DESIGN OF THE COMPACT HIGH AVERAGE CURRENT DC-SC PHOTO-INJECTOR AT PEKING UNIVERSITY*

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Abstract

A new compact high average current DC-SC photo-injector has been designed at Peking University. The main Part of the injector consists of a DC pierce gun and a 3+1/2cell superconducting cavity. The optimization of the DC gun and superconducting cavity are presented in this paper. The simulation results show that the new injector can provide high average current electron beams with bunch charge of 100pc, cw (or high repetition rate mode) operation, transversal emittance lower than 2 mm-mrad and bunch length of 4 ps.

INTRODUCTION

The concept of integration of a pierce gun and a superconducting cavity was first proposed by Peking University in 2001[1]. A prototype photoinjector with a pierce gun and 1+1/2 cell superconducting cavity was manufactured in 2002 to test the feasibility. The photocathode is placed on the cathode of the pierce structure, and the pierce anode is on the entrance of the superconducting cavity. With this design, the compatibility problem between the superconduting cavity and the photocathode is solved. After two years' commissioning and testing, the injector successfully provided and accelerated electron beams [2].

Based on the experimental results of the prototype injector and the need of Peking University energy recovery linac free electron laser (PKU-ERL-FEL), we need to upgrade the injector. PKU-ERL-FEL is a facility to provide users with IR FEL. The bunch charge is 60 pc, repetition rate is 26MHz and the average current is about 1mA. POSSION, SUPERFISH, PARMELA, ASTRA and ANSYS programs are used to do simulations. Simulation results show that the new injector can provide electron beams with low emittance and short bunch length.

DESIGN OF THE CORE ELEMENTS OF THE INJECTOR

The core elements of the injector are a 100kV DC pierce gun and a 3+1/2cell super-conducting cavity. Figure 1 shows the main parts of the injector.

The optimization of the main parts determines the performance of the injector. Figure 2 is the schematic of the pierce structure. The angles of the cathode and anode are 16 and 21, separately. The operation high voltage is 90kV. The distance between both electrodes is 14mm. The gradient at the cathode is 5MV/m, the peak surface electric field is 12 MV/m.

* Work supported by Major State Basic Research Development Program (2002CB713600)

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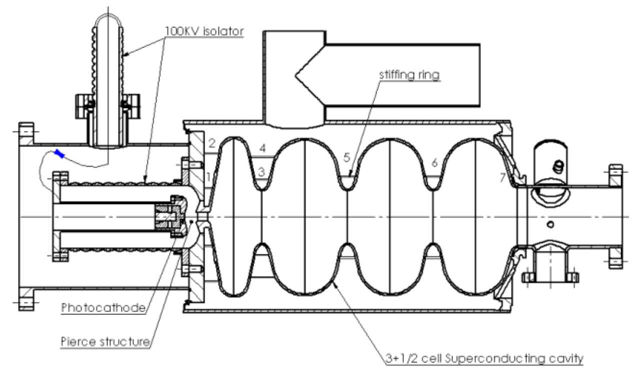

Figure 1: core elements of the upgraded photocathode injector.

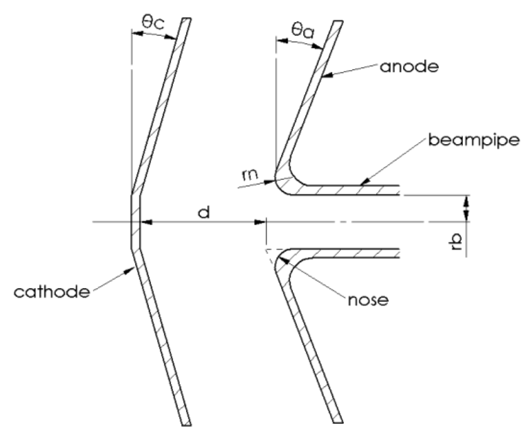

Figure 2: Schematic of the pierce structure.

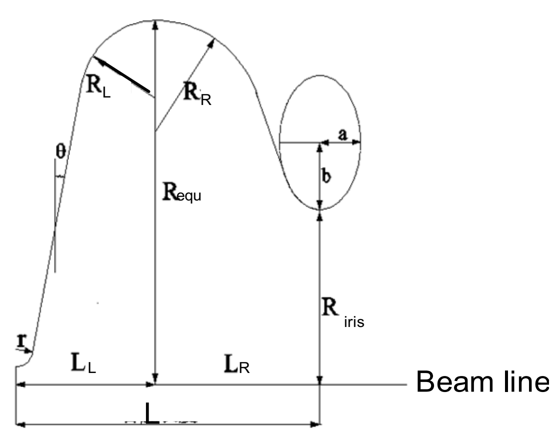

Figure 3: Shape of the first half cell of the sc cavity.

Three cells of the 3 ½ cell superconducting cavity adopt TESLA midcup and endcup[3]. So the optimization emphasis of the cavity is put on the first half cell (see in figure 3). There is a small beam tube between the DC gun and the superconducting cavity. In order to control the emittance increase, the length of the small tube is as short as possible. To avoid the fields from the superconducting cavity going inside the DC gun, the shortest length of the tube is 17mm when the radius of the tube is 6mm. With a conical wall, the first half cell has a negative value of the radial field near the entrance of the cavity and focuses the electron beam after the DC structure when the energy is only 90 keV.

Table 1 gives the RF simulation results of the 3+1/2 cell cavity.

Table 1: RF parameters of the 3+1/2 cell cavity

f (MHz)	Ep/Eacc	Bp/Eacc (mT/(MV/m))	R/Q (Ω)	Q (@2K)
1301.3	2.12	4.95	418	1.4E10

Beam dynamic simulation is done by PARMELA program. To get low emittance and small beam size, we add a solenoid with magnetic field of 850Gs. The solenoid is 50cm after the cavity (just behind the cryostat). The bunch shape has transverse uniform distribution and the beam transverse size is 3mm. The energy in the injector is relatively low. Therefore, the linear space charge effect dominates the transverse emittance increase. Such emittance increase can be compensated just by one solenoid [4]. Table 2 gives the initialized information and the simulation results of the injector. From table 2, we can see that the new injector can provide electron beam with 100 pc, high repetition rate, 5 MeV energy, bunch length of 5.6ps and transverse emittance of 1.2 mm-mrad, which meets the need of PKU-ERL-FEL.

Table 2: 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 Gaussian distribution
3 ½ superconducting cavity	
Accelerating gradient	13 MV/m
Electron bunch	
Charge/bunch	100 pc
Energy	5.0 MeV
Emittance (rms)	1.2 μm
Longitudinal emittance (rms)	14 deg-KeV
Bunch length	5.6 ps
rms beam size	0.4 mm
Energy spread	~0.5%

MECHANICAL PROPERTIES OF THE 3+1/2 CELL CAVITY

The bandwidth of the cavity is very narrow because the injector works at 2K and the external Q value (Qe) is 1×107. Without stiffing rings, the frequency shift caused by the Lorentz force detuning is higher than 500Hz when the cavity is operated at 13 MV/m. The resonant frequency is hard to be found when the cavity is operated at pulsed mode. By adding stiffing rings to the cavity, we can reduce the Lorentz force detuning coefficient to 1.2 Hz/(MV/m)2. The position of the stiffing rings are shown in figure 1 and listed in table 3. Under such condition, there is no problem with the RF control of the cavity.

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

Stiffer ring	Position (distance from the axis) /mm
1	38
2	85
3	50
4	80
5	53.5
6	53.5
7	53.5

Another difficulty is tuning of the 3 ½ cell superconducting cavity. Firstly, the pierce structure is connected to the cavity. The distance between the cathode and the anode should not be changed. At the meantime, the beam tube of the coupler side should be fixed. Secondly, the geometry of the first half cell is much different from the other three cells. It is not easy to keep the good flatness of the whole cavity while the cavity is tuned to the right frequency. To solve the first problem, we place a bellow between the outer wall of the helium vessel and the center flange. When the cavity is compressed or stretched, the whole DC part will move together with the cavity while the helium vessel is fixed. The tuning range of the cavity is about ±200kHz. The corresponding longitudinal length change of the cavity is about ±0.3 mm.

For the second problem, we use only one tuner to tune the 3 ½ cell cavity through optimizing the position and number of the stiffing rings. ANSYS and SUPERFISH programs are used to do the simulations. Without stiffing rings, the change of the field flatness of the 3+1/2 cell cavity is larger than 6% when the cavity is stretched or compressed 0.4mm. But with the stiffing rings listed in table 3, the change of field flatness of the whole cavity is within 3% when the cavity is compressed or stretched 0.4mm.

CONCLUSION

The design of the new compact high average current photoinjector with a 100kV pirece gun and a 3+1/2cell superconducting cavity has been finished. Simulation results show that the injector can provide electron beam with bunch charge of 100pc, energy of 5 MeV, cw or high repetition rate, emittance of 1.2 μm, pulse length of 5 ps. It meets the needs of PKU-ERL-FEL. This injector itself can also be a THz wave source.

The design of the cryomodule of the injector has also been finished. The whole injector is under construction now.

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