half-cell cavity with, 2 mm gap for thermal and electrical insulation. Due to this coaxial line structure, MP is highly suspected in the cathode region. Previously, we computed MP for Rossendorf SRF gun numerically and the results are presented in [2]. Moreover, from the HZDR experiences, high MP current is measured in the cathode unit. Due to this effect the RF energy is absorbed from the cavity. This leads to significant power loss and makes it unfeasible to raise the accelerating gradient by increasing the incident power. The numerical results are in good agreement with experimental values. Hence it is crucial to avoid MP from the structure. Here, we present three possible remedies to suppress MP:

- DC Biasing Voltage (Static Electric Perturbation)
- Geometric Modification (Frusto-Conical Cathode)
- Microstructure of the Cathode's Surface (Anti-Multipactor Grooves)

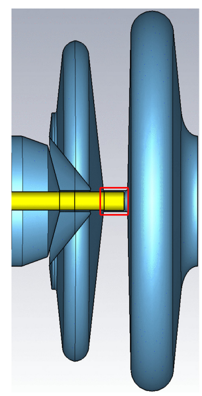

Figure 1: A simplified model of the SRF gun. The red box indicates a critical region where MP may occur.

MULTIPACTING SUPPRESSION TECHNIQUES

The frequency and the corresponding electromagnetic (EM) field pattern are calculated using the eigenmode solver in CST MWS. Sufficient mesh resolution and correct boundary conditions of the simulated model are significant in order to have accurate results. Perfect electric boundary at the surface and perfect magnetic boundary conditions at the end of the structure are specified. Two symmetry planes modeled by magnetic boundary condition are applied that reduce the calculation time by a factor of 4. Furthermore, CST MWS provides enhanced fast perfect boundary condition technique to increase the accuracy. The particle-in-cell (PIC) solver in the CST PS does not support tetrahedral mesh. Therefore, to avoid interpolation problem, a hexahedral mesh is used for EM field and MP calculation.

Subsequently, in order to track the trajectories of the particles in the field, the calculated EM field is imported to the PIC solver in CST PS internally. There are two major conditions for MP: a secondary electron emission yield (SEY) of the impact surface material larger than one and certain resonant conditions of the electron trajectories in the structure. The initial particle is assumed to emit from the surface of the cathode according to Gauss emission model. The initial

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particle energy is 2 eV. Furman's secondary emission model which is implemented in CST PS is used to calculate the secondary electrons, see Fig. 2.

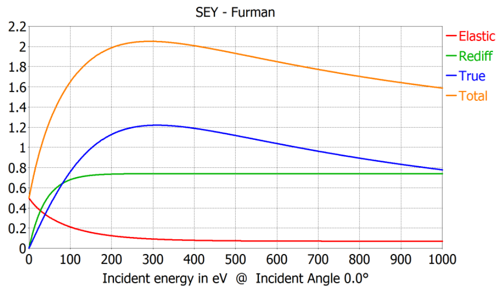

Figure 2: Furman model of secondary emission yield as a function of impact energy for a copper surface.

DC Biasing Voltage (Static Electric Perturbation)

The idea of DC biasing voltage is to perturb the resonant conditions of the trajectory by developing a repelling force. A detailed analysis of this method to suppress MP is discussed in [6, 7]. There is also a numerical solution for optimal suppressing DC voltage and it is stated as follows:

$$E_{DC}(r,z) = \frac{V}{ln\frac{b}{a}}\frac{1}{r}\,, \tag{1}$$

where b and a are the outer and the inner radii of the structure and (r, z) is a field point in a cylindrically symmetric structure. The suppressing DC voltage satisfies the following general scaling law [7]:

$$V \sim dZf\,, \tag{2}$$

The simulation has been performed in two ways: defining the voltage directly at the cathode and importing an electrostatic field to the cathode region after computing it separately. In both cases the results are similar. The results are achieved by varying the suppressing DC voltage in the range of 15 to 500 V. As it is illustrated in Fig. 3, MP is totally suppressed from the vicinity of the cathode within 100 V after 1.5 ns. It could be also sufficient to supply 50 V to the device in order to suppress MP; however, it requires further investigation to match the numerical and experimental study.

Geometry Modification: Frusto-Conical Cathode

The other attempted method is a slight geometrical modification of the cathode. For geometric simplification, the cathode model is cut into two parts. The critical area is the first section of the cathode which is nearby the end of the half-cell. In the present work, we have studied the effect of frusto-conical cathode on MP and the model is shown in Fig. 4. Due to the shape of the cathode, there is a heterogeneous field distribution. Electrons are considered to be eliminated where the electric field strength is weak. However, certain electrons fly to nearby the end of the half-cell where the secondary electrons are gaining enough energy to grow

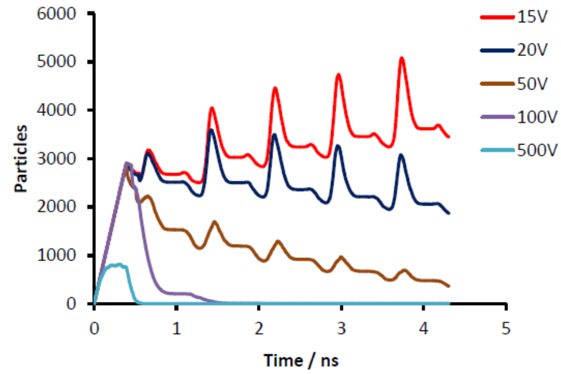

Figure 3: Number of Particles after 5 ns by varying biasing DC-voltage to the cathode.

exponentially. In order to have a better understanding of the effect, at least three cases of the geometry development are listed in Table 1. The existing radius of the cathode is 5 mm. As it is displayed in Fig. 5, there seems to be a promising

Table 1: Geometric Parameters for Frusto-conical Cathode

Radius of the cathode	The first part of the cathode	The second part of the cathode
Top - r_{t1}	5 mm	5 mm
Bottom - r_{b1}	2.5 mm	2.5 mm
Top - r_{t2}	5 mm	5 mm
Bottom - r_{b2}	2.5 mm	5 mm
Top - r_{t3}	5 mm	5 mm
Bottom - r_{b3}	4 mm	5 mm

result in the second geometry setup after 10 ns simulation time. Yet the particles start to increase after 11.5 ns because the surviving particles reach the top of the cathode where they gain an adequate energy.

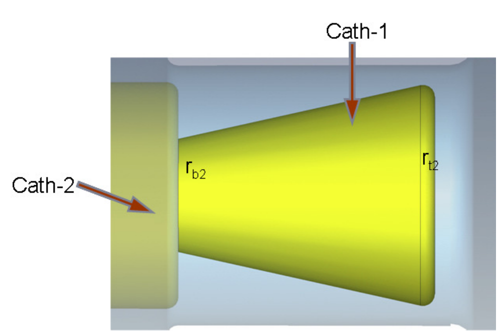

Figure 4: A frusto-conical cathode model for the second case of geometry setup.

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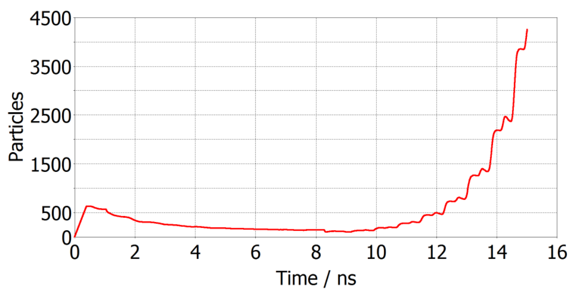

Figure 5: Number of particles after 15 ns for the second case of a frusto-conical cathode model.

Microstructure of the Cathode's Surface (Anti-Multipactor Grooves)

Beside various methods to suppress MP, grooving the surface has demonstrated success for different structures in several papers. Anti-multipactor grooves are firstly proposed in [8] and some investigating results are presented. Here, three different grooving techniques have been investigated numerically for the critical part of our model. In this paper we will only show the simulation result for periodic rectangular grooving of the cathode's surface, see Fig. 6. In the grooved surface the electric field is reduced and the electrons will not gain sufficient energy. Consequently, the trajectories of the electrons are perturbed, thereby MP is suppressed in a certain range of geometrical parameters. The main geometrical parameters are the width (w) and the depth (h) of each groove. As starting point, the distance between grooves (d) should also be set appropriately, otherwise it has also an effect on the production of secondary electrons. There are four models listed in Table 2 as an example and one of the results is illustrated in Fig. 7. The periodic rectangular grooving is considered as a promising suppression technique for our structure. Thus there will be done further investigations.

Table 2: Main Geometric Parameters for Periodic Rectangular Grooving

Param.	Model-1	Model-2	Model-3	Model-4
h	2 mm	1 mm	0.5 mm	0.2 mm
w	0.5 mm	0.5 mm	0.5 mm	0.5 mm
d	0.8 mm	0.8 mm	0.8 mm	0.8 mm

CONCLUSION

The effect of DC biasing voltage, geometry modification and microstructuring of the cathode's surface on MP has been presented. Introducing the periodic rectangular grooves on the cathode's surface is an efficient way to perturb the trajectories of the electrons. From PIC simulation it is observed that most of the secondary electrons eliminate at the bottom of the grooves where the electric field is attenuated.

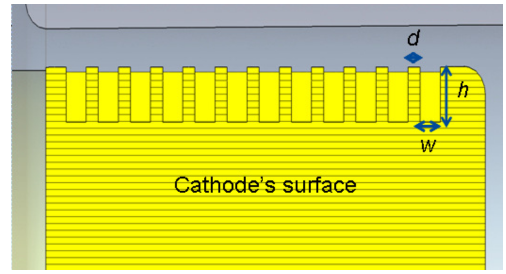

Figure 6: Periodic rectangular grooving of the cathode's surface.

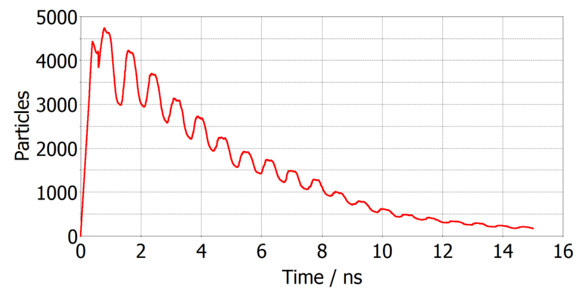

Figure 7: Number of particles in the case of "Model-3" as a function of time.

The remaining electrons are lost in the gap since they are out of phase with the electric field. Eventually, MP is suppressed from the region.

ACKNOWLEDGMENT

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