DESIGN OF A SRF QUARTER WAVE ELECTRON GUN AT PEKING UNIVERSITY *

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Abstract

Superconducting radio-frequency (SRF) electron guns hold out the promise of very bright beams for use in electron injectors, particularly in future high average power free-electron lasers (FELs) and energy recovery linacs (ERLs). Peking University is designing a new SRF gun which is composed of a quarter wave resonator (QWR) and an elliptical cavity. Comparing to the elliptical cavity, the QWR is sufficiently compact at the same frequency and its electric field is quasi-DC. We have finished the preliminary design of the QWR cavity. The simulation shows that multipacting (MP) is not a critical issue for our cavity structure. Beam dynamic simulation of the QWR cavity is also presented.

INTRODUCTION

The development of electron guns is widely believed to be a key requirement for future high average power free-electron lasers and energy recovery linacs. Superconducting RF electron guns hold out the promise of very bright beams for use in electron injectors. Up to now, most SRF guns have employed elliptical cavity geometries or quarter-wave resonator [1]. However, quarter-wave resonator presents certain advantages over the standard elliptical type. QWRs can be made sufficiently compact at low RF frequencies (long wavelengths). The long wavelength allows to produce long electron bunches which minimize space charge effects and enable high current. Because of these potential benefits, quarter-wave SRF electron gun projects have been developed by the Naval Postgraduate School (NPS) [2], the University of Wisconsin [3], and Brookhaven National Laboratory (BNL) [4]. Peking University is considering a new SRF injector which is composed of a quarter wave resonator gun and an elliptical booster cavity. The goal of the SRF injector is that it can deliver electron beam with energy of about 5MeV, normalized transverse emittance of about 1 mm-mrad, and average current of 10 mA. The QWR cavity works at 325MHz and the elliptical cavity, which adopts TESLA type, works at 1.3GHz. We have finished the preliminary design and beam dynamics simulation of the QWR gun. Detailed MP simulation has been studied to make sure that MP does not limit the gun performance.

325 MHZ QWR GUN CAVITY DESIGN

Quarter wave resonators can be thought of as coaxial transmission lines that are shorted on one end and unterminated on the other end.

Cavity RF design work is performed by using Superfish [5] and CST Microwave Studio [6]. The cavity structure was optimized to pursue high cathode surface electric field by adjusting the cavity geometry parameters, including coaxial line diameter, overall cavity diameter, cavity length, and coaxial line length, etc. Internal corners of the QWR cavity supposed to be round which is generally desired for ease of cleaning and to mitigate multipacting.

The fastigiate inner conductor geometry is applied to have a low ratio of peak magnetic field to accelerating electric field. Rational design of the nose cone can decrease the peak surface electric field.

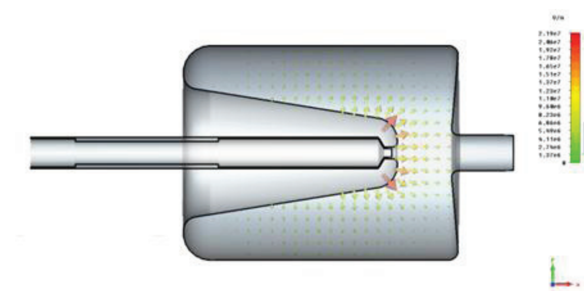

Figure 1: Longitudinal cross section and electric field within the cavity.

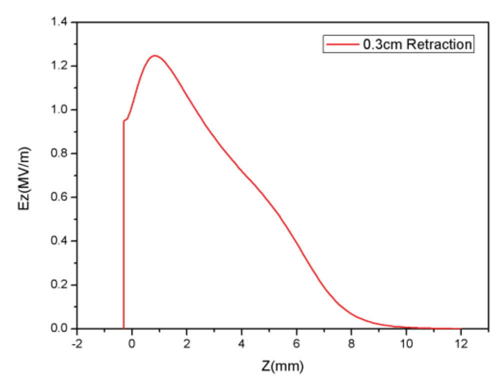

Figure 2: Accelerating electric field profile along beam axis.

Just like the input coupler, the cantilevered cathode stalk becomes an RF transmission line allowing RF energy to flow down it. Any RF power pulled from the cavity decrease the cavity fields. The cathode stalk is a half wavelength design serving as a choke joint for the cathode. The diameter is variable along the stalk which provides a large reflection of RF power for its varied impedance along the stalk.

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Figure 1 shows the longitudinal cross section and electric field within the cavity and Fig. 2 shows the accelerating electric field profile along beam axis.

RF parameters of the 325 MHz quarter wave electron gun are summarized in Table 1.

Table 1: RF Parameters of the 325 MHz Quarter Wave Electron Gun

Parameter	Value	Units
Frequency	325	MHz
Q_0	1.5e9	-
R/Q	156	Ohm
Geometry factor	63.1	Ohm
B_{pk}/E_{acc}	3.26	mT/(MV/m)
E_{pk}/E_{acc}	2.23	-
Aperture	40	mm
Maximum diameter	240	mm

At E_{acc}=1 MV/m and reference length 6 cm.

MULTIPACTING SIMULATION

Multipacting [7], a highly probable occurrence in most evacuated RF structures, is a low field electron avalanche phenomenon caused by resonant electron multiplication from secondary emissions.

MultiPac [8] is a MP simulation package for analyzing electron MP in axisymmetric RF structures and it's used for MP simulation of our QWR cavity. Code calculates 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.

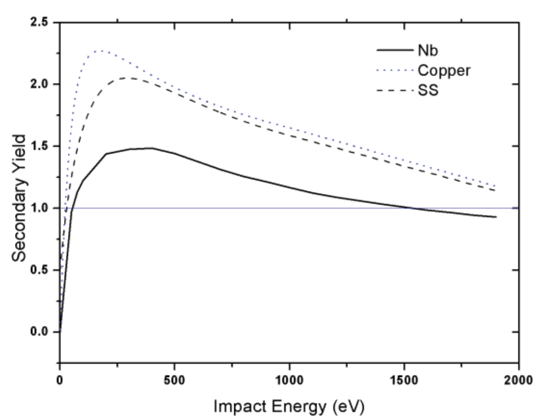

Figure 3: Secondary electron yield for niobium, copper and stainless steel as a function of the electron impact energy in eV.

In Multipac we are able to assign different materials to different wall segments. The material of the cavity is Niobium, the stalk is copper and the out tube of the stalk is stainless steel (data from CST material library). Figure 3 gives the secondary electron yield of these three materials.

The simulation was carried out with initial electron (seed electron) energy of 2 eV, a 5-degree rf phase interval, and a 2 kV/m electric field step. We scanned the cavity's peak surface electric field from 0.0 MV/m to 60 MV/m which corresponding to the gap voltage range from 0.0 MV to 1.6 MV.

We are interested in the MP on the short end of the cavity. After 25 impacts, the enhanced counter function for this part is only 1e-8 from 15MV/m to 20 MV/m. The electron trajectory at 17.5 MV/m is shown in Fig. 4. After 100 impacts, the enhanced counter function is zero.

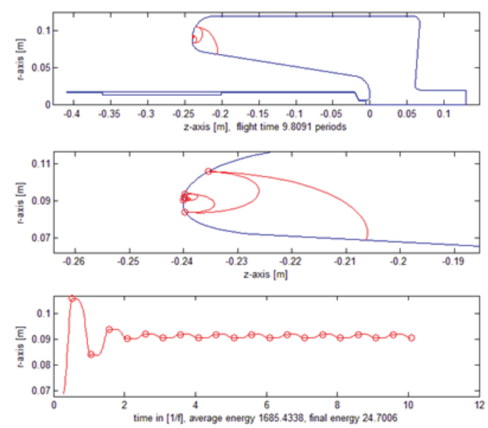

Figure 4: The electron trajectory at 17.5 MV/m. The top figure represents the trajectory of the electron in (*r*, *z*) coordinates, the middle one is an expanded plot of a part of the top one, and the bottom plot illustrates the electron's trajectory in the (*r*, *t*) coordinates where *t* is the time in rf periods. The circles indicate the impacts on the walls of the cavity.

When N=100, the final impact energy and enhanced counter function of the whole cavity is shown in Fig. 5. No multipacting is founded above 5MV/m. The position whose enhanced counter function is bigger than 1 is located in the corner of the open end of the cavity, and different types of MP is shown in Fig. 6.

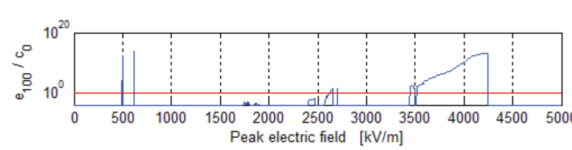

Figure 5: The plot of enhanced counter function. Multipacting occurs at peak surface electric field 494-498, 612-614, 2568-2650, 2700-2704, 3426-3500 and 3520-4250 kV/m.

Hence, we must suppress the MP phenomenon in the 325 MHz QWR. Electron's stable resonant trajectory can be broken by changing the radius of the corner. Enhanced

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counter function plot for different radius of the corner in the open end of the cavity is shown in Fig. 7.

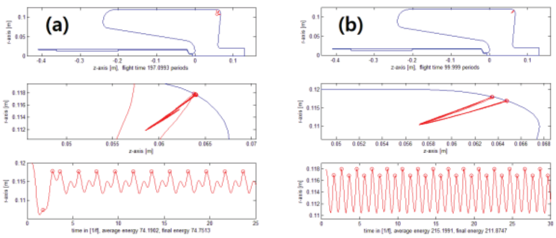

Figure 6: Two types of MP trajectories from Multipac results. (a) The second-order single-point MP at peak surface electric fields 2700kV/m. (b) The first-order two-point MP at peak surface electric fields 4000kV/m.

We noticed that most of the MP barriers disappear when the radius of the corner is 2mm. There is only one MP barrier with the enhanced counter function higher than 1. But because the electric field is very low and the range is very narrow, it is not a critical issue. The enhanced counter function is smaller than 0.01 at two different field levels. It is also not a problem if good processing procedures are applied to the cavity.

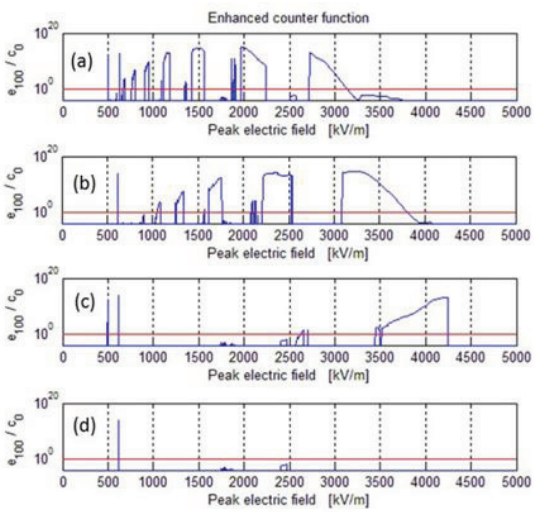

Figure 7: Enhanced counter function plot for different radius of the corner in the open end of the cavity. (a) R=30 mm. (b) R=20 mm. (c) R=5 mm. (d) R=2 mm.

BEAM DYNAMICS SIMULATION

Beam-dynamic simulation of the quarter wave resonator gun is performed by the code Parmela [9]. The electromagnetic rf field is generated by Superfish.

The radial distribution is uniform and the phase distribution is Gaussian. The initial conditions of the simulation and results from the exit of the cavity are listed in Table 2.

The goal of the SRF gun is that it can deliver energy of about 5MeV, normalized transverse emittance of about 1 mm-mrad. There is still some work need to do for the further beam-dynamic simulation.

Table 2: Initial Conditions of the Simulation and Results from the Exit of the Cavity

Parameter	Value	Units
Bunch FWHM radius	3	mm
Bunch FWHM length	20	ps
Bunch charge	100	pC
E_0	20	MV/m
Transverse emittance	0.97	mm-mrad
Energy gain	1.18	MeV
Energy spread	0.0023	-

CONCLUSION

We designed a QWR cavity for SRF electron gun and it shows good RF properties. By careful design of the QWR cavity shape, MP can be suppressed and it is not a critical issue if the cavity has good surface treatment. Preliminary beam-dynamic simulation of the QWR cavity has also been done. This gun can deliver electron beam with bunch charge of 100pC and low emittance of less than1mm-mrad. For the injector design with the booster cavity, more simulation work is undergoing.

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