

3D MULTIPACTING STUDY FOR THE ROSSENDORF SRF GUN*

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Abstract

The development of the superconducting radio frequency photoinjector (SRF gun) is the most promising technology for many applications beside the DC photoinjector and the normal conducting radio frequency photoinjector. However, there are various challenges during the operation [1, 2]. Multipacting (MP) is one of the recent difficulty for the SRF gun. Thus, among the several ongoing investigations on this phenomenon, the experimental results indicates that the high MP current has been measured in the cathode unit of the SRF gun at Helmholtz-Zentrum Dresden-Rossendorf research institute. This limits the cavity fields (accelerating gradient). To better understand this process, a three and half cells 1.3 GHz TESLA-shape cavity with cathode was modeled in CST Studio Suite[®] at the University of Rostock. All parameters were provided by Helmholtz-Zentrum Dresden-Rossendorf, Germany. The MP simulations have been performed with CST Microwave Studio[®] (CST MWS) and CST Particle Studio[®] (CST PS) [3] which are suitable and powerful for 3D electromagnetic designs. Further, CST PS provides the most advanced model of secondary emission [4]. The radio frequency fields are calculated using the eigenmode solver of CST MWS, whereas the CST PS is used for particle tracking simulation like [4, 5]. The purpose of these numerical simulations is to have a better understanding of MP in the Rossendorf SRF gun and to make a detailed analysis. The midterm goal is to find a new cavity shape, which might suppress the electron amplification so that the SRF gun will be able to operate up to an accelerating gradient of 50 MV/m.

INTRODUCTION

The Rossendorf superconducting radio frequency injector (SRF gun) has been utilized to produce a high-brightness, low emittance and high average current beam as a source of the ELBE linear accelerator which is already in operation since 2007 [6]. Yet, the operation of the SRF gun has been currently disturbed due to MP effects in the region of the photocathode. This limits the fields in the cavity. Thus, a new SRF gun with a three and half cells 1.3 GHz cavity is intended to be designed which should improve the cavity performance and allow to operate up to 50 MV/m at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) research institute.

The MP is caused by the unwanted electrons in the coaxial line of the structure (between the cavity and photocath-

ode). These electrons are accelerated by a leakage of RF fields from the end half cell of the cavity. Then, they produce a large amount of secondary electrons at certain favorable conditions. There are two crucial causes of MP: (i) The resonance of the trajectory of the secondary electrons due to the pattern of the fields which depend on the geometry of the structure; (ii) The secondary emission yield of the materials of the wall of the structure [7].

To analyze the effect of MP around the cathode numerical simulations have been performed. In this paper, it will be presented the simulation results which are performed with a simplified model of the Rossendorf SRF gun. The mesh resolution is increased in the simplified structure while the simulation time is minimized. The simplified SRF gun consists of a half cell, a photocathode and a choke filter as illustrated in Fig. 1. The complete structure of 1.3 GHz three and half cells TESLA shaped Rossendorf SRF gun is visualized in [1]. The main goal of this task is to analyze the MP behavior in the cathode unit of Rossendorf SRF gun and to obtain a consistent suppression technique. Thus, in this paper, as a first step, the MP simulation with copper photocathode and niobium cavity will be presented.

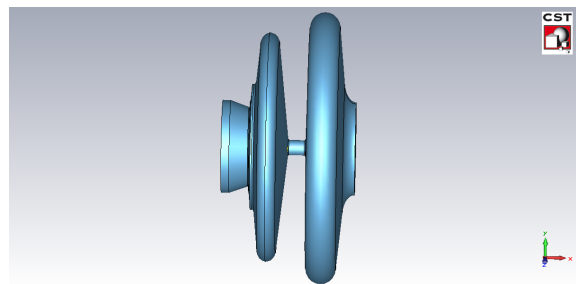


Figure 1: Simplified model of the Rossendorf SRF gun.

SIMULATION

Field Distribution in the Structure

Firstly, the simplified SRF gun has been modeled using CST Microwave Studio[®]. Electric boundary conditions ($E_t = 0$) are set on the surface of the structure, whereas magnetic boundary conditions ($H_t = 0$) are defined on both ends of the structure. In order to decrease the simulation time, two symmetry planes modeled by magnetic boundary condition are also applied. Around 530,000 mesh cells are used based on a convergence study. Additionally, in order to achieve a high field resolution which is required for our particular interest of MP study, the local mesh refinement is considered around the cathode region. The details will be discussed more in the result section. The distribu-

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tion of the RF electric and magnetic fields of the TM_{010} mode are shown in Fig. 2 and Fig. 3, respectively. The on-axis electric field is 18 MV/m, which is normalized by 1 J in CST MWS, whereas the highest field in the half cell is about 35.8 MV/m. The computed resonant frequency is 1.299 GHz.

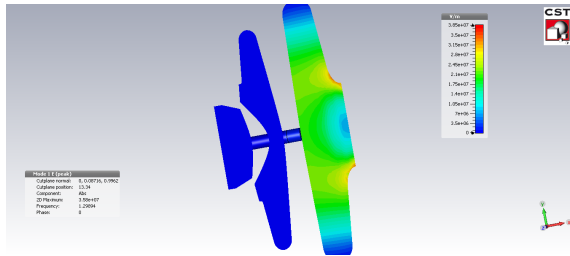


Figure 2: Electric field distribution of TM_{010} mode.

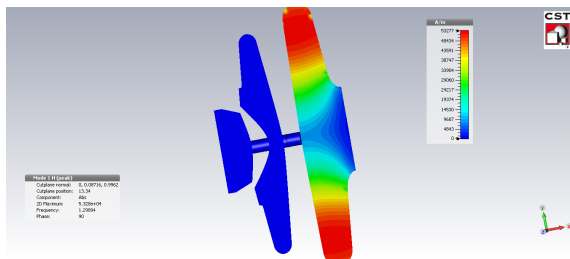


Figure 3: Magnetic field distribution of TM_{010} mode.

Multipacting Simulation

MP simulation is carried out with the particle-in-cell (PIC) solver of CST Particle Studio[®] (CST PS). Secondary emission yield (SEY), which can be defined as the secondary emitted per incident electrons (current), is the main parameter to perform an analysis of the generation of secondary electrons. CST PS uses probabilistic emission model developed by Furman and Pivi [8]. There are a number of secondary emitting materials in the material library of CST Studio Suite. Among them, copper cathode with 2.1 maximum SEY at 250 eV impact energy is chosen for this simulation, whereas niobium (300 °C Bakeout) with 1.49 maximum SEY at 300 eV is used for the wall of the cavity (background).

The RF field leaking out of the cavity into the photocathode region shown in Fig. 4 is high enough to observe strong MP around the photocathode of the SRF gun. In order to track the secondary electrons in this region, the calculated electric and magnetic fields are imported into the CST Particle Tracking Studio[®]. Moreover, the electrons are accelerated towards cavity wall due to the transverse direction of the electric field. The scale is changed to visualize the field.

The MP is highly suspected in the cathode region due to the experiment results at Rossendorf. Hence, the initial electrons distribution is considered on the surface of the

photocathode as shown in the Fig. 5. The initial energy of the electrons is 1 eV.

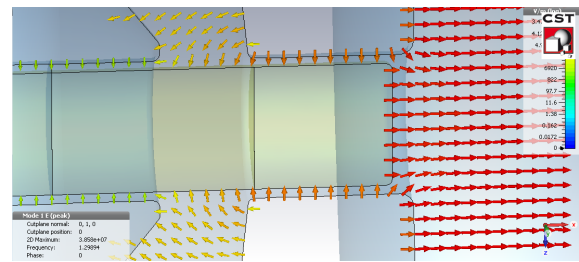


Figure 4: Transverse electric field distribution around the cathode.

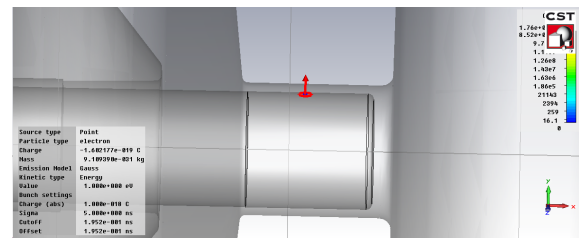


Figure 5: Initial particle distribution.

RESULTS

To better understand the MP behavior in the cathode unit of the Rossendorf SRF gun, it is intended to perform simulations with different materials which are in use at Rossendorf. The first simulation results are produced for copper photocathode with niobium (300 °C Bakeout) cavity. Fig. 6 depicts the exponential growth of secondary electrons as a function of time. Since MP simulation with CST PS doesn't allow to use symmetry plane, the full structure is used with around 2.2 million mesh cells. The CPU time needed to complete the MP simulation was 1 hour and 22 min using Intel(R) Xeon(R) CPU E5 with 3.30 GHz and 256 GB. The gradient scan was done with a factor *am* between 0.025 and 0.205 in steps of 0.02. In that case the amplitude of the fields vary in the range of 0.45 MV/m (0.025 * 18 MV/m) and 3.69 MV/m (0.205 * 18 MV/m). The results of the parameter sweep shown in Fig. 7 revealed that the second order of two-point MP exists in the region of the cathode. The band of emitted secondary electrons in the cathode region at different gradient are also shown in the Fig. 8.

Fig. 9 illustrates that the highest generation of secondary electrons at *am* = 0.085 which is corresponding occurs to $E_{pk} = 1.53$ MV/m. This value is in good agreement with the experimental result at Rossendorf.

The electron trajectories are shown in Fig. 10 during their acceleration towards the wall of the cavity after they gain an energy from the RF field in the coaxial line structure at about initial time (after 0.4 ns). Moreover, the resonant behavior of the electrons in this region in the interval

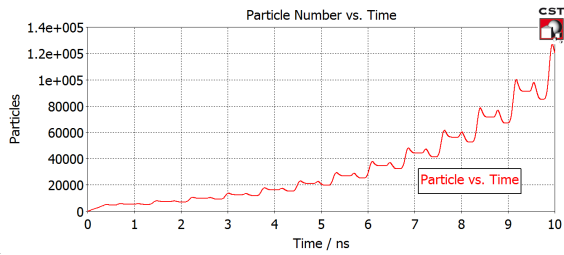


Figure 6: The exponential growth of secondary electrons as a function of time.

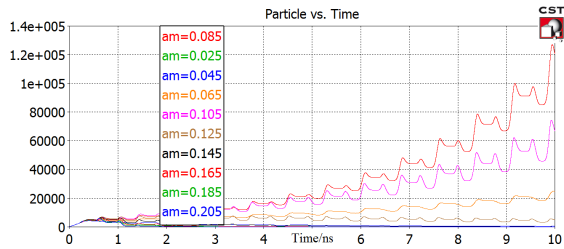


Figure 7: Parameter sweep of gradient.

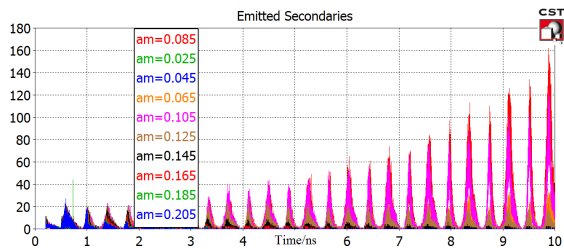


Figure 8: Band of secondary electrons.

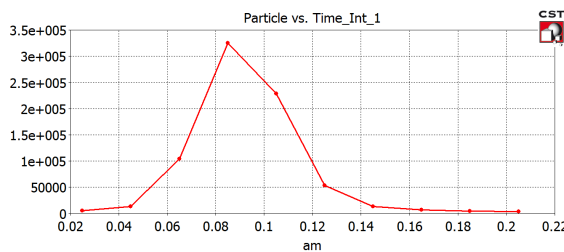


Figure 9: Particles as a function of a factor am .

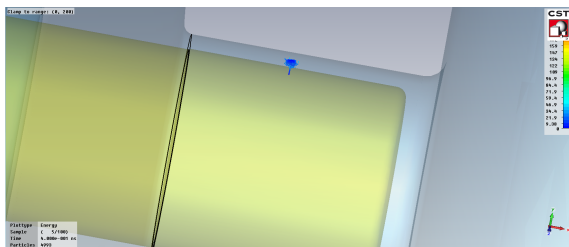


Figure 10: Particles trajectories at initial point.

the electrons become visible on the wall of the cathode after 0.53 ns. The colors indicate that the value of the impact energy of electrons. Then, after 0.2 ns they obtain sufficient energy to accelerate between the gap again. At 0.58 ns they hit the wall of the cavity at their impact energy. Finally, after 9.9 ns large number of electrons (117,743) are produced in the cathode unit as shown in Fig. 14.

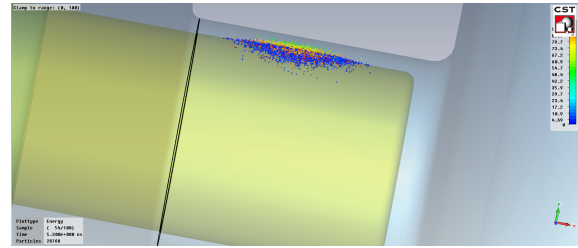


Figure 11: Particles trajectories after 5.3 ns.

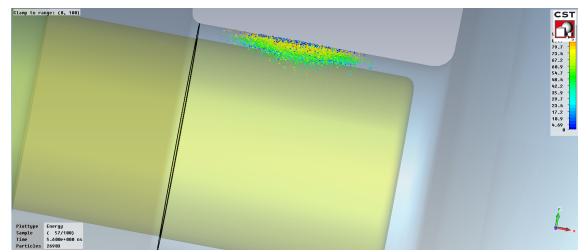


Figure 12: Particles trajectories after 5.6 ns.

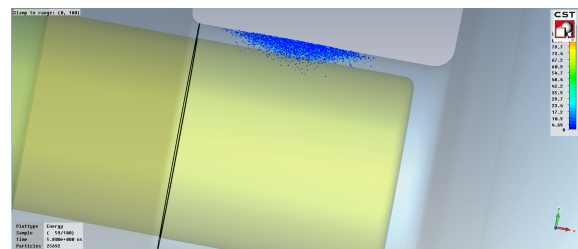


Figure 13: Particles trajectories after 5.8 ns.

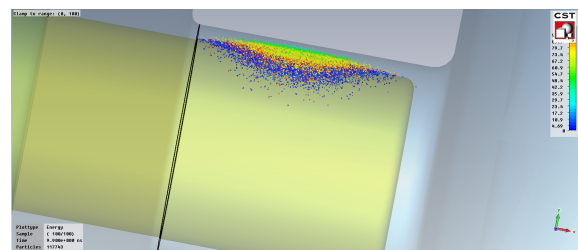


Figure 14: Particles trajectories after 9.9 ns.

of time 0.53 ns and 0.58 ns is shown from Fig 11 to Fig 13:

07 Cavity design

P. Cavity Design - Deflecting & other structures

CONCLUSION

The multipacting simulations for the simplified model of the Rossendorf SRF gun were carried out for copper

cathode. The results indicate that a strong MP barriers are observed between the cavity wall and the photocathode. It was observed that a high order two point MP exists in a cathode region. The highest MP is noticed around 1.53 MV/m. The achievable results are a signal to proceed our further studies about MP in the cathode unit using simplified model of Rossendorf SRF gun.

ACKNOWLEDGMENT

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