DESIGN OF A 4.6-CELL RF GUN FOR THE PHIL ACCELERATOR AT LAL*

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Abstract

A photo-injector with 4.6-cell and resonate frequency of 2.998 GHz has been designed and studied to replace the 2.5-cell RF gun + booster association. The cavity iris shape and dimensions were simulated systematically to optimize the shunt impedance. In this study, electron beam reaches to 9.7 MeV with a moderate peak accelerating gradient of 80 MV/m. Considering a beam charge of 1 nC/bunch, average transverse emittance of ~ 5.9 πmm mrad and energy spread of ~ 0.8% can be obtained at the exit of the gun. The RF input power is only 10.2 MW due to the high shunt impedance. Asymmetry of the electric field due to the coupling port has also been studied using 3D codes for RF and beam dynamics calculations. We will present the RF design and beam calculations results.

INTRODUCTION

The primary goal of PHIL (Photo-injector at LAL)[1] was to construct and test the photo-injector for the drive beam linac of the CLIC Test Facility 3 (CTF 3)[2] at CERN. A photo-injector with 2.5 cells was designed and fabricated on the CTF3. Now the PHIL was designed for two main purposes: R&D on the electron sources; providing the beam to users interested in low energy (E<10 MeV), low emittance (ε<10 πmm mrad), short pulse (<5 ps) electron beam [3]. PHIL is currently a 6 meters long accelerator with 2 diagnostics beam lines, shown in Fig. 1. The direct beam line is mainly devoted to 2D transverse emittance and bunch length measurement. The deviated beam line is devoted to the mean and dispersion energy beam measurement. The PHIL is basically composed of 1.5 cells RF gun and a standing wave booster to bring the beam energy up to 5 MeV. The upgrade phase is to bring the beam energy to 9 MeV with a 2.5 cells RF gun and a standing wave booster [4]. If it could be replaced by one single RF gun, the accelerator would be simpler to operate, shorter and cheaper [5]. Therefore we designed a 4.6 cells RF gun that we plan to fabricate and test in PHIL. The 4.6 cells RF gun works in 2.998 GHz and π mode.

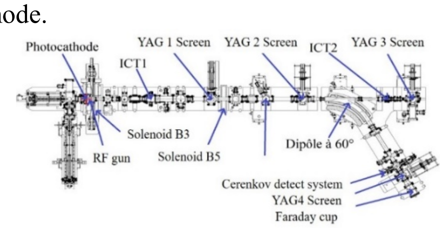

Figure 1: The current PHIL beam line.

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THE CAVITY DESIGN

The cavity design were carried out by using the SUPPERFISH code. The simulations are mainly to get high shunt impedance thus lower the input power and also to obtain a good balanced electrical field between each cells. The cavity cell length is determined by the gun frequency and work mode. The cavity radius is used to tune the frequency and balance the field. The iris radius Ri and length Li influence on the cavity performances, such as the shunt impedance, the dissipated power, the quality factor as well as the ratio of surface electric field and axis electric field, were simulated and study systematically. The results are shown in Fig. 2-5. For the moment, the iris shape is not optimized and it is cylindrical.

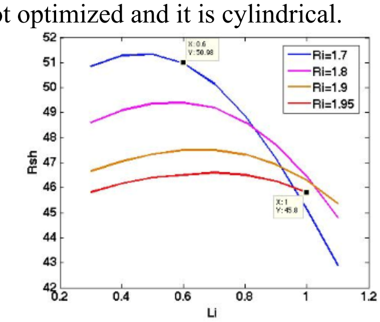

Figure 2: The shunt impedance versus Ri and Li.

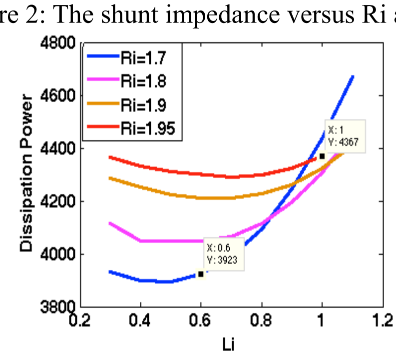

Figure 3: The dissipated power versus Ri and Li.

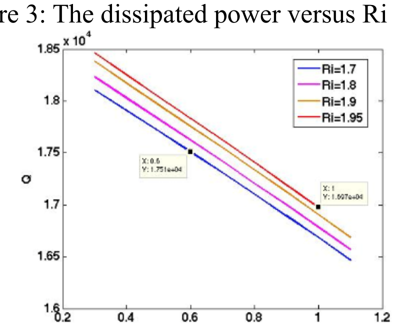

Figure 4: The quality factor versus Ri and Li.

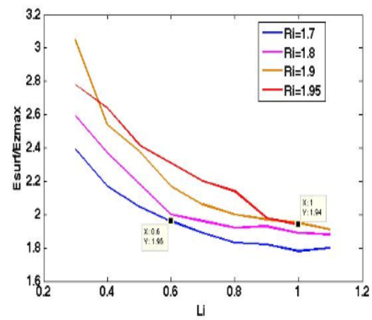

Figure 5: The Esurf/Ezmax versus Ri and Li.

When the Li is lower than 0.8, a smaller iris radius is good for improving the shunt impedance and decreasing the dissipated power as well as the surface electric field. The dissipated power here is a relative value for normalized electric field on axis is 1 MV/m. While the quality factor is higher with large Li. Therefore, two different Li and Ri were chose for the next step optimizations: Ri=1.7, Li=0.6; Ri=1.95, Li=1.1.

Then we optimized the iris shape to be elliptical by changing the ratio of semi major axis and semi minor axis (a/b). The results are shown in Fig. 6-9.

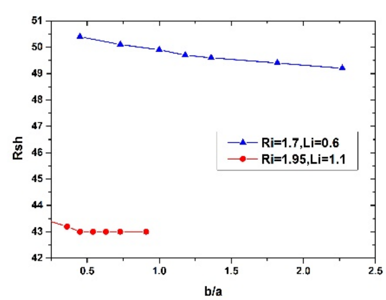

Figure 6: The shunt impedance versus b/a.

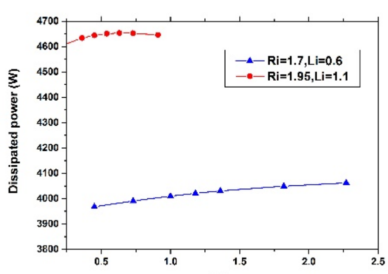

Figure 7: The dissipated power versus b/a.

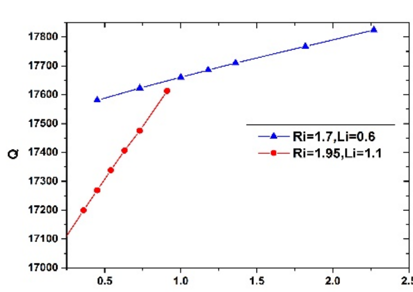

Figure 8: The quality factor versus b/a.

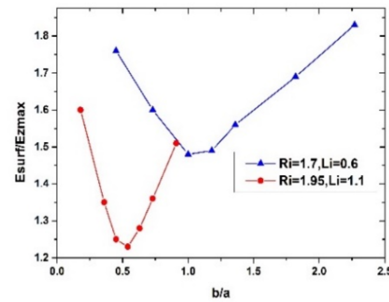

Figure 9: The Esurf/Ezmax versus b/a.

The combination of Ri=1.7, Li=0.6 shows higher shunt impedance, lower dissipated power and better quality factor for all b/a. Even though its Esurf/Ezmax is higher because of the smaller iris, the 120 MV/m on the surface is acceptable (the accelerating gradient is 80 MV/m). Therefore it was chosen for the 4.6-cell cavity and the RF parameters were summarized in Table 1. Fig. 10 is the balance longitudinal electric field on axis.

Table 1: RF Parameters of the 4.6-cell RF Gun

Parameter	Superfish results
Frequency (MHz)	2988.72
Quality factor	19533
Shunt impedance (MΩ/m)	64.9
Power (MW) for Eacc=80MV/m	9.7

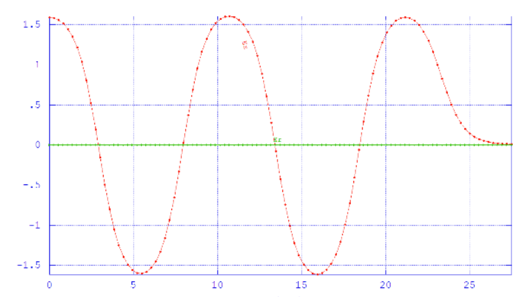

Figure 10: The longitudinal electric field on axis.

THE COUPLES DESIGN

The RF energy from the power source is transported to the photo-injector by waveguides and enters the gun through coupling holes. The coupler should be carefully designed to minimize the reflected power. In our RF gun, the power is feed by side coupling. Two couplers were employed in the third cell symmetrically with respected to the longitudinal plane. However the RF power is just feed from one coupler in order to reduce the input power and the other one is closed as a short circuit. The asymmetry field is less than 0.2 % off axis 5 mm in the coupling cell with two couplers, which is 0.9% if there is just one coupler. The area over a distance of 5 mm from the axis is where 99.7% of the particles are located.

The resonate frequency calculated by HFSS is 3029.06 MHz, which is lower than that without couplers. This is due to the opening of the cavity by the coupling apertures decreases the frequency and the magnitude of the electric field in the coupling cell. So the model was optimized

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again by satisfying in simultaneously the resonated frequency, the coupling and the field-flatness. The final model was got which resonate frequency is 2998.1 MHz, and the peak electric field on the axis of the gun difference is no more than 2.5% in each cell. The coupler iris is like a court. The S parameters are shown in Fig. 11.

The input power for the gradient of 80 MV/m is 10.2 MW calculated by HFSS.

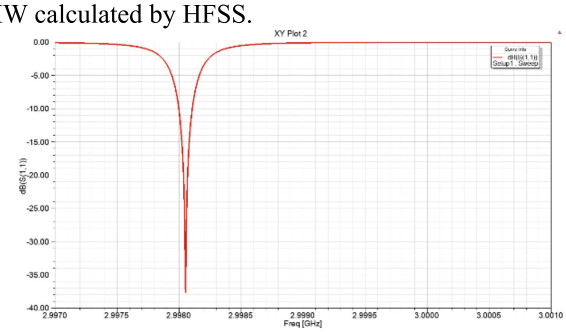

Figure 11: S1,1 parameter.

THE BEAM DYNAMICS

Beam dynamics studies were performed using ASTRA Code. For bunch charge 1nC, we have done tracking calculations in order to know the beam characteristics from the cathode up to the exit of the gun (0.4 m). The electric field used in Astra is extracted from the results of the 2D RF simulations by Superfish and the accelerating gradient is 80 MV/m. The particles are generated according to the data got from the PHIL experiments shown in Table 2. The grid settings in Astra which influence the calculation accuracy were studied and the optimum one was applied for our model.

Table 2 Main Parameters of the Particles Generated on the Cathode

Parameter	Value
Number of particles	6000
Total charge (nC)	1
Initial kinetic energy (eV)	0
Distribution of z,x,y	gauss
Sigma z (mm)	0.0036
Sigma x (mm)	0.5
Sigma y (mm)	0.5
Distribution of p_z, p_y, p_x	gauss
Emittance z (π.mm.mrad)	0
Emittance x (π.mm.mrad)	0.323
Emittance y (π.mm.mrad)	0.323

Table 3 Beam Characteristics at the Exit of the Gun

Parameter	Value
Cavity length (cm)	23.4
Bunch charge (nC)	1
Phase of the field (°)	205
Average beam energy (MeV)	9.67
Energy spread (%)	0.82
Beam size (mm)	3.1
Transverse emittance (π mm mrad)	5.9
RMS bunch length (mm)	1.2
Longitudinal emittance (π keV mm)	32.8
Particle velocity	0.9867

The beam dynamics (as seen in Table 3) show that at the end of the gun, the beam energy reaches about 9.67 MeV with the peak accelerating gradient 80 MV/m. The transverse emittance is lower than 10 π mm mrad. The emittance growth and energy spread can be compensated further by employing the focusing solenoids. Fig. 12 is the mechanical drawing of the 4.6-cell RF gun with couplers.

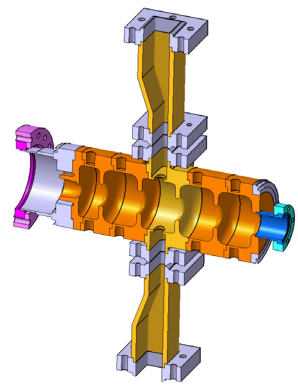

Figure 12: The mechanical drawing of the 4.6-cell RF gun.

CONCLUSION

The design of the 4.6 cells RF is almost completed and the mechanical drawing has been done. Tolerances remain to be defined and the few changes maybe be made for the mechanical issues. For the present model, the Superfish and HFSS simulations and beam dynamics with ASTRA show that it can fulfill the PHIL requirements. It can also transport high charge beam such as 2 nC with good beam properties which is potential for PHIL to provide different beam to users.

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