STUDY ON THE 3.5-CELL DC-SC PHOTO-INJECTOR*

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Abstract

In order to get high quality electron beam for PKU-ERL-FEL project. A 3.5-cell DC-SC photo-injector was designed and optimized. The pierce gun and 3.5-cell superconducting Nb cavity are DC acceleration section and RF acceleration section, respectively. A tuner for the whole 3.5-cell superconducting cavity has been designed. The beam parameters of 3.5-cell DC-SC photo-injector are also presented in this paper. The disadvantage and problem of 1.5-cell DC-SC photo cathode injector which was for principle demonstration have been overcame in the design of 3.5-cell DC-SC photo cathode injector.

INTRODUCTION

After successful proof-of-principle experiments on a 1.3GHz, 1.5-cell DC-SC photo-injector [1], a 3.5-cell DC-SC prototype photo-injector for PKU-ERL-FEL has been under developing since 2004. Up to now, both the physics and engineering design of the injector are finished almost and some components are being fabricated. Fig.1 is the schematic structure of the cryostat of the 3.5-cell DC-SC injector. It consists of a DC pierce gun, a 3.5cell-superconducting cavity, a He-vessel, a LN2 cooling thermal shield, a warm magnetic shield, a tuner and so on. The design parameters of the DC-SC injector are shown in Table 1. The injector will be operated in macro-pulse mode with 100pC and 26MHz pulse repetition. It would also allow CW operation if the liquid He supplying is enough. The 3.5-cell DC-SC injector will provide a final electron energy of about 5MeV and bunch length of 5.6ps, which could not only provide high quality electron beam for PKU-FEL, but also be a Tera-Hz source with about 300 um wavelength.

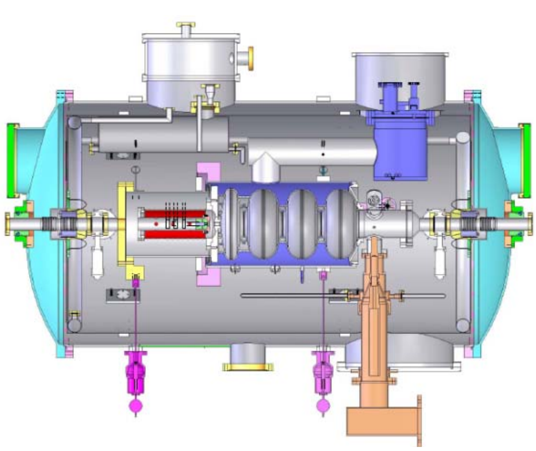

Fig1. The schematic structure of cryostat for 3.5-cell DC-SC photo-injector

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Table1 Simulation results of the upgraded DC-SC photocathode injector.

Drive laser	
Pulse length	8ps
Spot radius	3.0mm
Repetition rate	26 MHz
Bunch shape	Transverse uniform, longitude Gaussion
3 ½ superconducting cavity	
Accelerating gradient	13 MV/m
Charge/bunch	100 pc
Energy	5.0 MeV
Emittance (rms)	1.2 um
Longitudinal emittance (rms)	14 deg-KeV
Bunch length	5.6 ps
rms beam size	0.4 mm
Energy spread	~0.5%

CROMODULE

The cryomodule is shown in Fig.1. The DC gun and 3.5-cell superconducting cavity are assembled in the centre of the cryomodule. A titanium bellow at the side of DC-gun allows the cavity to be tuned. The tuning pivot is located at the helium vessel made of titanium. And the force acts on the superconducting cavity through pushing or pulling the whole DC-gun so that the DC-gun will not distort. The 77K shielding uses liquid nitrogen. The cavity is passively shielded against ambient magnetic fields by means of the outer vacuum vessel made of pure ion (impurity<0.05%) with 8mm thickness. The use of thin titanium spokes for cavity support, thin stainless-steel bellows in the beam line and RF couplers, as well as the multi-layer supper-insulation foils ensures low thermal losses of the cryostat. The 2K helium is supported by the helium refrigerator produced by Linde.

DC-SC INJECTOR

Fig.2 shows the design of the DC pierce gun and Superconducting cavity. The Cs2Te cathode is put at the negative electrode of the DC-gun. As showing in fig.3, the angle of electrode, size of cathode and tube are optimized to provide a proper electron beam for superconducting cavity. The DC gun and superconducting cavity is connected with a short tube with 12mm diameter and 17mm length. For the DC-gun, the size of cathode, distance between the electrodes, the angle of the electrodes are optimized to produce a proper electron beam for the superconducting cavity. The superconducting cavity is composed of a half cell and three TESLA cells. The design of half cell is very important for a good matching with the DC gun. The wall of the half cell next to the DC-gun is about 10^{o} slope. The field on axis of the superconducting cavity is shown in Fig.4. And there will be about $\pi/8$ phase slip for 70keV electron from DC-gun when electron beam passes the half cell. The main RF parameters are listed in the Table2.

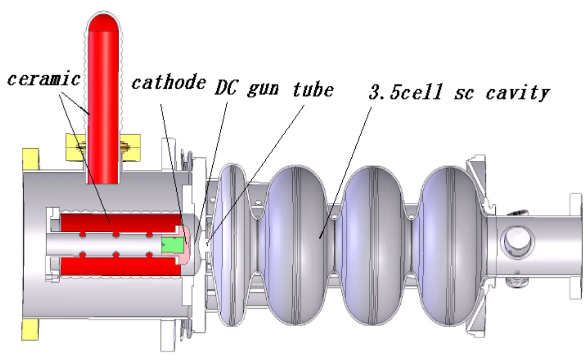

Fig.2 The DC-SC injector

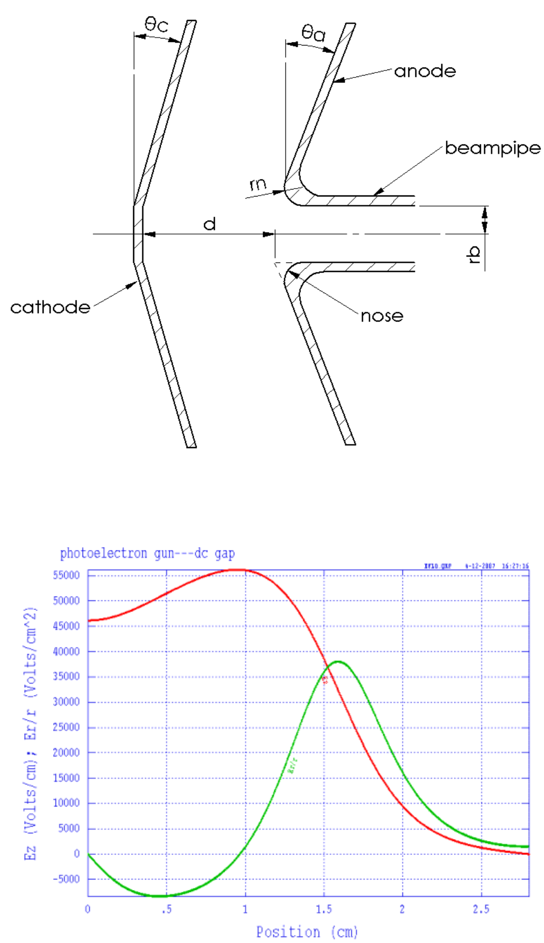

Fig3. Upper : The schematic structure of DC-gun
Lower: The field Ez(red) and Er/r(green) on axis

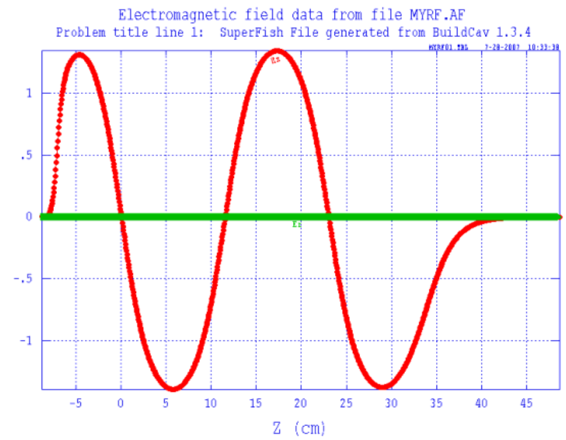

Fig.4 E-field on the axis of 3.5-cell cavity

Table2, Main RF Parameters of the 3.5-cell superconducting Cavity

Cavity Frequency	1301.7MHz
Quality Factor Q0 at 2K	1.43×10^{10}
Epeak/Eacc	2.13
Bpeak/Eacc	5.03
Geometry fator	241.6 Ohm
R/Q	417.9 Ohm
External Qext	1×10^{7}

LORENTZ FORCE DETUNING AND CAVITY STIFFENINGUCTION

Since the injector will be operated in macro-pulse mode and the high external Qext of the 3.5cell superconducting cavity, Lorentz detuning is a very important issue. The frequency error caused by Lorentz detuning would be more than 500Hz without any cavity stiffening, when the injector is operated at 13MV/m. So, it is necessary to make rigid cavity with proper stiffing rings. The principle is to dispose a fixed point in the cavity wall in order to balance the electric and magnetic part of the detuning.

Lorentz force is the result of the electromagnetic field in a cavity interacting with the RF wall current. The frequency shift is proportional to the square of the accelerating field is described as [2].

$$\Delta f = -KE_{acc}^{2}$$

Here, Eacc is the cavity accelerating gradient. K is the Lorentz force coefficient, which strongly depends on the cavity wall's rigidity. The stiffening structure is to reduce the K value as less as possible.

To simplify the tuning system and with the consideration of mechanical space, we tune the whole 3.5-cell cavity with only one tuner. Employing the code ANSYS and SUPERFISH, we get the minimum Lorentz force coefficient K as 1.2 Hz/(MV/m)^2, when double stiffening rings are welded to each side of the half cell and one stiffening ring is welded between the adjacent TESLA cells as seen in Fig 2. So the frequency error will be about 202Hz due to Lorentz detuning at the gradient of 13MV/m. Table 3 shows the locations of each stiffening rings.

Table 3 Locations of the stiffing rings of the 3+1/2 cell cavity

Stiffening ring	Position (around from the cavity axis) /mm
The half cell to LHe vessel	38
half cell to LHe vessel	85
half cell to TESLA cell	50
half cell to TESLA cell	80
Adjacent of TESLA cell	53.5

For DC-SC injector, there is a DC gun adjacent to the half cell, the tuning should not destroy the pierce structure and change the distance between the cathode and the anode. To stiffen the pierce gun, we make the anode with thickness 20mm and 4mm near the beam pipe. ANSYS and Poisson SUPERFISH were used to simulate the effect of tuning on the cavity frequency and field flatness. Either side of the cavity was fixed, pressing and stretching the other side of the cavity. The range of pressing and stretching is 0.4mm, which is enough for our situation. The tuning displacements lead to frequency shift Δf, as shown in Fig.5. It demonstrates that the frequency shift is still linear to the displacement even tuning the whole 3.5-cell cavity with only one tuner. And tuning either side of the cavity is the same to the frequency shift, which is very important for the cryo-module integration. With consideration the mechanical space in the cryo-module, we tune the cavity at the cathode side as seen in Fig.1.

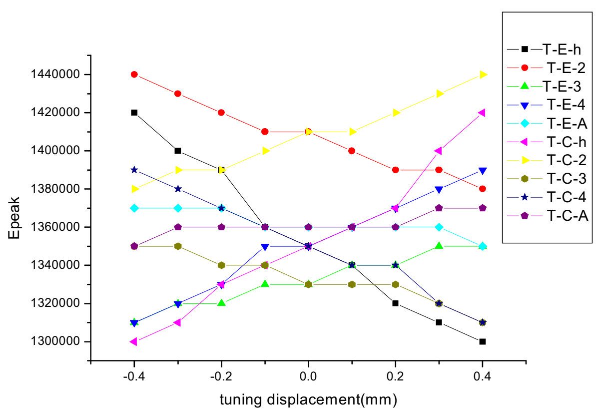

Fig5. The E-peak of each cell for tuning displacement T- E-h/2/3/4/A means the peak E-field of the half cell/2d cell/3d cell/4th cell/average when tuning is at end cell side (the 4th cell). T-C-h/2/3/4/A the E-peak of the half cell/2d cell/3d cell/4th cell/Average when tuning is at half cell side

SUMMARY AND PROGRESS

A DC-gun, 1.3GHz 3.5-cell superconducting cavity with special stiffness of photo-injector for PKU-ERL-FEL facility has been designed with careful consideration about the physics and engineering. The cryo-module is being fabricated by a company. The large grain size Nb sheets for the 3.5-cell superconducting cavity have been ordered from OTIC in Ninxia, China. We also signed the contract with Linde for 2K LHe system in July this year. We hope the cryomodule will be commissioning in the end 2008.

REFERENCES

[1] K. Zhao, et al., Nucl. Instr. and Meth. A475 (2001), p. 564.

[2] Hasan Padamsee, et al. RF Superconductivity for Accelerators[M], New York: John Wiley&Sons,1998