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MULTIPACTING STUDY OF 112 MHZ SRF ELECTRON GUN*

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Abstract

The 112 MHz quarter wave superconducting electron gun was designed and built as an injector for the coherent electron cooling experiment. Besides that, the gun is suitable for testing various types of photocathodes thanks to its specially designed cathode holder. In recent RF tests of the gun at 4 K, the accelerating voltage reached 0.9 MV CW and more than 1 MV in pulsed mode. During this testing, we observed several multipacting barriers at low electromagnetic field levels. Since the final setup of the gun will be different from the cool down test configuration, we want to understand the exact location of the multipacting sites. We used Track3P to simulate multipacting. The results show several resonant trajectories that might be responsible for the observed barriers, but fortunately no strong multipacting barriers have been found in the cavity.

INTRODUCTION

The fabrication of the 112 MHz SRF quarter wave cavity as well as the cryomodule has been finished and the cold test was successfully conducted early this year. The gap voltage had reached 0.9 MV in CW mode test and 1 MV in pulsed mode. Further increase in gap voltage was limited by radiation. During the conditioning process we encountered several multipacting barriers. The purpose of study shown in this paper is to investigate the relative strength of the known barriers to the ones that are predicted by the simulation under higher field level with different FPC and cathode stalk for future test so that the difficulty of future conditioning can be estimated.

EXPERIMENTAL ASPECTS

General Layout

The cavity and a new cryomodule were built and assembled at Niowave. The layout of the cavity, fundamental power coupler (FPC) and pickup antenna is shown in Figure 1. The FPC antenna was designed with an adjustment range allowing critical coupling at different levels of RF losses in the cavity. Special precaution was taken during the cool down to avoid the accumulation of residual gas on the outer conductor of the FPC. We suspected that changing of surface condition might explain multipacting in a previous cold test. Also a standing wave structure was introduced between the RF

amplifier and the feed through of the FPC to further enhance the coupling in case stronger coupling is needed to condition a multipacting barrier. The design parameters of the 112 MHz electron gun are shown in Table 1.

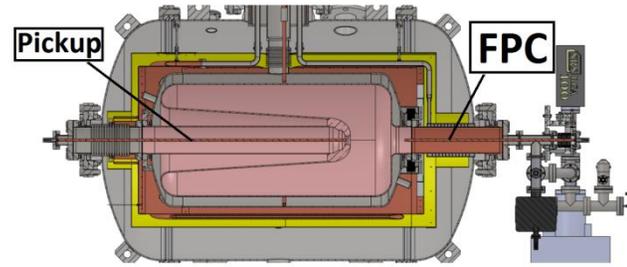


Figure 1: Layout of the 112 MHz SRF cavity horizontal test. The coaxial FPC approaches from the exit of the cavity and the pickup antenna goes through the nose cone part of the cavity and positioned 2 cm behind the entrance of the cavity.

Table 1: Design Parameters of the 112 MHz Electron Gun

Parameters	Value
Frequency	112 MHz
Charge per Bunch	1~3 nC
Repetition Rate	78 kHz
Acceleration Voltage	1~2 MV
Cavity Q_0	1.8e8
R/Q	122 Ω

Experimental results

The cool down took about 4 hours to bring the cavity to superconducting status. To avoid condensation of residual gas on the FPC, the thermal shield was not cooled until later in the process.

Soon after the superconducting status was reached, the multipacting barriers were observed at relatively low field level. The corresponding gap voltage was estimated to be below 50 kV and the more accurate value was later confirmed to be in the range of 30 kV to 40 kV by Track3P simulation.

After overcoming the multipacting barriers, the cavity Q vs. accelerating voltage V_c was measured. Figure 2 shows the result of the measurement.

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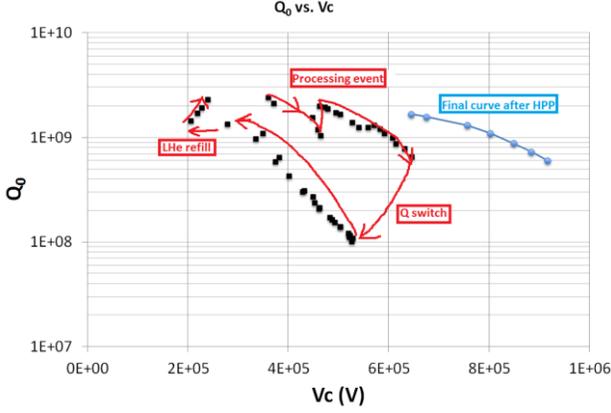


Figure 2: Q_0 vs. V_c during the 112 MHz SRF cavity cold test. The black squares show the process of conditioning and the blue dots show the final measurement after the high power pulse processing.

Black squares show the processing which includes the activation of emitter and the consequent Q switch. Blue dots show the final Q_0 vs. V_c curve after the high power pulse process. As we can see under CW mode the gap voltage reached 0.9 MV, only limited by the radiation concern at Niowave test facility.

MULTIPACTING SIMULATION

The multipacting barriers we encounter in this cold test were relatively easy to overcome as soon as we improved the FPC coupling. However, in a future test of the gun at Brookhaven National Lab, there will be a different fundamental power coupler. In addition, a cathode stalk, which is specially designed to transport and support the photocathode in the gun, will take the place of the pickup antenna [1, 2]. All these differences might introduce different multipacting barriers and we want to see the relative strength between the known one and the barriers predicted by simulations.

Secondary Electron Yield Curve

For the Secondary Electron Yield (SEY) curve, we chose Furman's model [3]. The SEY curves of the materials we encounter in our gun are shown in Figure 3. The parameters used to generate these curves are shown in Table 2. The formulae for three different type of secondary emission are shown below.

True secondary:

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

Elastic backscattering:

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

Rediffused electrons:

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

Total SEY:

$$\delta = \delta_{ts} + \delta_e + \delta_r \quad (4)$$

The cavity and part of the beam pipe is made of niobium. For Niowave test, the center conductor of the FPC and pickup were copper.

Table 2: Parameters used to generate SEY curves

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

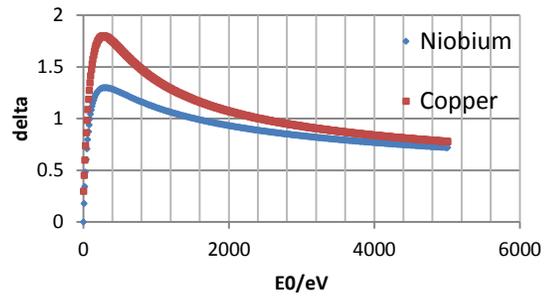


Figure 3: SEY curves of niobium (blue diamonds) and copper (red squares).

Simulation Result for Niowave Test

Figure 4 shows the electric field and magnetic field simulated by Omega3p. This field distribution was used as the input for Track3p simulation. The primary electrons were generated from the inner surface of the whole assembly near the vertical symmetry plane. Then the electrons would be tracked under the force exerted by the RF field. After each impact the phase of the field will be evaluated, if the direction of the field favours the emission of the secondary electron, the impact energy and the location of the electron will be recorded. If the field on impact phase doesn't allow the emission of secondary electron then the particle is removed from simulation. After 50 RF cycles, only the survived particle would be recorded and marked as resonance particle [4]. The total enhanced counter function of these particles will be calculated based on the impact energies and the SEY curve of the impact surface. By looking at the relative height and width of the Enhanced Counter Function peaks we can get the idea of the difficulties in overcoming those barriers.

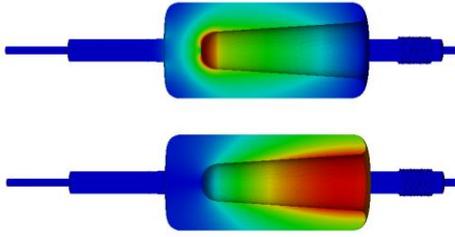


Figure 4: Electric (upper) and magnetic field (lower) simulated by Omega3p for the 112 MHz SRF cavity in the Niowave test configuration.

The simulation gives two potential bands of multipacting. Figure 5 shows the longitudinal location of resonance particles versus impact energy. Since the SEY curve of niobium surpass unity between 100 eV and 1300 eV, we only have to pay special attention to the particles that have impact energy fall into this range.

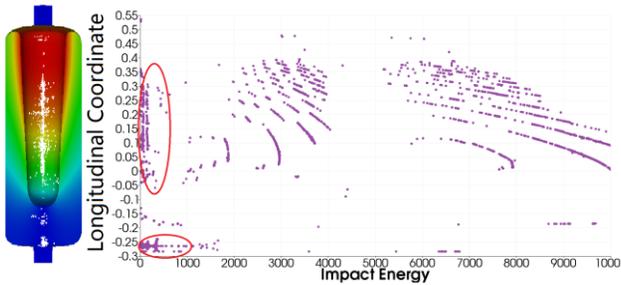


Figure 5: The diagram on the right hand side shows longitudinal location of potential multipacting sites. Picture on left hand side shows the locations (white dots) of those sites inside the cavity. The longitudinal Coordinate axis is mutually applicable to both pictures. The gap voltage was scanned between 100 V to 100 kV.

Post processing of Track3P data shows two multipacting barriers near 30 and 40 kV gap voltage, which is consistent with the observation during the Niowave cold test. Figure 6 shows the Enhanced Counter Function versus the gap voltage of the cavity. One site is located near the gap of the cavity and the other one is located near the high magnetic field region. Both of them survived 50 impacts in RF cycles.

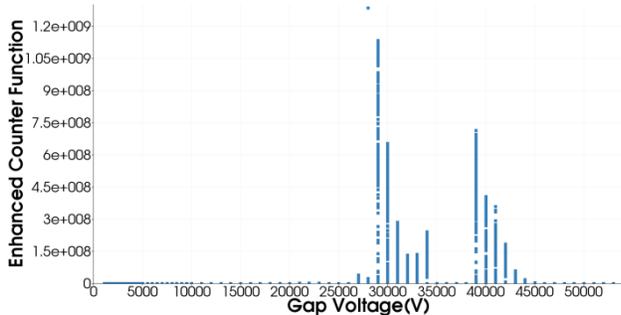


Figure 6: Enhanced Counter Function versus gap voltage of the cavity.

After identifying the field level of two multipacting barriers, we performed the single field mapping with Track3P and extracted two typical trajectories of the

potential multipacting electrons. Figure 7 shows the trajectories of two suspicious multipactors. The one that is close to the gap of the cavity is a 1st order multipacting and the one located in the high magnetic field region is a 2nd order multipacting.

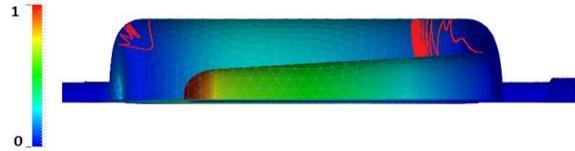


Figure 7: Trajectories of electrons at two multipacting sites (red lines). The left one is under 29 kV gap voltage and the right one appears at 40 kV gap voltage. The color scale indicates the relative strength of electric field.

CONCLUSION

The successful cold test at Niowave gave us a good opportunity to compare the experimental result with the simulation result of the multipacting barriers in the 112 MHz cavity. Two major sites of potential multipacting in the cavity were captured by the simulation of Track3p and also observed during the conditioning process. The multipacting barriers were relatively easy to overcome. This gives us more confidence in future test at BNL since the strength of the suspected multipacting barriers given by previous simulation in the FPC and cathode stalk are much lower than what we found from this run.

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