SIMULATIONS OF MULTIPACTING IN THE CATHODE STALK AND FPC OF 112 MHz SUPERCONDUCTING ELECTRON GUN*

T. Xin#, S. Belomestnykh, I. Ben-Zvi, and X. Liang, Brookhaven National Laboratory, Upton, NY 11973, and Stony Brook University, Stony Brook, NY 11794
T. Rao, J. Skaritka, E. Wang, and Q. Wu, Brookhaven National Laboratory, Upton, NY 11973
X. Chang, Far-Tech, Inc.， San Diego, CA 92121-1136

Abstract

A 112 MHz superconducting quarter-wave resonator electron gun will be used as the injector of the Coherent Electron Cooling (CEC) proof-of-principle experiment at BNL. Furthermore, this electron gun can be used for testing of the performance of various high quantum efficiency photocathodes. In a previous paper, we presented the design of the cathode stalks and a Fundamental Power Coupler (FPC). In this paper we present updated designs of the cathode stalk and FPC. Multipacting in the cathode stalk and FPC was simulated using three different codes. All simulation results show no serious multipacting in the cathode stalk and FPC.

INTRODUCTION

A 112 MHz superconducting quarter-wave resonator electron gun had been built under the cooperation between Brookhaven National Lab and Niowave Inc. Figure 1 shows the layout of the gun. This 112 MHz QWR gun will be used as the injector of the Coherent Electron Cooling experiment in BNL [1]. Besides that, we are also preparing it as a test facility for various photocathodes. The first cold test of the gun has already been done last year [2]. We presented the design of the cathode stalk and new fundamental power couple for this gun in a previous paper [3]. The new FPC is basically a coaxial structure with a coupling antenna. And the cathode stalk is a modified half wavelength resonator serving as a choke joint for the cathode. In this paper we focus on the simulation done with three different codes on the issue of multipacting in these two parts.

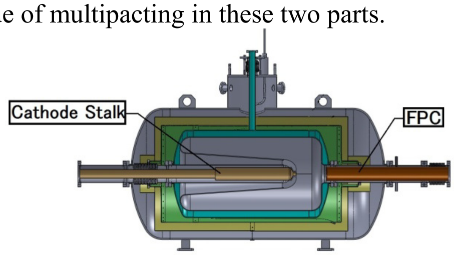

Figure 1: Layout the 112 MHz QWR Superconducting Electron Gun. Stalk is gold plated, FPC is made of copper, beam pipe at both end outside the He vessel are copper plated.

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#txin@bnl.gov

MULTIPACTING SIMULATIONS

To study the possibility of multipacting in the FPC and cathode stalk, we applied and cross compared three different simulation codes that we had access to. Each one of them has its own advantages, which will be discussed in the following subsections. We applied Furman's model [4] for the secondary electron yield data in all three codes. Since this simulation only concerns the trajectories between outer and inner wall of coaxial structures, we considered only the normal incident case. The SEY curves of the materials we encounter in our gun are shown in Figure 2. The parameters used to generate these curves are shown in Table 1. The formulae for three different type of secondary emission are shown bellow. The lower and upper crossover energies of niobium, copper and gold are 100 eV and 1300 eV, 27 eV and 2500 eV and 274 eV and 4000 eV respectively.

True secondary:

$$\delta_{ts} = \frac{s\times\frac{E_0}{E_{max}}}{s-1+\left(\frac{E_0}{E_{max}}\right)^s} \tag{1}$$

Elastic backscattering:

$$\delta_e = P_{1,e}(\infty) + \left(\hat{P}_{1,e} - P_{1,e}(\infty)\right)\mathrm{EXP}\left[-\frac{\left(\frac{E_0}{W}\right)^p}{p}\right] \tag{2}$$

Rediffused electrons:

$$\delta_r = P_{1,r}(\infty)\left\{1-\mathrm{EXP}\left[-\left(\frac{E_0}{E_r}\right)^r\right]\right\} \tag{3}$$

Total SEY:

$$\delta = \delta_{ts} + \delta_e + \delta_r \tag{4}$$

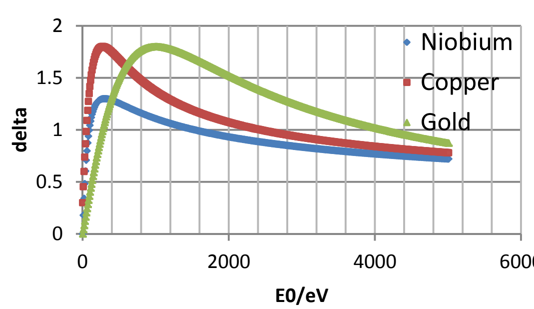

Figure 2: SEY curve of Niobium (blue diamond), copper (red box) and gold (green triangle).

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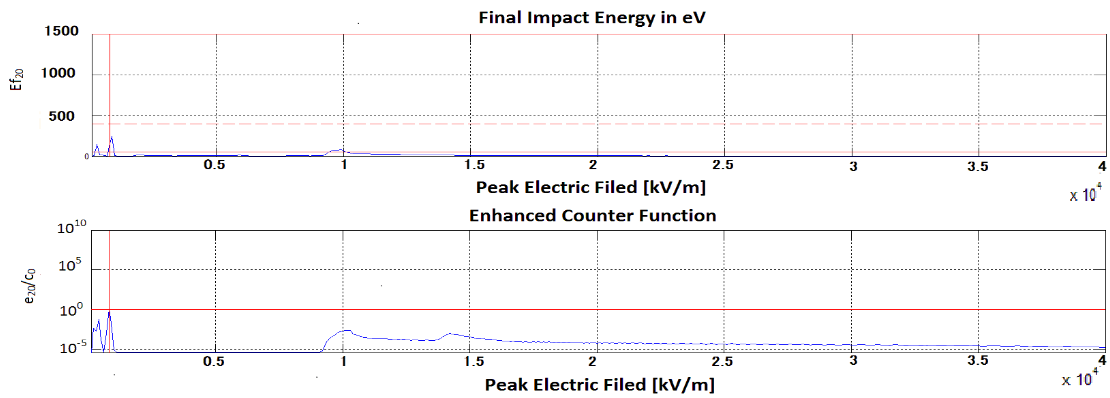

Figure 3: The plot of final energy and enhanced counter function Multipac.

Table 1: Parameters Used to Generate SEY Curves

	Niobium	Copper	Gold
True secondary			
δ_{max}	1.36	1.88	1.78
E_{max}(eV)	300	276e	1000
s	1.3	1.54	1.8
Elastic backscattering			
$P_{1,e}(\infty)$	0.001	0.02	0.01
$\hat{P}_{1,e}$	0.002	0.496	0.02
W	100	60.86	100
P	0.9	1	0.9
Rediffused			
$P_{1,r}(\infty)$	0.001	0.2	0.01
E_r	40	0.041	40
r	1	0.104	1

Result from Multipac

We first investigated our model with Multipac2.1 windows edition [5]. In Multipac we were able to assign different materials to different wall segments. We scanned the cavity's peak surface electric field (Epeak) from 0.1 MV/m to 40 MV/m which corresponding to the gap voltage range from 5 kV to 2 MV in this cavity.

The results of simulation are shown in Figure 3. The main indicator for multipacting is the "enhanced counter function", e_N/C_0, which denotes the ratio of the total number of secondary electrons after N impacts (e_N) to the initial number of electrons (C_0). When the enhanced counter function is greater than 1 for 20 electron impacts, then multipacting is possible (but yet to be verified) at that field level. As we can see, there are indeed some peaks in the lower curve, but all peaks in enhanced counter functions are below unity.

We then focused on each suspicious region indicated by the first run. First two possible candidates at Epeak = 0.55 MV/m and 0.75 MV/m are located in the FPC. The third one at Epeak = 10 MV/m is in cathode stalk structure. The most dangerous point is the one under E_{peak} = 0.75 MV/m and located in FPC. We zoomed in to the region where it happens and narrowed down the field level to a much smaller range. It turns out that even for the seemingly most dangerous point, its enhanced counter function is still smaller than 0.1. Figure 4 shows the zoomed in view of the first two peaks.

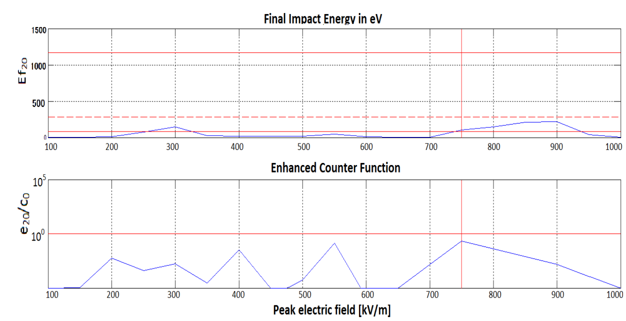

Figure 4: The plot of final energy and enhanced counter function of the multipactor in FPC.

Figure 5 shows the second scan for the third peak at E_{peak} = 10 MV/m. The location of this candidate multipacting region is in the cathode stalk. As we can see, the enhanced counter function is still much smaller than 0.01 due to the fact that the first crossover energy of gold is larger than 270 eV, and the final energy of this resonance point is around 150 eV. For other peaks we made similar investigations. It turns out that for all peaks their enhanced counter function is no larger than 0.01.

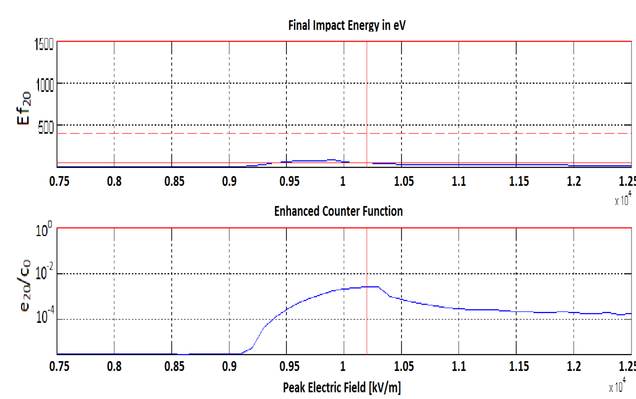

Figure 5: The plot of enhanced counter function of the multipactor in cathode stalk.

Result from CST Particle Studio

Besides the code Multipac, we also applied the PIC solver of CST Particle Studio to our model. This is a 3D code which can easily read and rescale field data from CST's Microwave Studio. The emission process in particle studio is also following Furman's model. We first investigated the FPC. Fifty thousand electrons were generated and equally distributed in the space between outer and inner conductor of the FPC. The total number of electrons was continuously counted during some specific time period under each different field level. We first scanned the Epeak from 0.5 MV/m to 1.5 MV/m, which is the range that indicated by Multipac as the most dangerous field level. As we can see in Figure 6, the electrons indeed tend to die out after 10 RF periods. For the other two candidate multipacting zones, we performed similar scans and neither of them survived 15 RF periods.

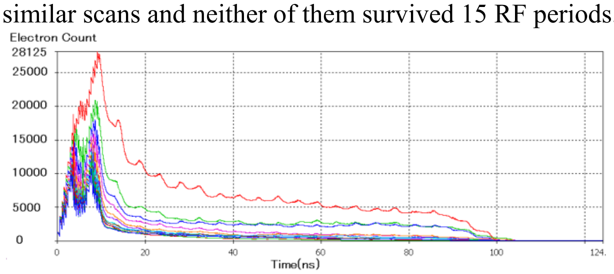

Figure 6: Number of electrons vs time. The highest curve (red) represents the field level which is indicated by a vertical red line in Figure 3. After 100 ns, which is approximately 11 period of 112 MHz, the electrons die out.

Result from Fishpact

The last code we applied was Fishpact. In Fishpact we were able to get the field very precisely since it directly reads the results from Superfish. Therefore the trajectory simulation should be quite reliable. One shortcoming of Fishpact is that it doesn't recognize different wall materials in one run. As shown in Figure 1, our cathode stalk structure has half outer wall as copper and half as niobium and its inner wall is gold. Therefore we can only take the counter function and final energy data from Fishpact as a reference.

We first investigated the FPC. We scanned the gap voltage from 2.5 kV to 2 MV with step size equal to 2.5 kV. We didn't see any suspicious point in this region. The code didn't show any counter function that satisfies the criteria we set, which is 30 impacts. Namely, according to the code there is no electron emitted from surface can survive 30 impacts without encountering wrong phase.

As for the cathode stalk, we did the same scan. Yet there was also no multipacting showed by Fishpact in this part.

CONCLUSION

In order to investigate the possibility of having multipacting in the cathode stalk and FPC structure of 112 MHz QWR gun, we applied and cross-compared the results from three different simulation codes. According to the results from all the codes, there is no multipacting in these two structures. Three candidate multipacting zones were found in the range of field level we scanned. Two of them are located in FPC, which has relatively strongest enhanced counter function at Epeak around 0.55 MV/m and 0.86 MV/m. Another place was found in the cathode stalk, at Epeak around 1 MV/m. However, none of these shows an enhanced counter function larger than 0.1.

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