MULTIPACTING BEHAVIOR STUDY FOR THE 112 MHz SUPERCONDUCTING PHOTO-ELECTRON GUN

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Abstract

Superconducting 1.2 MV 112 MHz quarter-wave photo-electron gun (SRF gun) is used as a source of electron beam for the Coherent electron Cooling experiment (CeC) at BNL. During the CeC commissioning we encountered a number of multipacting zones in the gun. It was also observed that introduction of CsK_2Sb photocathode creates additional multipacting zone. This paper presents numerical and experimental study of the multipactor discharge in the SRF gun. We also discuss ways of crossing the multipacting levels to the operational voltage. Finally, we compare the results of our numerical simulations of the multipactor discharge using ACE3P with experimental data.

INTRODUCTION

The superconducting 112 MHz photo-injector based on Quarter Wave Resonator (QWR) was designed to serve as a source of electron beam for the Coherent electron Cooling [1] Proof-of-Principal (CeC PoP) experiment, which is currently undergoing commissioning at Brookhaven National Laboratory [2]. The goal of the experiment is to demonstrate efficient cooling of a hadron bunch circulating in Relativistic Heavy Ion Collider (RHIC).

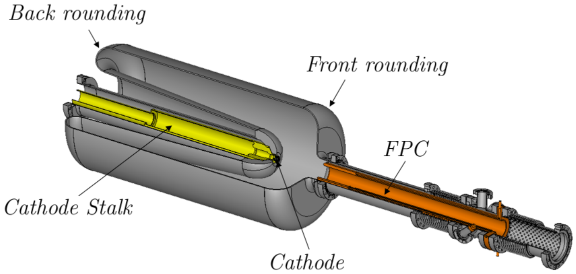

Figure 1: Simplified geometry of the SRF Gun.

A simplified model of the gun is shown in Fig. 1. The cavity provides 1.2 MV of accelerating voltage and was designed to generate electron bunches with maximum charge of 5 nC with repetition rate of 78 kHz. The Fundamental Power Coupler (FPC) can transmit up to 4 kW RF power to the cavity, and also provides fine frequency tuning of the gun. The CsK_2Sb cathode on a molybdenum puck can be easily replaced through the hollow half-wave long cathode stalk, which serves as RF choke. A more detailed description of the SRF gun design and parameters can be found in [3-5].

Along with advantages in performance of SRF guns compared to the normal-conducting injectors, there are several challenges in the design and operation of such a cavity. One of the most common problems of the RF accelerating units is multipacting (MP)—a resonant process in which an electron avalanche builds up within a small region of a cavity surface, absorbs large amounts of RF power and deposits it as heat. Since multipactor discharge can significantly limit the performance of a SRF unit, this phenomenon must be analyzed and studied in detail.

COMMISSIONING

During the Run'16 CeC comissioning, a number of multipacting barriers were encountered in the SRF injector [6]. It was observed that the magnetic field of the first solenoid led to substantial vacuum activity in the FPC, especially for the field of about 400 Gs. This solenoid is the first focusing element of the lattice, located at the bellow section of the FPC, and such structures as bellows often create geometrical resonant conditions for the stable multipacting trajectories to occur.

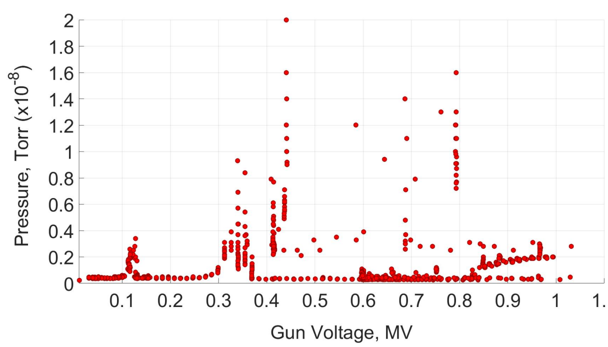

Figure 2: Pressure in the FPC during commissioning.

The most stubborn multipacting barriers were found to be at 30 kV and 40 kV located in the front rounding of the cavity. By the end of Run'16 it became challenging if not impossible to overcome these levels. After extracting the cathode from the cavity, this problem disappeared, which led to the conclusion that introduction of the cathode, which has a very high Secondary Emission Yield (SEY), creates additional conditions for the multipacting to appear.

In the beginning of Run'17 multipacting behavior in the gun was studied separately. Since vacuum activity is one of the signs of possible multipacting, we monitored pressure while varying the voltage in the cavity. The vacuum gauges are located in the laser cross (downstream of the cavity), FPC and the cathode manipulator at the end of the stalk, which allowed us to judge which part of the system undergoes the multipacting. The measurements were performed without the cathode puck and for the solenoid field of about 400 Gs.

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The CW conditioning results for the FPC are shown in Fig. 2. One can see that there was significant vacuum activity in the FPC at the gun voltage of about 120 kV, and at the voltages above 300 kV. While it was possible to overcome these multipacting barriers, operating the gun at levels below 50 kV would immediately lead to the voltage trip. Several multipacting levels were observed with vacuum activity detected in the FPC and the laser cross, with the latter being a sign of stable trajectories within the cavity body. These MP barriers occurred at about 4 kV, 30 kV and 40 kV—the levels which were observed during the previous run.

During the CeC PoP commissioning, when the cathode puck was installed, the 40 kV MP level was the most challenging to overcome. To resolve this issue, the system start-up script was written in order to capture the gun voltage above the dangerous multipacting zone as soon as it crosses the threshold. This allowed us to reach operational gun voltage without tripping on the low level multipacting, while we still observed some vacuum activity in the FPC, cavity, and stalk during the start-up process. Even though the existing script significantly simplified reaching the desired operating voltage of the gun, the 40 kV multipacting level remained to be a problem in certain cases, and once the MP occurred, it was impossible to start-up the system right away. The only solution which helped in this situation, was to let the system "rest" by leaving the gun off for about an hour. After that, the script would bring the gun voltage to the operational regime without any problems. It is possible that this can be explained by the presence of the photocathode within the cavity body. Once the MP starts, the surface of the cathode would be affected by secondary electrons, which would lead to a deposit of active elements, such as Cs, on the walls of the cavity, increasing its SEY and making the MP worse. Since the gun works at cryogenic temperatures, all the chemical processes within the cavity would be significantly slowed down, which could explain better gun performance after being shut down for some time, since it would let the active elements to oxidize.

A few weeks into commissioning another multipacting barrier was found to be around 200 kV, which interrupted operation of the cavity, but didn't show any pressure changes in the vacuum gauges. This event could possibly be explained by the stable trajectories located in the back rounding of the cavity (see Fig. 1), so that the vacuum gauge in the laser cross located far away from the MP area couldn't detect the signal. In order to understand the multipacting behavior in the system and locate stable resonant trajectories, it was necessary to perform numerical studies of multipactor discharge in the gun.

SIMULATIONS

Multipacting simulations were performed using Track3P package of the Advanced Computational Electromagnetic Simulation Suite ACE3P [7].

Since the areas of the cavity affected by multipacting were supposedly known, it was possible to reduce computational resources and time consumption by performing the simulations separately for two different regions: the FPC and the cavity body.

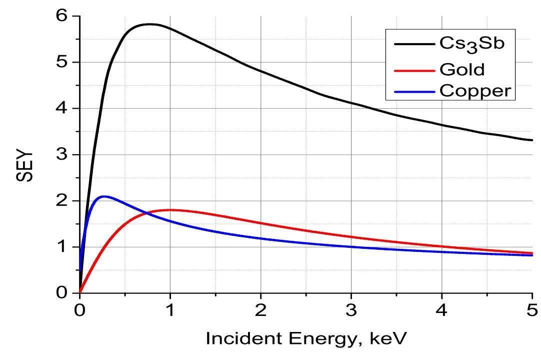

Figure 3: Secondary Electron Yield (SEY) used for MP simulations.

Even though the cavity is made of Nb, it was decided to assign SEY corresponding to Cu for the whole surface of the gun, which has properties similar to a poor quality Nb, and allowed us to take into account possible impurities and contamination on the surface (see Fig. 3). Since the Secondary Electron Yield of CsK_2Sb has never been measured, the SEY curve used in the simulations for the surface of the cathode was Cs_3Sb [8].

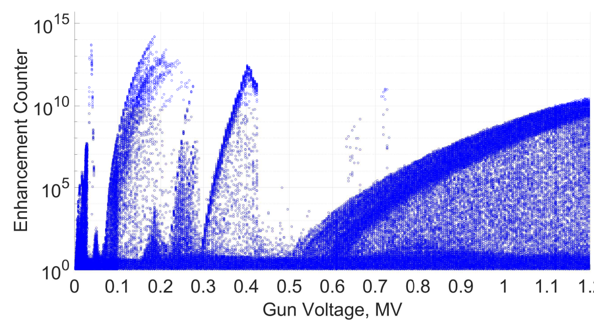

Figure 4: Enhancement Counter function vs. voltage in the cavity gap.

Simulation was performed in the full region of the accelerating voltage for 50 RF cycles. The resulting Enhancement Counter (EC) function for the cavity showed substantial increase in a number of particles at low voltages—the first two peaks on the graph correspond to 30 kV and 40 kV, which agrees with MP bands observed during the commissioning (see Fig. 4).

Figure 5 shows the areas of the gun surface affected by MP at different levels of accelerating voltage. It was observed that even though the primary particles were emitted from the surface of the cavity itself, the stable trajectories at low levels of the voltage (0.4-40.5 kV) were found to be in the FPC gap. Also, at low voltages, stable trajectories were present within the cavity body between the inner and outer conductors of the quarter-wave resonator. Those trajectories moved from the nose of the cavity toward the back rounding of it, when the voltage was increasing, and survived less than 20 RF cycles (see Fig. 6).

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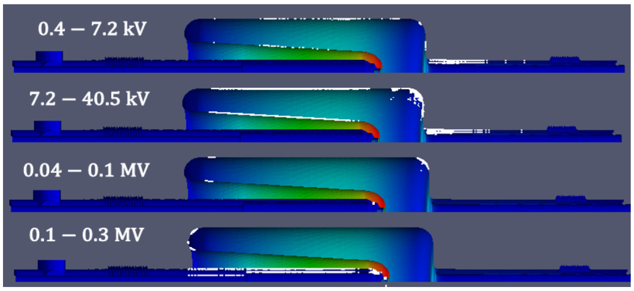

Figure 5: Areas of the gun affected by multipacting. Primary electrons are emitted from the surface of the cavity.

The trajectories corresponding to the peaks of the EC function at 30 kV and 40 kV are located in the front rounding of the cavity. These trajectories are mainly 1^{st} and 2^{nd} order MP trajectories which survive more than 50 RF cycles, and are the most challenging to suppress. For voltages higher than 100 kV, the trajectories move toward the back rounding of the cavity and become stable 1^{st} order MP trajectories at about 200 kV, which confirms the experimental observations mentioned earlier.

While studying multipacting behavior in the FPC region, a quarter of the FPC surface was set as a primary source of electrons, and the rest of the structure could emit only secondary electrons. The SEY curve for gold was used in simulations for the surface of the FPC, and the rest of the cavity was set to have the SEY of copper. The calculations were performed with an external magnetic field of 400 Gs.

The resulting EC function showed several peaks at low voltage in the gun, which corresponded to stable trajectories within the cavity body observed in the previous simulation, along with 1^{st} order MP trajectories in the FPC. One can see in Fig. 7, that MP trajectories move along the FPC gap from cavity side toward the bellow when the gun voltage is increasing. At voltages above 500 kV, all of the stable trajectories are located in the stalk gap.

CONCLUSION

The presence of a photo-cathode within a cavity body can be very challenging when working with SRF guns. The first issue to be addressed is if the cathode can survive a SRF environment without being destroyed by the secondary electron bombardment. The second problem is the deposition of active elements such as Cs on the surface of the cavity, which can lead to higher SEY, making the cavity more vulnerable to multipacting. These issues must be considered in the early stages of SRF gun design and development.

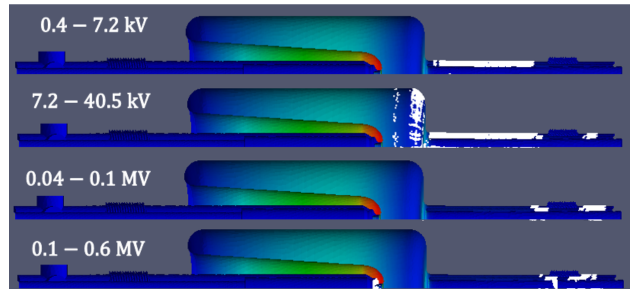

Figure 7: Areas of the gun affected by multipacting. Primary electrons are emitted from the surface of the FPC.

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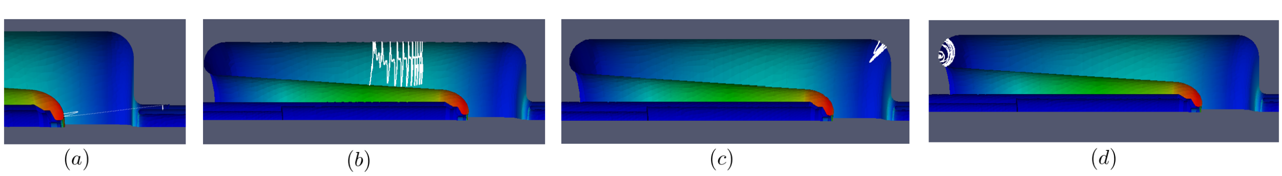

Figure 6: Stable MP trajectories in the gun. (a) – 1^{st} order MP in the FPC at 7 kV, impact energy E_i = 28 eV; (b) – 8^{th} order MP in the cavity at 7 kV, E_i = 900 eV; (c) – 1^{st} order MP in the front rounding of the cavity at 40 kV (E_i = 500 eV); (d) – 1^{st} order MP in the back rounding of the cavity at 200 kV, E_i = 20 eV.

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