Multipacting Simulation for the PITZ RF Photo Gun

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Abstract

Multipactor discharge leads to high losses of the RF power, an increase of the conditioning time, an additional heating of the structure, and can even lead to a breakdown. The multipacting simulations for the PITZ RF photo gun were performed using CST Studio. Research on the influence of an external magnetic field on the multipactor discharge in the PITZ gun was performed.

Contents

1 Introduction

1.1 PITZ overview

The Photo Injector Test facility (PITZ) at DESY, Zeuthen site was built to develop, test and optimize high quality beam source for Free Electron Lasers (FELs) like FLASH and European XFEL. The main requirement for a FEL electron injector is the ability to generate reliable brightness beams with a very small transverse emittance and a reasonably small longitudinal emittance. Therefore, one of the main research goals at PITZ is the reliability of the photo electron source.

The PITZ setup consists of the cathode laser system, the electron RF gun cavity with a pair of focusing solenoids, the normal conducting accelerating cavity based on Cut Disk Structure (CDS), and multiple diagnostic components for beam investigations. A simplified layout is shown in Fig. 1.

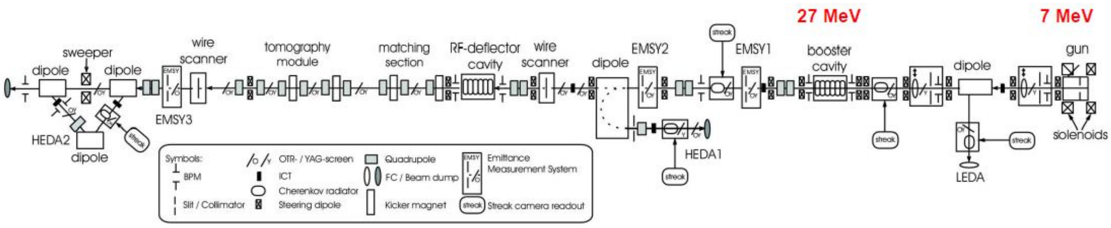


Figure 1: PITZ facility layout.

The main part of the PITZ setup is the RF photo gun [1]. Electron bunches are produced by the interaction of pulsed laser radiation with the photo-cathode in the RF gun. The produced electron bunches are accelerated by high gradient RF fields in the gun cavity to energies up to 6.8 MeV. A high quality electron source which can produce electron bunches with small transverse emittance is very important for FELs.

1.2 RF photo gun

The RF photo gun operates with a standing wave regime in the π-mode with resonant frequency of 1.3 GHz. It is a normal-conducting cavity and it consists of 1.6 copper L-band cells which provides an accelerating gradient of about 60 MV/m at the cathode. The gun can be operated with full RF power of 8 MW at 1 ms RF pulse at 10 Hz repetition rate. It allows to produce and accelerate up to 800 electron bunches within the flat-top part of the RF pulse. The molybdenum plug of the exchangeable cathode is fixed in the position with a contact spring. Solenoids provide primarily focusing of the bunch within the RF cavity and compensation of the space charge induced emittance growth. The gun structure is shown in Fig. 2.

During the gun operation dark current measurements were performed. Significant dark current growth was observed at certain operational conditions. One of the reasons for this growth can be the multipacting effect. There are electromagnetic fields in the gap between cathode and outer cylinder which may lead to discharge. The aim of the simulations is to obtain power levels on which multipacting occurs and to define the area of the cathode where stable discharge electron trajectories can be present.

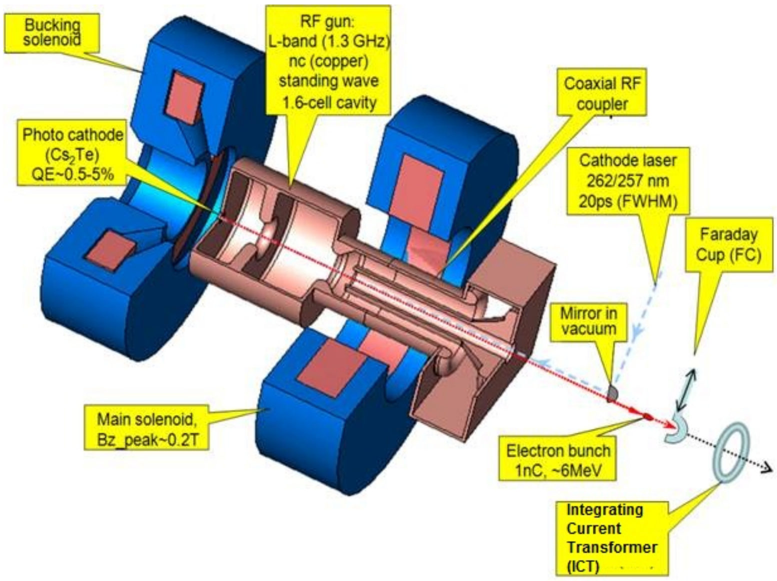


Figure 2: RF photo gun.

1.3 Electron multipacting

Multipactor discharge (multipacting) is the phenomenon of undesirable resonant secondary electron emission which occurs at certain conditions. Multipacting depends on the field configuration, the cavity geometry and the secondary electron yield (SEY) of the cavity materials.

One or more secondary electron can be released from the cavity surface after an electron impact if its energy matches with the range where SEY is more than 1 for the material. These secondary electrons may be accelerated by the alternating field and they consequently may produce even more electrons. If an emitted electron returns to the same point of the cavity wall from which it was released after an integer number of RF cycles, this process will repeat resonantly and an electron avalanche will appear. Multipacting is characterized by an exponential increase of the secondary electron number [2]. The mechanism of electron avalanche formation is shown in Fig. 3.

The multipactor discharge may lead to operational problems of the RF systems such as vacuum breakdown, power losses, overheating and damage of RF components. In superconducting cavities it may cause a quench effect, when the material becomes normal-conducting. Therefore, multipacting simulations are important for the RF structure development.

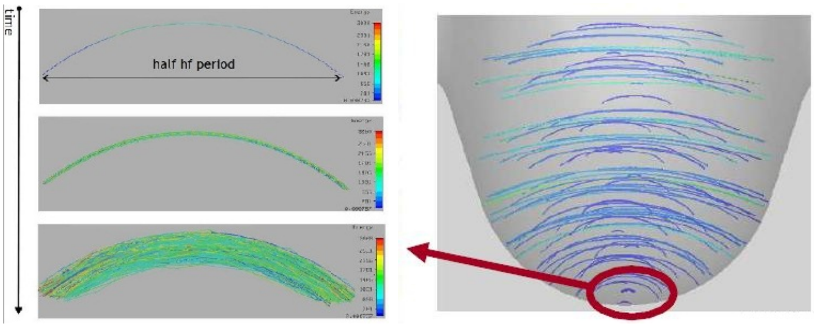


Figure 3: Left: Electron avalanche formation ; Right: Example of a stable multipacting trajectory.

2 Multipacting simulations

The process of multipacting simulations consists of three steps. The first step is the definition of the geometry and the calculation of the RF and static fields in this geometry. The second step is tracking the motion of a large number of particles in the structure. Finally multipacting behavior in the collection of particle tracking data has to be identified. CST Studio has been used for this purpose since it provides the tools for realization of all three steps.

2.1 RF and external magnetic fields simulations

The first step of multipacting analysis is field simulations. CST Microwave studio (MWS) is used for RF field simulations. The frequency domain solver is used to calculate the electromagnetic fields utilizing a waveguide port at the coaxial part of the structure and the open boundary condition at the cathode side of the gun to obtain a standing wave solution. A very dense tetrahedral mesh is required in order to obtain a field map with sufficient accuracy. The distribution of the electric and magnetic fields in the gun cavity are shown in Fig. 4.

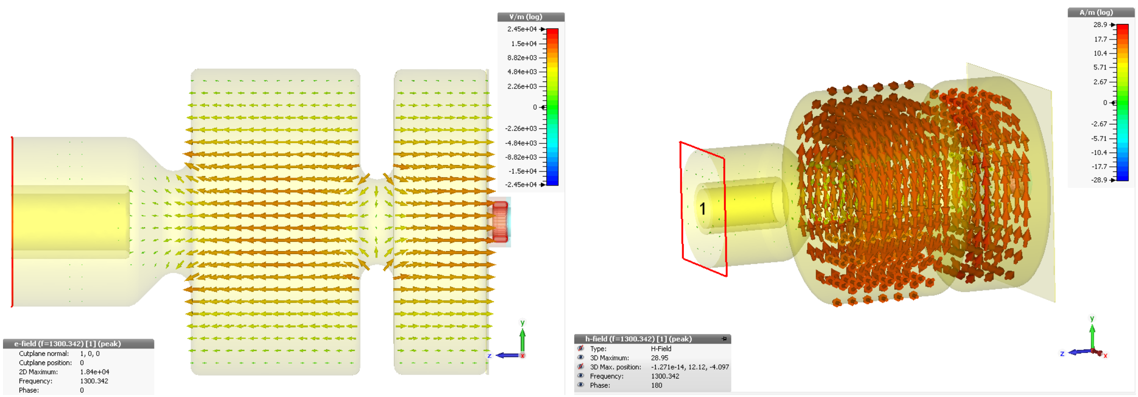


Figure 4: Left: Distribution of RF electric field ; Right: Distribution of RF magnetic field.

External magnetostatic fields of the solenoids are simulated by CST Electromagnetic Studio (EM). The geometry of the gun is imported to the CST EM and two solenoids with opposite current directions are created. The magnetostatic solver is used for the external magnetic field calculations. The simulations are done for two configurations of magnetic fields: the first one corresponds to normal gun operation with emittance measurements, while the second represents a situation when the solenoid field induces the multipacting in the cavity. The difference between these magnetostatic fields is in the solenoids currents. An example of the magnetic field distribution for gun operation case is shown in Fig. 5.

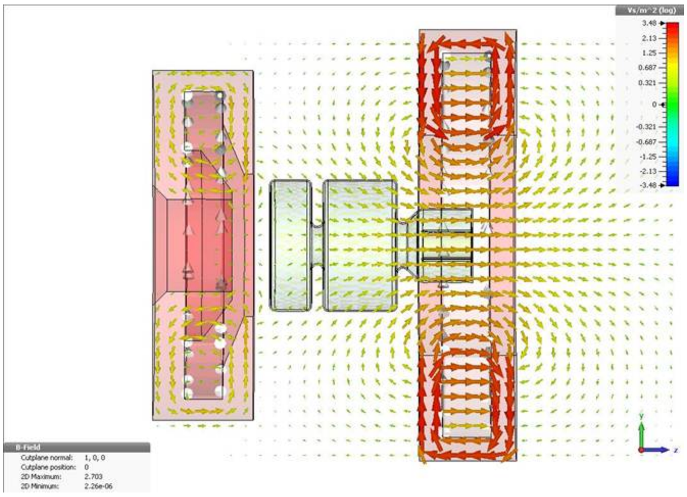


Figure 5: Example of external magnetic fields distribution.

The fine mesh in the cathode area is very important for particle tracking simulations. To increase the precision of the calculations and reduce the computing power demands, further simulations were done with a simplified model shown in Fig. 6. It consists of the cathode area and a small part of the first cell of the cavity. For particle tracking simulation electromagnetic fields are imported from CST MWS and CST EM and then combined in CST Particle Studio (PS). However, the extraction of these fields with the required precision from the whole structure is very time consuming and needs a lot of memory. This problem was solved with a simplified model where only fields in the cathode area are considered. One of the problem was the absence of special tools in CST MWS and EM that allow field extraction only from a certain area. The special script for the field extraction was developed with CST Visual Basic for Applications (VBA). This script provides the possibility to extract the electromagnetic fields from the desirable area.

2.2 Particle tracking simulations

The Furman model of the secondary emission for copper and molybdenum is used with the default CST PS parameters for particle tracking simulations [3]. The common parameter to describe the secondary electron emission is the Secondary Emission Yield (SEY), which is defined as the ratio of the incident over the secondary or emitted current. The SEY depends on the material, surface treatment, special coating of the metal (if any) and

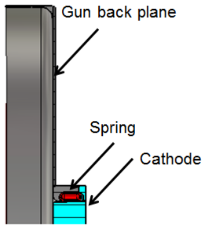


Figure 6: Half of the simplified model.

on the impact energy of the primary electron. These characteristics are shown in Fig. 7. The maximum number of generations which the primary electron source can produce is set to 25 and the maximum secondaries per hit is set to 10.

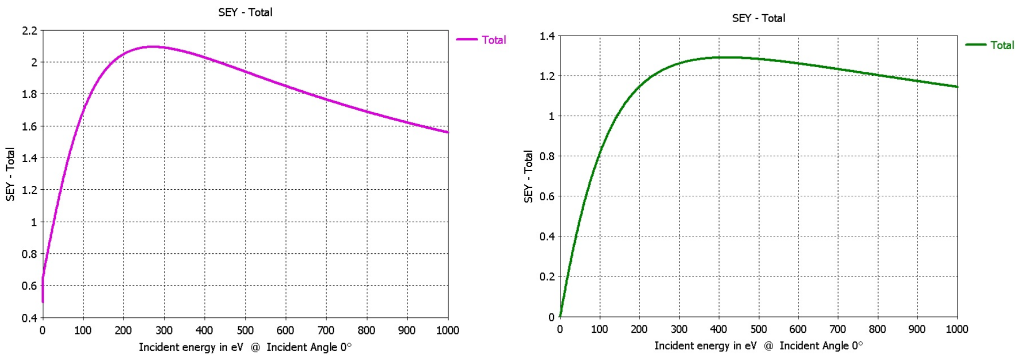


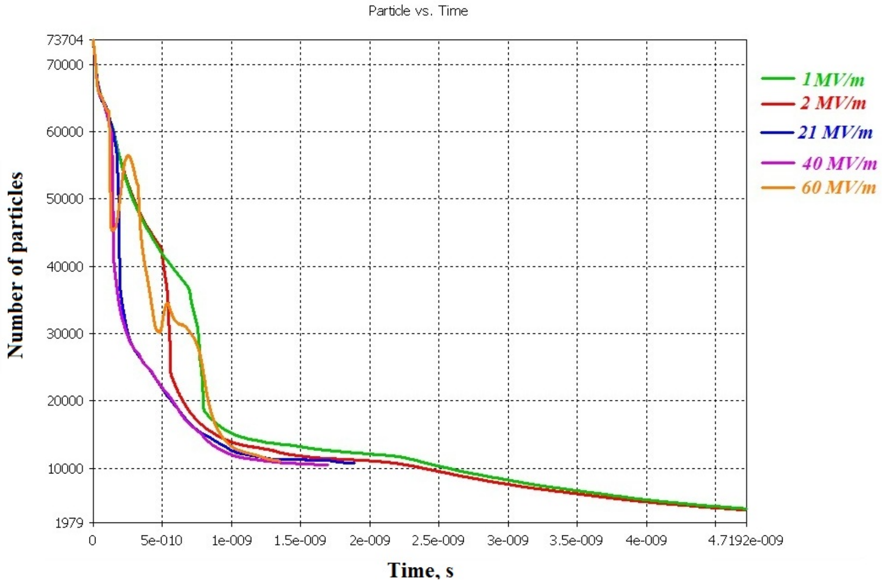
Figure 7: Left: SEY for copper ; Right: SEY for molybdenum.

The position of the initial electron source has to be predefined by guessing the most critical part of the device. In our case the cathode surface and the surface of the gun around the cathode were chosen as the emitters because the space between them is interesting for our simulations. The electron source is chosen at 1/4 of the cathode area in order to save memory and reduce computational time. Such simplification is valid due to the symmetry of the fields.

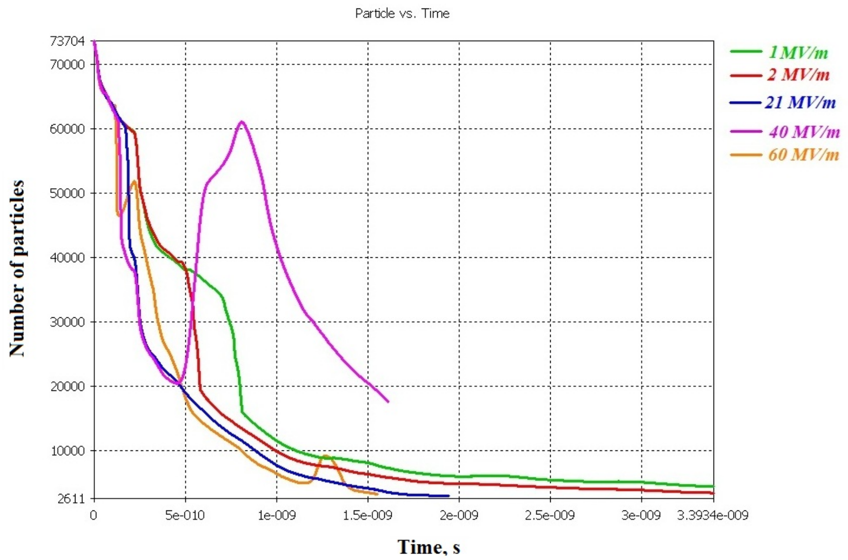
Table 1: Simulation parameters.

Frequency Domain Solver Mesh: max. step width, mm	0.3
Tracking Mesh: max. step width, mm	0.1
Emission energy, eV	0 – 5
Maximum generations	25
Maximum secondaries per impact	10

We can predict multipactor appearance by performing tracking simulations for a finite number of RF periods. CST PS evaluates the particle number within the cavity volume vs. time, which is a common characteristic to indicate and verify the electron multipacting. This dependence was calculated for different levels of the electric field at the cathode area and for two kinds of the magnetostatic fields.



a



b

Figure 8: The number of particles in the gun as a function of time. a: Operating magnetic fields; b: Special magnetic fields for multipacting investigation.

The gradual decrease in the number of electrons with time is obtained at all investigated gradients and for both external magnetic field configurations. However, the particle amount growth is visible at some RF field levels. These peaks mean that resonant conditions for secondary emission appear at certain moments and the number of particles starts to grow. But there are no resonant conditions leading to electron avalanche since there is no synchronization between the field and particles. Such growth does not lead to multipacting.

The difference between the simulations for two kinds of external magnetic fields are obtained at a field level of about 40 MV/m. The particle count rise was obtained for such magnetic fields at which a multipactor was observed experimentally. Further decrease in the electron count (Fig. 8 b) shows that multipacting process is impossible. Secondary electron trajectories during the particle number growth were investigated in details. The major part of the secondary electrons concentrates in the gap between the cathode and the outer cylinder close to the cavity area (Fig. 9).

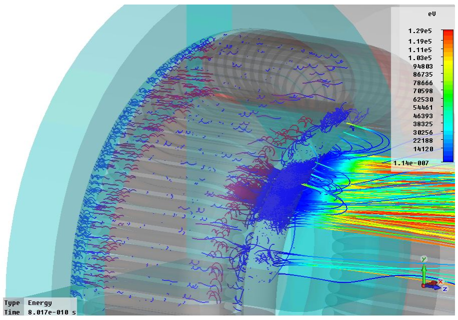


Figure 9: Secondary electrons in the cathode area.

Multipacting simulations were also performed for the 60 MV/m accelerating gradient at the cathode and the external magnetic field distributions as shown in Fig. 5. The dependence of the particle count vs. time (Fig. 9) shows that there are no conditions for multipacting appearance, but there is still a high probability for the secondary electron emission between the cathode and the blending part of the outer cylinder.

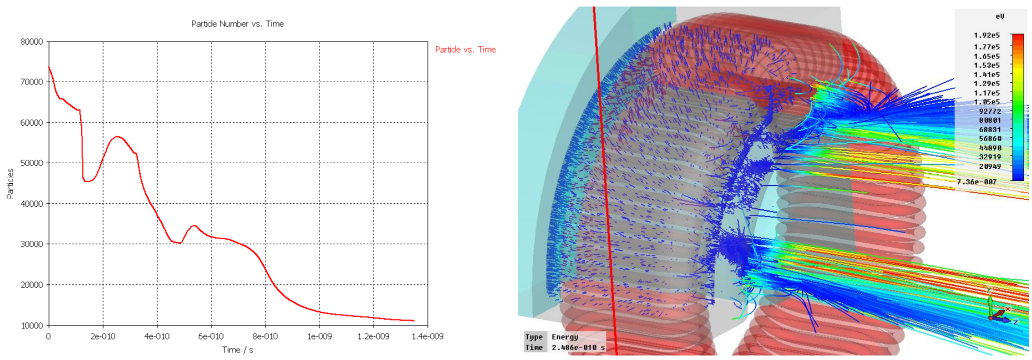


Figure 10: Left: The number of particles in the gun as a function of time for operating regime ; Right: Secondary electron trajectories in the cathode area.

3 Conclusions

The results of multipacting simulations in the cathode area of the PITZ photo gun showed that there is no possibility of multipactor discharge. However, the area between the cathode and the blending part of the outer cylinder undergo the secondary electron emission at operating levels of the accelerating gradient of about 60 MV/m.

For the determination of the reason of the dark current growth further simulations for the whole structure of the gun have to be performed.

Acknowledgements

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